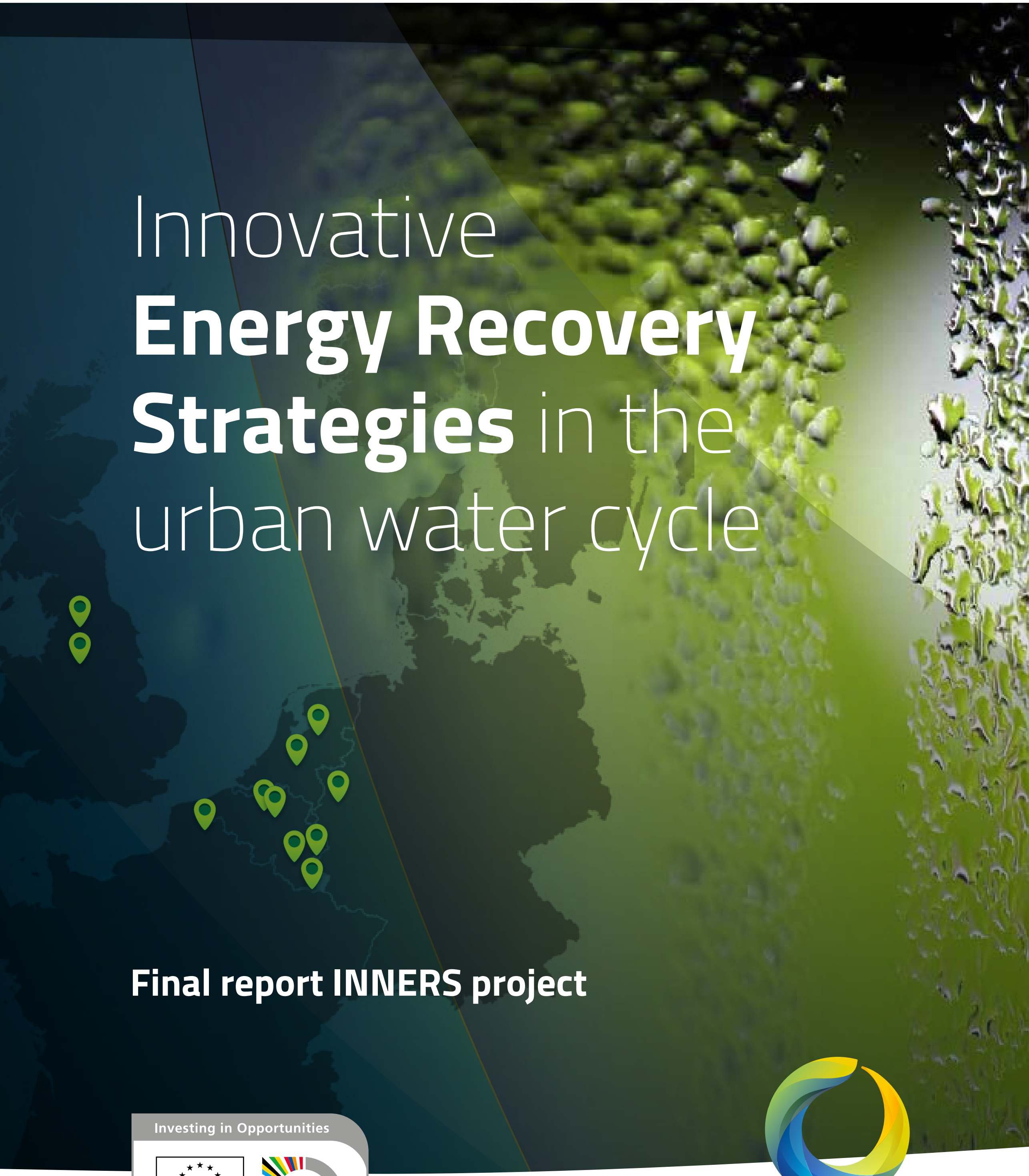

Innovative **Energy Recovery Strategies** in the urban water cycle

Final report INNERS project

Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

INTERREG IVB

inners

Final report INNERS project

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SUMMARY

The work described in this report is the result of the co-creation of eleven partners from six North West-European countries. In the project INNERS we worked together to improve the effectiveness of energy use within the urban water cycle. The search for renewable energy sources becomes more important as we face different future challenges like diminishing fossil fuel sources, increasing energy prices and stricter carbon emission limits. The INNERS team believed that the source of "blue energy" that is present in the urban water cycle might contribute significantly to addressing these challenges and at the same time to the Europe 2020 carbon reduction targets.

HOW WE WORKED AND WHAT WE DID

INNERS was developed to test and implement different strategies with the ultimate aim to make the urban water cycle more sustainable in terms of energy.

The work in INNERS was organised around four main questions:

1. What is the energy potential of the urban water cycle?
2. How to recover heat/energy from the urban water cycle?
3. How to reduce the energy consumption and how can we make the step towards mining of blue energy sources?
4. How to promote a transition towards a more sustainable urban water cycle?

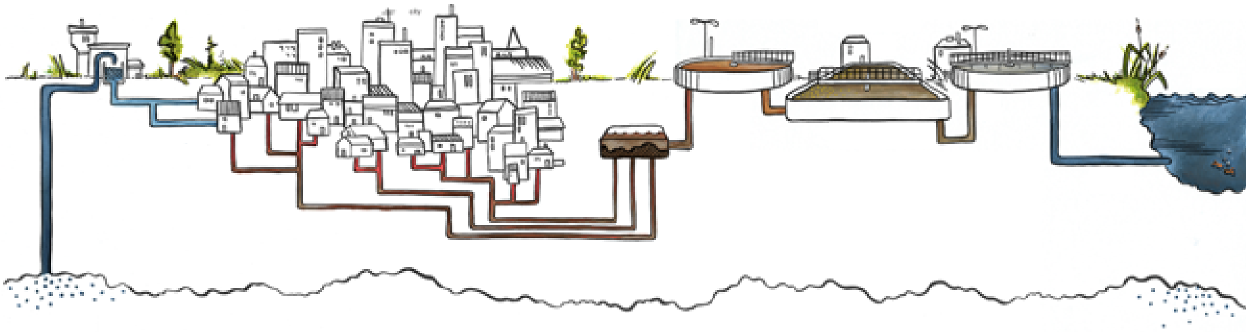
Several studies were completed and seven demonstration projects were implemented to find answers to these four questions.

CONCLUSIONS

- Water utilities use large amounts of energy to treat and supply drinking water and to transport and treat wastewater. These two activities use similar amounts of energy. However, the largest proportion of energy in the UWC is used to heat water.
- To recover heat from the urban water cycle efficiently, a minimum and constant flow of water is necessary. Also, the location where heat is recovered is important. Not only to recover as much energy as possible (for heat this is directly after the point where hot water is produced and discharged), but to ensure it is used locally and also to prevent a negative impact on the working of the wastewater treatment plant.
- All North West-European wastewater treatment plants together could reduce their energy consumption by 30% simply by optimizing their systems! This reduction could even increase to 45% if techniques for an energy efficient treatment of wastewater are implemented.
- For a transition towards a new perspective on the urban water cycle as a source of energy different target groups need to be convinced. Involve these groups in your work and find out what they really need and in which form. This will help convincing them that it is possible to recover, reduce and re-use energy from the water cycle. Physical proof in the form of video's and demonstration projects can significantly contribute to overcome all kinds of barriers that might endanger the implementation of your innovative techniques.

1 Introduction

CURRENTLY, A TRANSITION IS TAKING PLACE IN EUROPE TOWARDS AN INCREASING AWARENESS OF THE IMPACT OF OUR BEHAVIOR ON THE ENVIRONMENT. INSTEAD OF UNRESTRICTED USE OF FOSSIL FUELS, THE FOCUS IS SLOWLY SHIFTING TOWARDS MINIMIZING ENERGY CONSUMPTION OR USING RENEWABLE SOURCES OF ENERGY WITH THE PURPOSE TO REDUCE CARBON EMISSIONS.



The urban water cycle

In this report you find the strategy and conclusions of the INNERS project. The INNERS project aims to make the urban water cycle more sustainable in terms of energy. The project shows the potential of this new source of "blue energy" and helps to enable the water sector to deal with future challenges such as diminishing fossil fuel sources in Europe, increasing energy prices and stricter carbon emission limits.

The urban water cycle covers the path from water supply to waste water treatment. This cycle was designed to create a reliable and safe (in terms of human health), system to transport clean and dirty water to and from its users. In general, the urban water cycle is designed at a scale that maps onto our large urban environments, such as cities.

1.1 BACKGROUND

In line with the Europe 2020 strategy many local authorities made agreements to become energy or carbon neutral. However, at both the European and national level the main focus has been on improving buildings, and supporting renewable energy sources such as solar panels and wind energy. The field of blue energy remained quite unexploited.

To run and maintain the different steps in the urban water cycle (drinking water supply, water and wastewater transport, and wastewater treatment) energy is needed. Users of water add energy to the cycle, for example in the form of heat when taking a shower. This raised the question whether the energy efficiency of the urban water cycle could be an interesting topic. Until now, several studies have investigated the energy potential of the urban water cycle. However, these studies are small scale, uncoordinated, not widely disseminated and many are focused on the wastewater treatment plant. Moreover, evidence in the form of pilot projects that provide practical proof of the potential for energy recovery and re-use in the urban water cycle described in reports and studies is missing. Given the interconnective nature of the urban water cycle the challenge is to achieve maximum energy benefit from the whole cycle.
To ultimately deliver a transition towards a more sustainable water cycle in Europe two steps are needed. First, it is necessary to get insight in the energy potential of the urban water cycle. The second step is to demonstrate how the urban water cycle can be made more sustainable in terms of energy. This is why the INNERS project was developed.

1.2 ENERGY IN THE URBAN WATER CYCLE

Three types of energy can be identified in the urban water cycle: thermal energy, chemical energy and operational energy.

(Blom, J.J, Telkamp, P., Sukkar, R., de Wit, G. (2010). Energie in de waterketen. STOWA.)

THERMAL ENERGY

By taking a shower or doing the laundry households add heat or thermal energy to water. This thermal energy can be recovered, depending on the temperature difference with the surroundings, and can be re-used for different heating purposes.

CHEMICAL ENERGY

Chemical energy is the energy that is being stored in chemical bonds. In the urban water cycle this type of energy is stored in carbon and nitrogen bonds. Bacteria in waste water use the chemical energy that is stored in these bonds for their metabolism processes. One example to use the chemical energy from wastewater is to digest the wastewater sludge. In this process biogas is produced, this can be ignited to release energy.

OPERATIONAL ENERGY

Operational energy is the energy used for the different steps of the urban water cycle; water supply, transport and wastewater treatment. This type of energy consists mainly of electric energy, gas and fuel (for transport). Steps can be taken to reduce the use of such energy.

Since INNERS' focus on the whole urban water cycle, all types of energy are taken into account in the project strategy.

1.3 MAIN GOALS AND OBJECTIVES OF INNERS

The overall goal of INNERS is to make the urban water cycle more sustainable in terms of energy. To realize this ambition, INNERS focuses on identifying opportunities to recover, reduce and re-use energy in the urban water cycle. The final step is then to share the new knowledge with our key target groups in a way that the results can really be used by them.

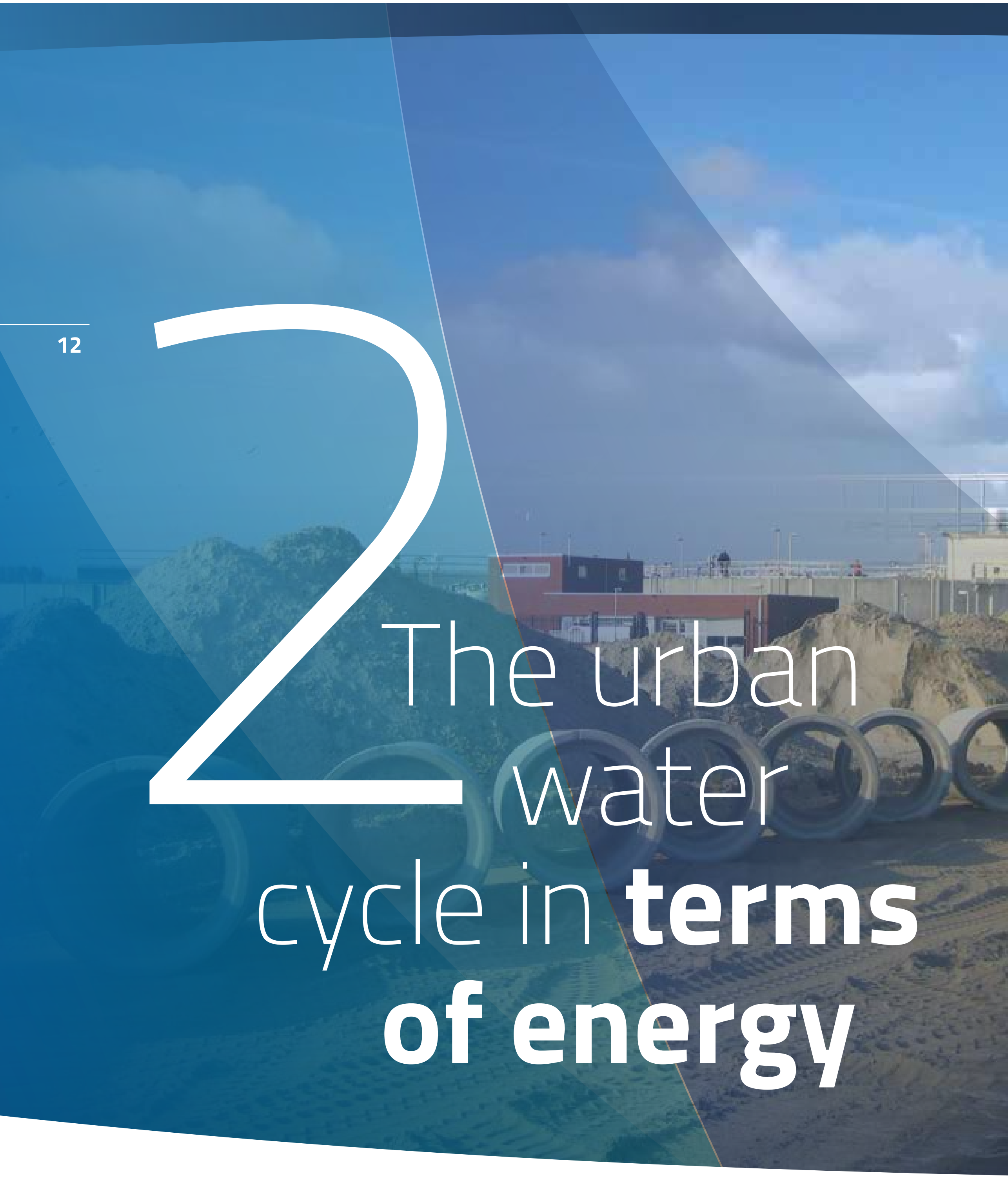
This can be translated into the following objectives:

1. To investigate the urban water cycle in terms of energy to gain insight in to energy recovery and re-use potential
2. To create and accelerate the transition to a sustainable water cycle by providing evidence from demonstrations for innovative solutions
3. To influence key stakeholders by showing the short and long term benefits and opportunities with regard to energy management and minimization in systems used to manage the urban water cycle.
4. To identify and explore the legal and policy barriers to the implementation of innovative energy re-use and recovery techniques in urban water systems within North West-Europe.

1.4 GUIDE THROUGH THIS REPORT

In this report four central questions will be answered:

1. What is the energy potential of the urban water cycle? This topic will be highlighted in chapter 2.
2. How to recover heat from the urban water cycle? In chapter 3 heat recovery is the central theme.
3. How to reduce the energy consumption and how can we make the step towards mining of blue energy sources? These questions are answered in chapter 4.
4. How to promote a transition towards a more sustainable urban water cycle? The strategy for the final step is explained in more detail in chapter 5. Here, you can also find a description of the barriers for implementation of the innovative techniques that we applied in INNERS.



2 The urban water cycle in **terms of energy**

TO ANSWER THE FIRST QUESTION (WHAT IS THE ENERGY POTENTIAL OF THE URBAN WATER CYCLE?) WE NEED TO FIND OUT HOW MUCH ENERGY IS AVAILABLE WITHIN THE URBAN WATER CYCLE. TO DO THIS IT IS IMPORTANT TO UNDERSTAND HOW ENERGY IS USED IN THE SUPPLY, CONSUMPTION AND DISPOSAL OF WATER AS IT TRAVELS THROUGH THE URBAN WATER CYCLE. AND WHEN THIS IS KNOWN IT IS IMPORTANT TO DEVELOP TOOLS TO MAKE THIS VISIBLE FOR OTHERS. IN THIS CHAPTER YOU FIND HOW THIS WAS DONE, WHAT THE ENERGY POTENTIAL OF THE URBAN WATER CYCLE IS AND WHICH TOOLS HAVE BEEN DEVELOPED.

2.1 BACKGROUND

It has to be recognized that energy and water are strongly linked within the urban water cycle. Traditionally water utilities focused on the provision of enough drinking water at the correct quality, and on treating waste water to achieve an effluent that they could release into a natural receiving water body without significant local ecological impact. Energy was considered a resource to meet these objectives, but how it was used and how much was used was not previously considered important. The increasing awareness of climate change, rising energy prices and the need to take measures to mitigate climate change has resulted in a strong drive to *reduce* carbon dioxide emissions. Commitments by EU governments to reduce their carbon emissions by 20% by 2020 relative to 1990's levels, has resulted in governments focusing on large energy users. Governments have identified water utilities as large energy users and so have required them to reduce their energy use significantly within the 2020 timescale, but also maintain the requirements to supply safe and plentiful drinking water and treat waste water to protect the environment in order to comply with the Water Framework Directive. This has led water utilities to really start to focus on their energy use, and identify and explore the potential for energy re-use and recovery within their own systems.

Urban water systems are complex systems. These systems are subjected to wide variations in demand and are also impacted by the weather but are required to perform at a consistently high level for a range of performance indicators (for example drinking water quality, supply pressure and quantity, flood risk and effluent discharge quality). Therefore being able to minimise energy use and maximise energy recovery opportunities is very challenging.

As water utilities have optimised their activities, with regard to energy use, over the last few years little attention was paid to the energy balance of the whole urban water cycle. This is a missed opportunity, as it is only by understanding the overall energy balance that the activities that are most effective for reducing overall energy use and carbon emissions can be identified.

2.2 DEVELOPMENT OF AN ENERGY BALANCE ASSESSMENT TOOL

One of the aims of INNERS was to develop an Energy Balance Assessment Tool (EBAT). A tool that can be used to get an easy to understand representation of the energy balance of the urban water cycle: energy input and energy output.
EBAT is based on the collection and synthesize of information on available data and models that quantify the energy used in different parts of the urban water system. The review of existing studies showed that for drinking water the amount of energy used in the abstraction of groundwater is greater than that used for the collection and transport of surface water, which is often transported by gravity. However, the treatment of surface water was a more energy intensive process than the treatment of ground water. Considering several countries around 0.52 kWh/m^3 was used to collect, treat and supply drinking water. The review also identified the amount of energy used in heating domestic hot water. Previous studies estimated that around 35-42 kWh/m^3 was used to heat water. For the transport and treatment of wastewater around 0.54 kWh/m^3 was needed.

kW/h is the average power that is consumed within 1 hour

	US	SE	GB	NL	NO	NZ	Mean
Total for treating and transporting potable water (kWh/m^3)	.75	.36	.59	.50	.41	.29	.52
Total for treating and transporting waste water (kWh/m^3)	.39	.56	.63	.59	.74	.60	.54
Total energy used for the supply of drinking water and the disposal of waste water (kWh/m^3)	1.14	0.9	1.22	1.06	1.15	.89	1.06
Domestic Hot Water (UK default of 42.67 kWh/m^3 where actual values are unknown)	35	42.67	42.67	42.67	42.67	42.67	*
Total energy (per m^3) across the whole of the urban water cycle	36.14	43.57	43.89	43.73	43.82	42.56	*

* Due to the use of a default value accurate figures are unknown for the mean but range is around 36-44 kWh/m^3

Figure 2.1 Energy use in the urban water cycle in different countries

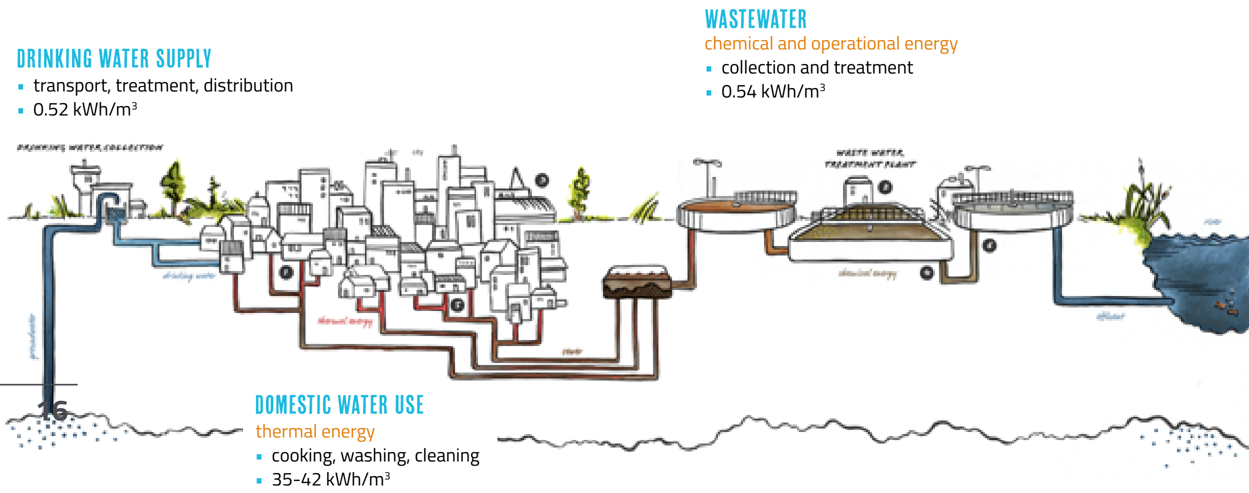
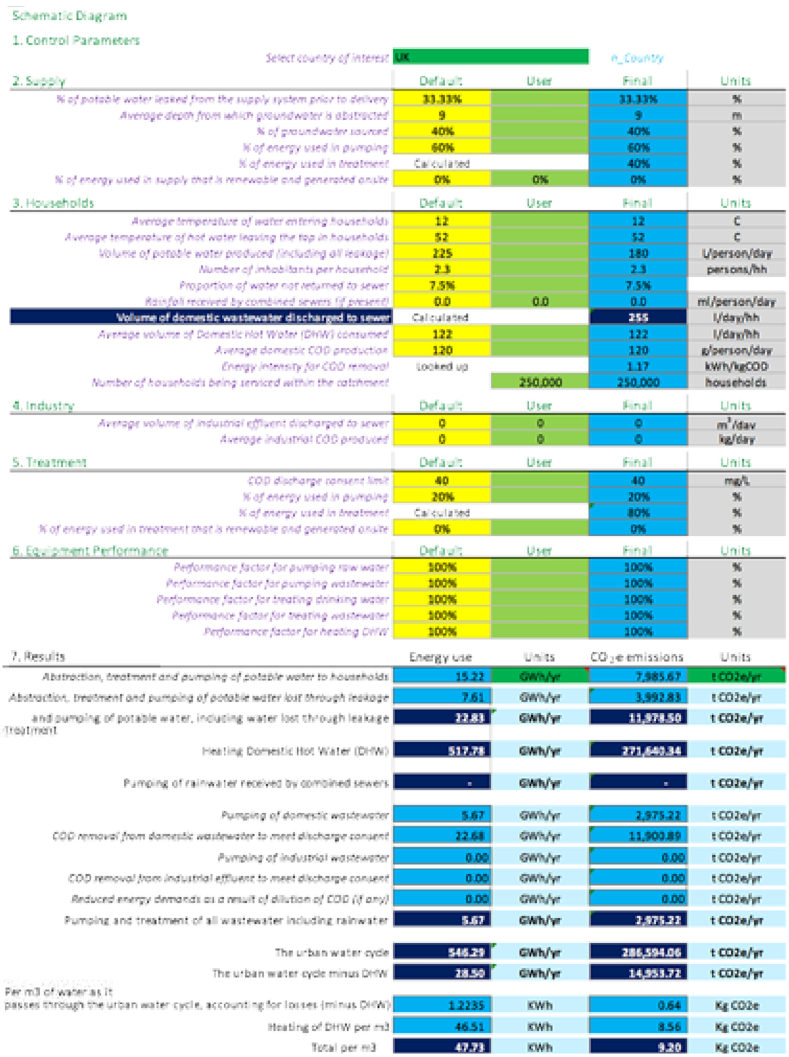


Figure 2.2 Energy used in the urban water cycle Pheasant R.J. and Tait S.J. (2014)

EBAT is a spreadsheet based tool that allows its users to identify the areas in the urban water cycle using the most energy. In EBAT the user focuses on a single catchment area and can input site specific values of energy use if available, or use averaged national data. The user is able to calculate the impact of various types of intervention such as reduced water consumption or storm water disconnection or better energy usage at treatment plants. In EBAT the user therefore gets an overview of the amount of energy used and carbon emissions in the supply, consumption and disposal of the overall values for a specific catchment and for 1m³ of water as it travels through the urban water cycle to permit comparison. The tool can be used by policy makers to assess the impact of different policy options, and by managers of catchments to investigate the impact of specific interventions on a particular catchment.



Schematic Diagram

1. Control Parameters

Select country of interest	UK		n_Country	
2. Supply	Default	User	Final	Units
% of potable water leaked from the supply system prior to delivery	33.33%		33.33%	%
Average depth from which groundwater is abstracted	9		9	m
% of groundwater sourced	40%		40%	%
% of energy used in pumping	60%		60%	%
% of energy used in treatment	Calculated		40%	%
% of energy used in supply that is renewable and generated onsite	0%	0%	0%	%
3. Households	Default	User	Final	Units
Average temperature of water entering households	12		12	C
Average temperature of hot water leaving the tap in households	52		52	C
Volume of potable water produced (including all leakage)	225		180	l/person/day
Number of inhabitants per household	2.3		2.3	persons/hh
Proportion of water not returned to sewer	7.5%		7.5%	
Rainfall received by combined sewers (if present)	0.0	0.0	0.0	ml/person/day
Volume of domestic wastewater discharged to sewer	Calculated		255	l/day/hh
Average volume of Domestic Hot Water (DHW) consumed	122		122	l/day/hh
Average domestic COD production	120		120	g/person/day
Energy intensity for COD removal	Looked up		1.17	kWh/kgCOD
Number of households being serviced within the catchment		250,000	250,000	households
4. Industry	Default	User	Final	Units
Average volume of industrial effluent discharged to sewer	0	0	0	m^3/day
Average industrial COD produced	0	0	0	kg/day
5. Treatment	Default	User	Final	Units
COD discharge consent limit	40		40	mg/L
% of energy used in pumping	20%		20%	%
% of energy used in treatment	Calculated		80%	%
% of energy used in treatment that is renewable and generated onsite	0%		0%	%
6. Equipment Performance	Default	User	Final	Units
Performance factor for pumping raw water	100%		100%	%
Performance factor for pumping wastewater	100%		100%	%
Performance factor for treating drinking water	100%		100%	%
Performance factor for treating wastewater	100%		100%	%
Performance factor for heating DHW	100%		100%	%
7. Results	Energy use	Units	CO_2e emissions	Units
Abstraction, treatment and pumping of potable water to households	15.22	GWh/yr	7,985.67	t CO2e/yr
Abstraction, treatment and pumping of potable water lost through leakage	7.61	GWh/yr	3,992.83	t CO2e/yr
Treatment and pumping of potable water, including water lost through leakage	22.83	GWh/yr	11,978.50	t CO2e/yr
Heating Domestic Hot Water (DHW)	517.78	GWh/yr	271,640.34	t CO2e/yr
Pumping of rainwater received by combined sewers	-	GWh/yr	-	t CO2e/yr
Pumping of domestic wastewater	5.67	GWh/yr	2,975.22	t CO2e/yr
COD removal from domestic wastewater to meet discharge consent	22.68	GWh/yr	11,900.89	t CO2e/yr
Pumping of industrial wastewater	0.00	GWh/yr	0.00	t CO2e/yr
COD removal from industrial effluent to meet discharge consent	0.00	GWh/yr	0.00	t CO2e/yr
Reduced energy demands as a result of dilution of COD (if any)	0.00	GWh/yr	0.00	t CO2e/yr
Pumping and treatment of all wastewater including rainwater	5.67	GWh/yr	2,975.22	t CO2e/yr
The urban water cycle	546.29	GWh/yr	286,594.06	t CO2e/yr
The urban water cycle minus DHW	28.50	GWh/yr	14,953.72	t CO2e/yr
Per m3 of water as it passes through the urban water cycle, accounting for losses (minus DHW)	1.2235	KWh	0.64	Kg CO2e
Heating of DHW per m3	46.51	KWh	8.56	Kg CO2e
Total per m3	47.73	KWh	9.20	Kg CO2e

Figure 2.3 Screen shot of EBAT showing input parameters and output results

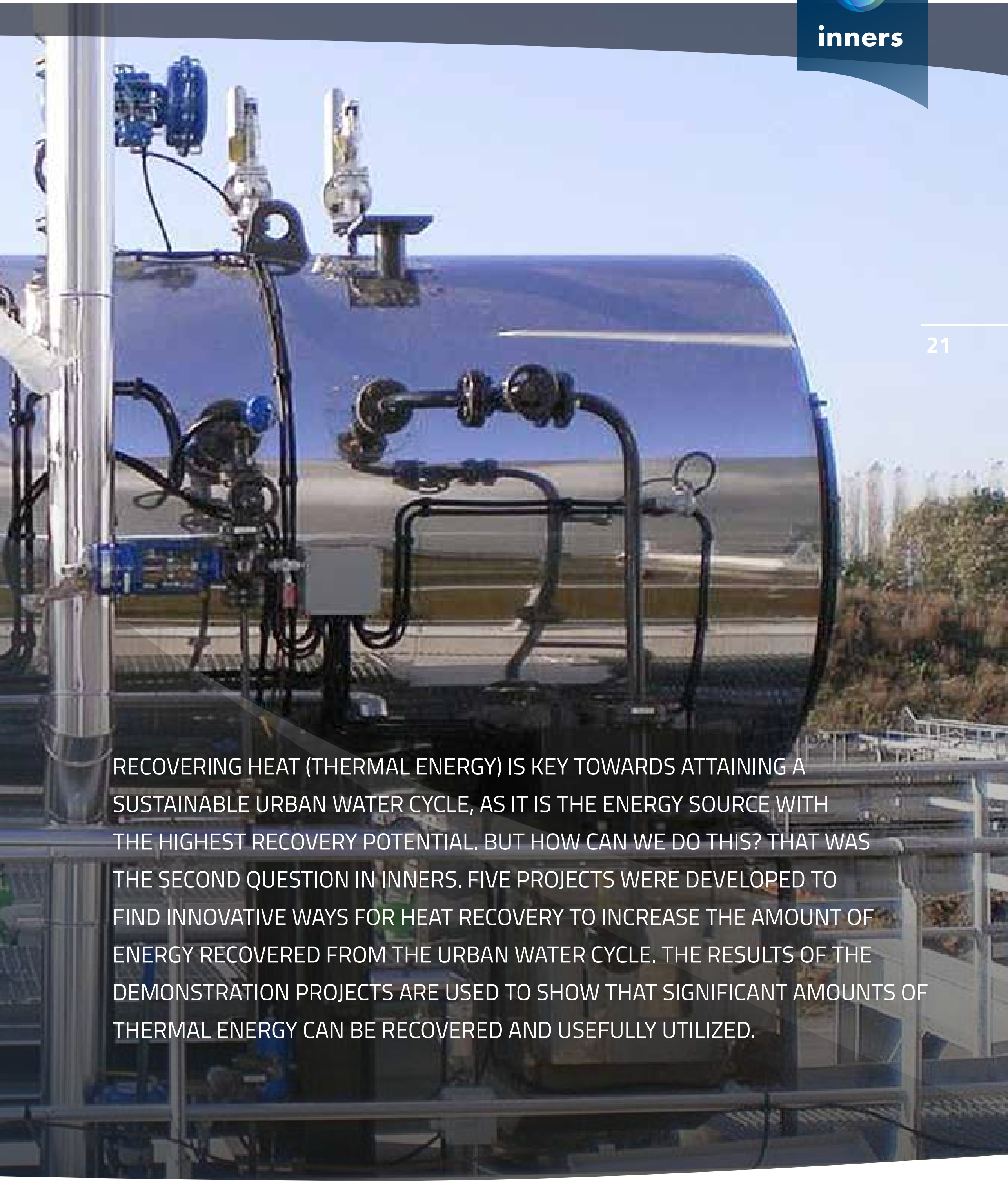
Information used has been drawn from a broad range of academic, water-industry, national government and EU literature, to enable a representative outline of water related energy consumption to be presented.
With EBAT the user can identify locations and behaviors, where improvements on heat recovery or energy efficiency should begin.

Contrasting systems of reporting and governance at both the institutional and corporate levels, made finding common, accurate energy consumption values for each stage of the urban water cycle across the EU problematic. This was further compounded by geographic, climatic, topographical, hydrological, process and legislative differences that exist across the countries where existing data was available.

2.3 CONCLUSIONS

- The urban water cycle uses significant amounts of energy to deliver safe drinking water, using the water, by heating some of it and then collecting and treating wastewater.
- The largest proportion of energy used in the UWC is used to heat water
- Water utilities use large amounts of energy to treat and supply drinking water and to transport and treat wastewater. These two activities use similar amounts of energy per m^3 of water.
- There are several interventions, both initiated by water utilities and also by other bodies and individuals that can reduce substantially energy use in the urban water cycle.

3 Heat recovery



RECOVERING HEAT (THERMAL ENERGY) IS KEY TOWARDS ATTAINING A SUSTAINABLE URBAN WATER CYCLE, AS IT IS THE ENERGY SOURCE WITH THE HIGHEST RECOVERY POTENTIAL. BUT HOW CAN WE DO THIS? THAT WAS THE SECOND QUESTION IN INNERS. FIVE PROJECTS WERE DEVELOPED TO FIND INNOVATIVE WAYS FOR HEAT RECOVERY TO INCREASE THE AMOUNT OF ENERGY RECOVERED FROM THE URBAN WATER CYCLE. THE RESULTS OF THE DEMONSTRATION PROJECTS ARE USED TO SHOW THAT SIGNIFICANT AMOUNTS OF THERMAL ENERGY CAN BE RECOVERED AND USEFULLY UTILIZED.

3.1 STUDY HEAT POTENTIAL

The first step before demonstration projects were carried out was a study on the heat potential in the urban water cycle by the European Métropole of Lille (see appendix 3 for more detail). The study contained 4 aspects:

1. Heat capacity of the effluent;
2. The range of waste water temperatures;
3. The flow of the sewage;
4. The COP (coefficient of performance, or working) of the heat recovery device

The outcome of the heat potential study was that a combination of the flow and temperature is important. Flow can vary from a few liters to thousands of cubic meters per hour, depending on the location in the sewer network and on the time of day. The fact that the flow is variable (depending on day or night time) must be taken into account in a demonstration project. Simulations of the flow and temperature in a sewer network can define the amount of heat available at each point. The average flow can be modeled by estimating the number of people inputting into the sewer network.

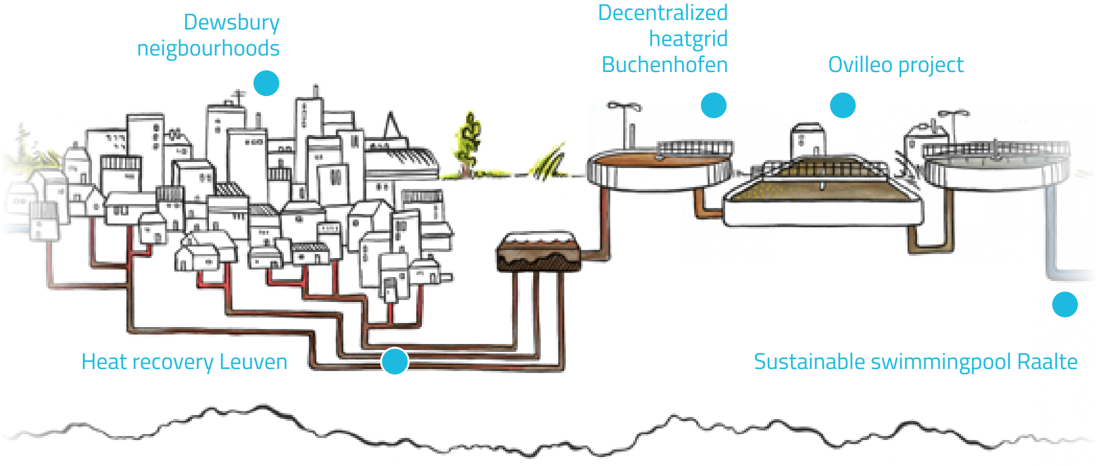


Figure 3.1 **Locations of the five heat recovery projects**

Modeling tools developed in INNERS used output from existing sewer models to identify suitable locations for heat recovery. The amount of heat that can be recovered from the sewer network is limited by the waste water treatment plant (WWTP). This is because the biochemical reactions in the plant are influenced by the temperature of the sewer waste water (influent) when it enters the WWTP. When the temperature is below 10°C these reactions are not as efficient as needed to obtain a good water quality. This is explained in more detail in appendix 1. The limiting impact of the temperature of the flow at the entrance of the waste water treatment plant can be avoided when the heat is recovered from treated waste water. This is demonstrated in the project in Raalte (see appendix 2). Another possibility to prevent a negative impact on the functioning of the WWTP is to recover a controlled amount of heat far enough away from the inlet to the WWTP.

3.2 DEMONSTRATION PROJECTS

Five different demonstration projects on heat recovery have been completed

- **Sustainable swimming pool in Raalte.** A project where heat from treated waste water (effluent) was recovered and used to heat a nearby swimming pool. The project resulted in a CO2 reduction of 137 tons, 33% less use of gas (which equals to the average gas use of almost 100 households) and a cost saving of € 25.000 per year on gas. (see appendix 2 for more information).
- **Dewsbury neighborhoods.** In this project heat was recovered from the storm water soil infiltration system and used to heat 3 houses (see appendix 4 for more information). The project found that energy use in the 3 houses to heat and provide hot water was reduced by 48% in comparison to a control house using a conventional heating system. Although no reduction in carbon emissions was noted, it is expected that as the UK de-carbonizes its electricity supply system that by 2024 this system will achieve around 36% reduction in CO_2 emissions.
- **Decentralized heat grid at Buchenhofen WWTP.** Central aspect in this project was to recover the surplus heat at the WWTP Buchenhofen and to use it to heat nearby buildings (see appendix 5 for more information). It is expected that 120.000 liters of fuel and 18.000 liters of propane gas per year will be saved with the demonstration project. The total financial saving is

up to €110,000 per year. The assumed CO_2-emission of the WWTP can be reduced up to 380 Mg per year by using the heat grid.

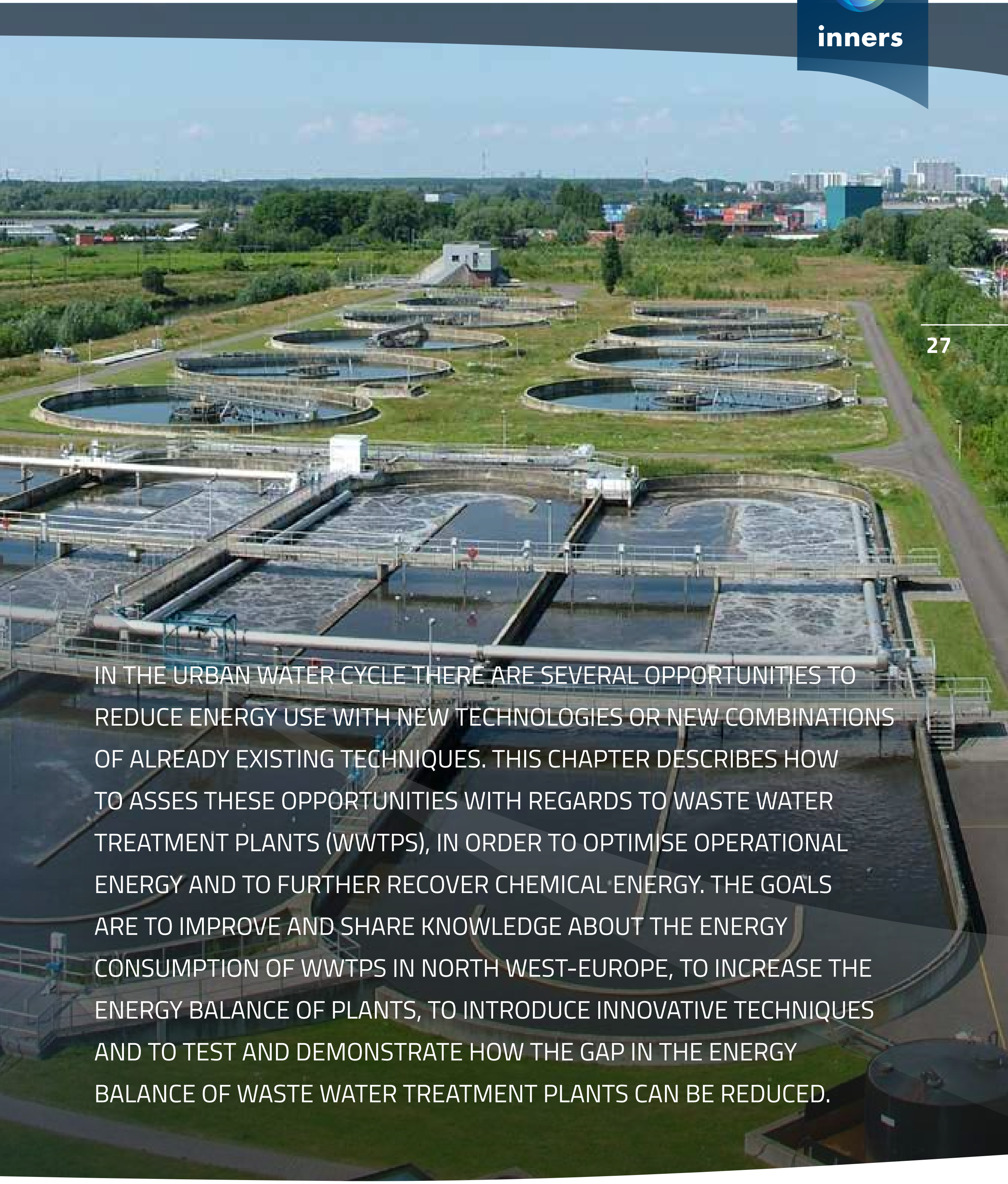
- **Heat recovery at WWTP OVILLEO.** In this project an energy efficient system, called "Exelys", to produce more biogas from sludge, was implemented at the waste water treatment plant Ovilleo which is under construction and will be made public accessible. So far the project is expected to result in 259.000 normal cubic metres of gas savings and a cost saving of €112.600 per year (see appendix 3 for more information).
- **Heat recovery from the sewer system in Leuven.** The aim of this demonstration project was to recover heat from the public sewer system and to use it to heat an apartment complex with 93 houses. Based on the first results the amount of heat recovered with this system is 172 MWh per year (see appendix 6 for more information).

3.3 CONCLUSIONS

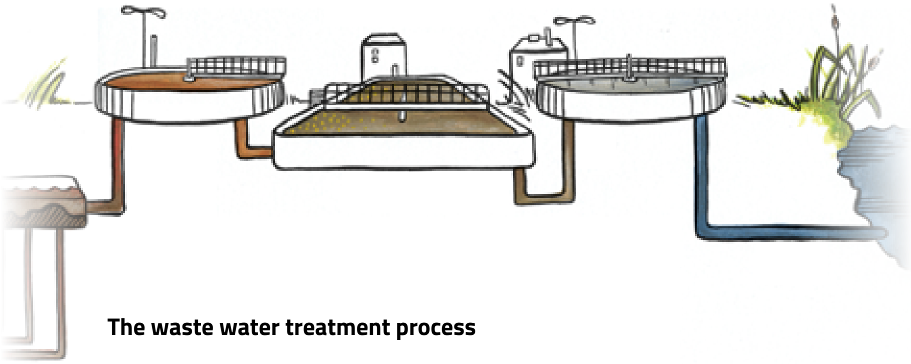
First of all, according to the conclusions from chapter 2 the amount of energy used in the urban water cycle to collect and to treat wastewater is minor compared to the energy thatheats water so there is a significant potential. This was the reason to work on five demonstration projects on heat recovery from the urban water cycle. Based on the heat recovery projects in INNERS the following conclusions can be drawn:

- From the study on the heat potential it was concluded that to recover heat from the urban water cycle efficiently, a minimum and constant flow rate is necessary. Also, the location where heat is recovered is important to prevent a negative impact on the WWTP.
- The different demonstration projects show the results of the new application of existing heat recovery techniques to recover heat from the urban water cycle. All demonstration projects were successfully implemented, meaning that heat is recovered and used for different purposes.
- As explained in chapter 2 the biggest heat potential is present directly after hot water production (for example, from showers).

4 Energy reduction and mining **blue energy sources**



IN THE URBAN WATER CYCLE THERE ARE SEVERAL OPPORTUNITIES TO REDUCE ENERGY USE WITH NEW TECHNOLOGIES OR NEW COMBINATIONS OF ALREADY EXISTING TECHNIQUES. THIS CHAPTER DESCRIBES HOW TO ASSES THESE OPPORTUNITIES WITH REGARDS TO WASTE WATER TREATMENT PLANTS (WWTPS), IN ORDER TO OPTIMISE OPERATIONAL ENERGY AND TO FURTHER RECOVER CHEMICAL ENERGY. THE GOALS ARE TO IMPROVE AND SHARE KNOWLEDGE ABOUT THE ENERGY CONSUMPTION OF WWTPS IN NORTH WEST-EUROPE, TO INCREASE THE ENERGY BALANCE OF PLANTS, TO INTRODUCE INNOVATIVE TECHNIQUES AND TO TEST AND DEMONSTRATE HOW THE GAP IN THE ENERGY BALANCE OF WASTE WATER TREATMENT PLANTS CAN BE REDUCED.



The waste water treatment process

4.1 WHY CHEMICAL AND OPERATIONAL ENERGY REDUCTION?

WWTPs are one of the main municipal energy consumers. Although the portion of energy demand by WWTPs in the urban water cycle is comparably low, the overall uptake of the plants with serving sizes of up to more than 100,000 inhabitants can be very high. The energy consumption of WWTPs differs due to waste water characteristics, treatment technologies, operational decisions or customs and plant design. Investigations, carried out at plants in Germany, show that at WWTPs up to 30 % of the required operational energy can be saved by optimisation of the system. By sludge digestion, energy self-sufficiency of more than 60 % in power and 100 % in heat can be achieved.

In order to evaluate data on a European level, the current energy demand of WWTPs was investigated in a benchmark study. This study comprised the energy consumption and production data of about 350 WWTPs in North West- Europe were collected and evaluated. In a different step, new and innovative techniques for improvement of the energy consumption at sewage transport and treatment were investigated. In addition, for a detailed energy assessment of WWTPs, data from about 60 energy analyses of WWTPs in Germany were evaluated in order to determine the overall energy consumption as well as the specific consumption of the process steps in operation. Based on the available data benchmarks for the specific energy consumption of the treatment stages were developed.

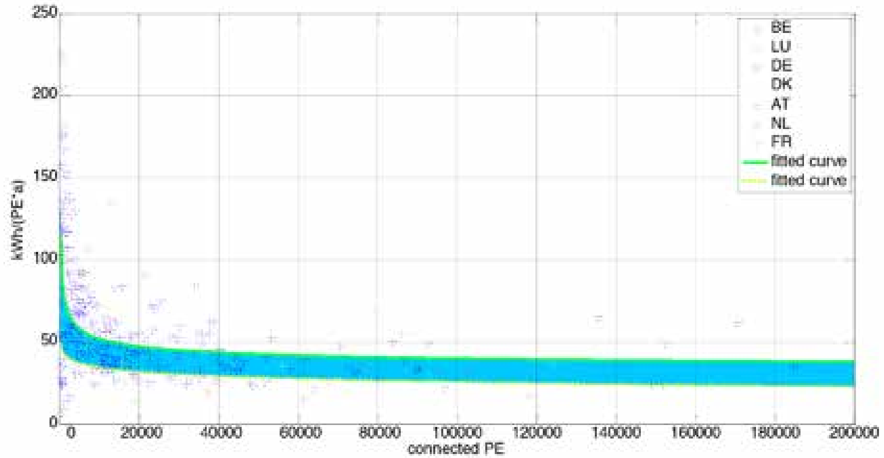


Figure 4.1 **Total specific electricity consumption of wastewater treatment plants**

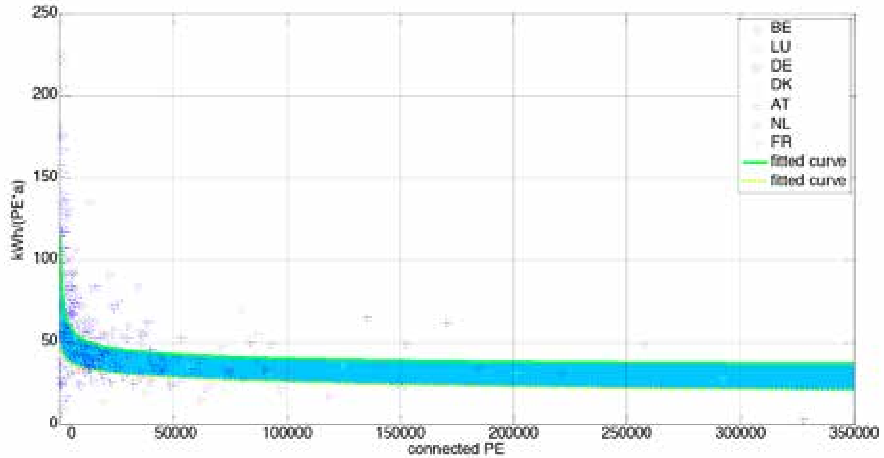


Figure 4.2 **Total specific electricity consumption of wastewater treatment plants**

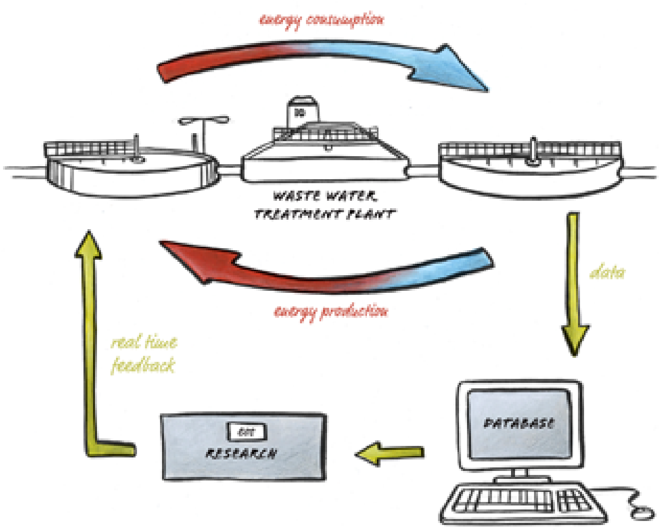
The population equivalent explains the how many people are connected to the WWTP. Because also the load of industrial water is considered they use the word population equivalent.

The benchmark study shows that there are large differences in the specific electricity demand for WWTPs in North West-Europe. Power consumption refers to connected population equivalent per year (PE*year).). The overall energy consumption ranges from 27.7 kWh/(PE*year).) to 45.3 kWh/(PE*year). with an average value of about 32.1 kWh/(PE*year)..
Generally the amount of power consumed can be explained by the size of the plant: There is a clearly decreasing consumption per (PE*year). at larger plants. However, there are also relatively large differences of power consumption per (PE*year). between the evaluated countries. These differences between countries can have several reasons, like the installed treatment technology, quality of the waste water, national characteristics (e.g. topography, residential density), or the national importance of the subject 'Energy'. Nevertheless, a power consumption between 20–25 kWh/(PE*year). seems to be the lowest possible value that can be achieved at present.

WWTPs with a sludge digestion process, allow the recovery of a significant amount of the chemical energy from the waste water by the production of digester gas. This gas is produced by the anaerobic degradation of the sewage sludge and can be used for the production of power and heat in a combined heat and power plant (CHP). The evaluation shows that by use of a CHP, full thermal self-sufficiency of the waste water treatment plant can be achieved. Furthermore a power self-sufficiency rate of 55 % - 70 % is possible. Rates of more than 70 % can only be achieved with co-digestion of organic residual matter from other sources. Considering these values, a high potential of energy-saving possibilities on waste water treatment plants in North West -Europe exists.

4.2 HOW CAN WE GET RELIABLE ENERGY DATA ON WWTPS?

For optimisation of the energy balance, reliable energy consumption and production data on a very dense data level is a precondition. Tools like the Energy Online System (EOS), developed in the INNERS project as a case study, are a main step forward to improve the energy balance of waste water treatment plants. The main focus of EOS is on the optimisation of the energy consumption of aggregates like blowers and pumps and process steps, as well as increasing the internal production of electricity and heat on the plants. In addition, a decision support system (DSS) is giving direct feedback to the plant operator to reveal this potential with a daily resolution.



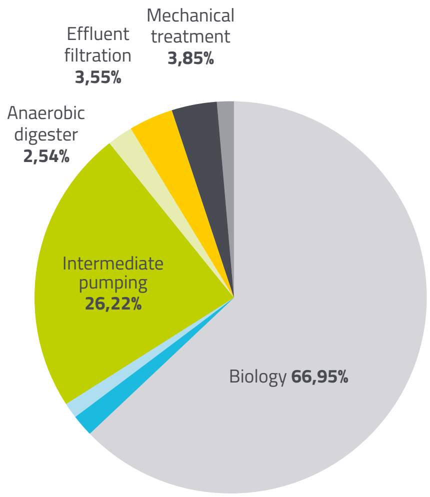


Figure 4.3 **Scheme of the Energy online system**

EOS contains different tools: data quality checking, data analysis by calculation of so called key performance indicators (KPI's), a benchmarking tool and a user interface. The system was installed and tested at two different types of WWTPs: Heiderscheidergrund, a WWTP in Luxembourg, operated by the waste water Syndicate SIDEN, and Burg WWTP, operated by the Wupperverband in Germany. Whereas the first plant is designed for simultaneous aerobic stabilisation and agricultural use of the produced sewage sludge, the sewage sludge in Burg is digested and incinerated. The produced digester gas is used for operation of two combined heat and power plants.

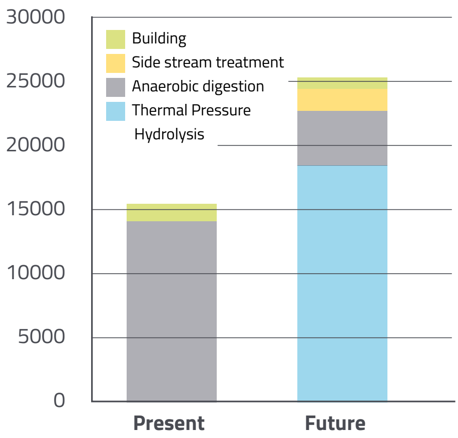
The testing of EOS at two different WWTPs

In order to provide the required energy uptake data, both plants were equipped with online measurement units for larger aggregates like blowers and pumps. Data is transferred on a daily basis to the EOS-host system, located at the LIST (Luxembourg Institute for Science and Technology) where it is aggregated and the energetic and operational KPIs are calculated. The plant operators are informed online about the energy performance of the plant and can initiate optimisation measures immediately. The KPIs are plant independent and allow for an in-depth comparison of plant, process stage and aggregate power consumption. Therefore, with the connection of additional plants in North West-Europe to the EOS, the system will allow for the comparison of the energetic performance of WWTPs all around North West-Europe. Further work must hence concentrate on getting more plants connected to the system and so go further into the comparisons between plants. This where the opportunities created by a true benchmarking systems will become apparent.

4.3 IS HEAT RECOVERY NOT AN ISSUE FOR WWTPS?

Yes, it is! WWTPs have a high potential for heat and energy recovery when applying new technologies or changing already existing processes. For instance, the WWTP of Amersfoort was evaluated in terms of energy and heat consumption with the intention to reach a net energy balance by producing power from waste water and sewage sludge. The heat balance for Amersfoort WWTP shows that the potential production of thermal energy is much higher than the demand (Figure 4.4). In this balance, the energetic cascading use and re-use of heat was considered. The surplus of heat can be used for new technologies like thermal pressure hydrolysis (TPH) of the sludge, heating of the DEMON reactor for separate treatment of reject water from sludge dewatering, or for the heat supply for surrounding buildings. Although the heat demand rises with the implementation of these new technologies, the benefits of the implementation include a 60% higher biogas production and an overall reduction of operational costs by 15%.

Heat demand
per process



Demand and potential production
of energy on the WWTP Amersfoort

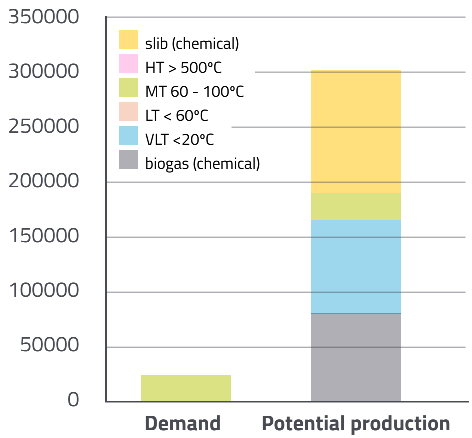


Figure 4.4 Demand and production of thermal energy of WWTP Amersfoort (present and future)

4.4 TELL ME SOMETHING ABOUT INNOVATIVE TECHNIQUES!

At WWTPs plants innovative techniques may increase the energy self-coverage significantly. In INNERS one of these techniques has been tested and implemented at the WWTP Amersfoort. A so-called DEMON reactor was installed to improve the process of deammonification, which is done to improve the released treated waste water. Figure 4.5 shows an infographic with the old and new situation at the WWTP. Thanks to the new DEMON reactor the treated waste water now releases 2 MG/liters less Nitrogen per year than compared with the existing situation and yearly €38.000 on energy costs were also achieved. In the textbox the deammonification technique is explained in more detail.

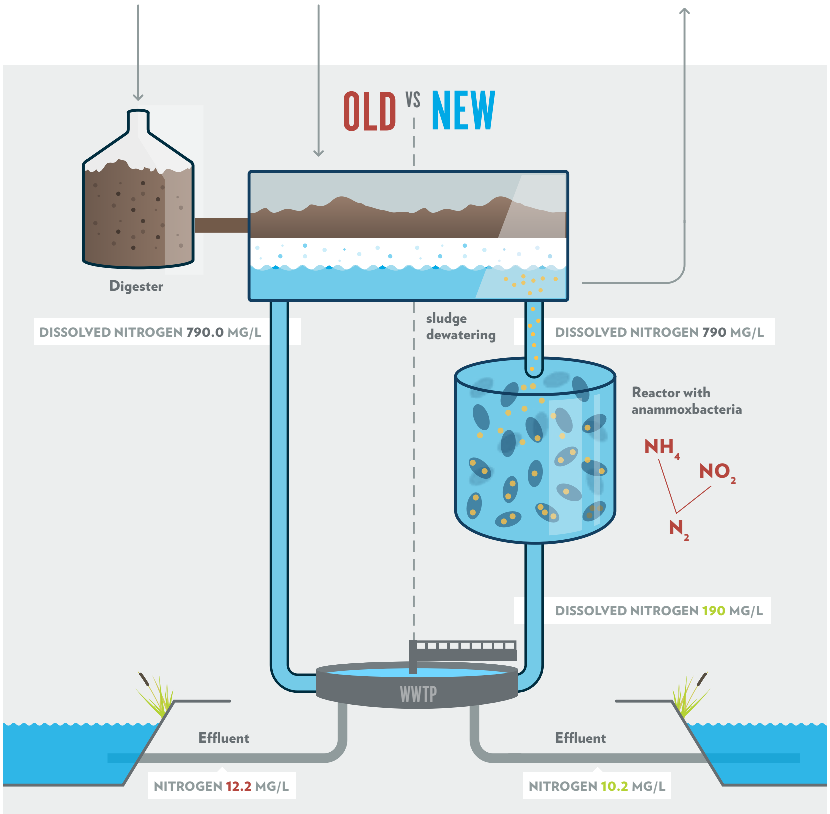


Figure 4.5 Energy saving and improvement of the effluent quality using the deammonification process

Innovative techniques explained in detail

For WWTPs with separate anaerobic sludge digestion, one main step towards energy self-sufficiency is an increased production of primary sludge from the incoming waste water. With its higher organic content, this sludge fraction has a significantly higher gas production potential than the excess sludge from the biological stage. The amount of primary sludge drawn-off can be increased by an increasing the primary settler retention time. However, this causes a reduced carbon to nitrogen ratio in the inflow of the biological reactor and may decrease the overall nitrogen elimination.

With the implementation of a so-called deammonification process the nitrogen concentration in the treated waste water (effluent) decreases. The energy consumption for the elimination of nitrogen with the deammonification process is lower in comparison to a conventional activated sludge plant. Therefore, the combination of an increased primary sludge production with a separate deammonification of the reject water from sludge dewatering, may enable a self-sufficient energy operation of sewage plants with sludge digestion. The increase in the energy potential of this approach is estimated to be up to 9 kWh/(PE*year)which is about 25 % to 30 % of the current energy consumption of WWTPs.

4.5 A SHIFT TO WASTE WATER COLLECTION IN THE YEAR 2100

In conventional combined sewer systems, which are very common in North West-Europe, washing water, urine, faeces, and even rain water is collected in single pipe systems and conveyed to the WWTP. As explained in chapter 1 waste water contains chemical energy in the form of organic matter. When waste water is diluted with rain water, the concentration of organic matter decreases. This makes it less suitable for energy recovery.

With a view to the energy content of the different parts of waste water, separate collection of black water (from toilets) combined with kitchen waste and grey water (water from the kitchen, shower, etc.) may be technically feasible. The resulting concentrated black water waste stream, rich in organic material (energy source), can be directly digested for biogas production. The collected grey water can be treated in a biological system, e.g. equipped with reed plants; in the housing area or connected to the conventional waste water treatment plant.
This concept was investigated in INNERS (see figure 4.6 for a visualisation of the concept). The idea was that with the separate collection of waste streams energy recovery can be more efficient leading to more biogas used to produce electricity. The concept also opens up possibilities to recover valuable substances, like micro-nutrients nitrogen and phosphorus. Finally, it increases convenience for the house owner by avoiding a kitchen waste bin.

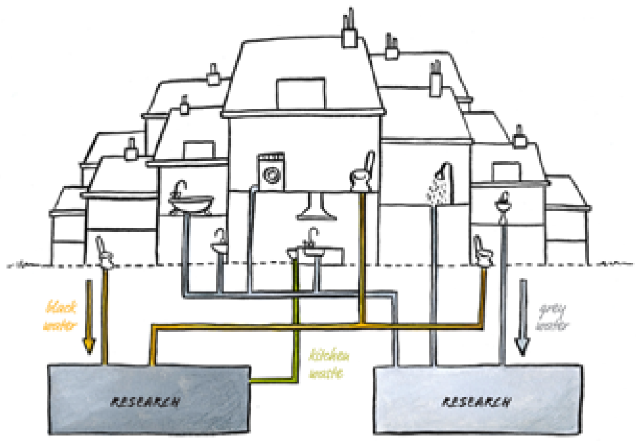


Figure 4.6 Illustration of the concept of a separate waste water collection system

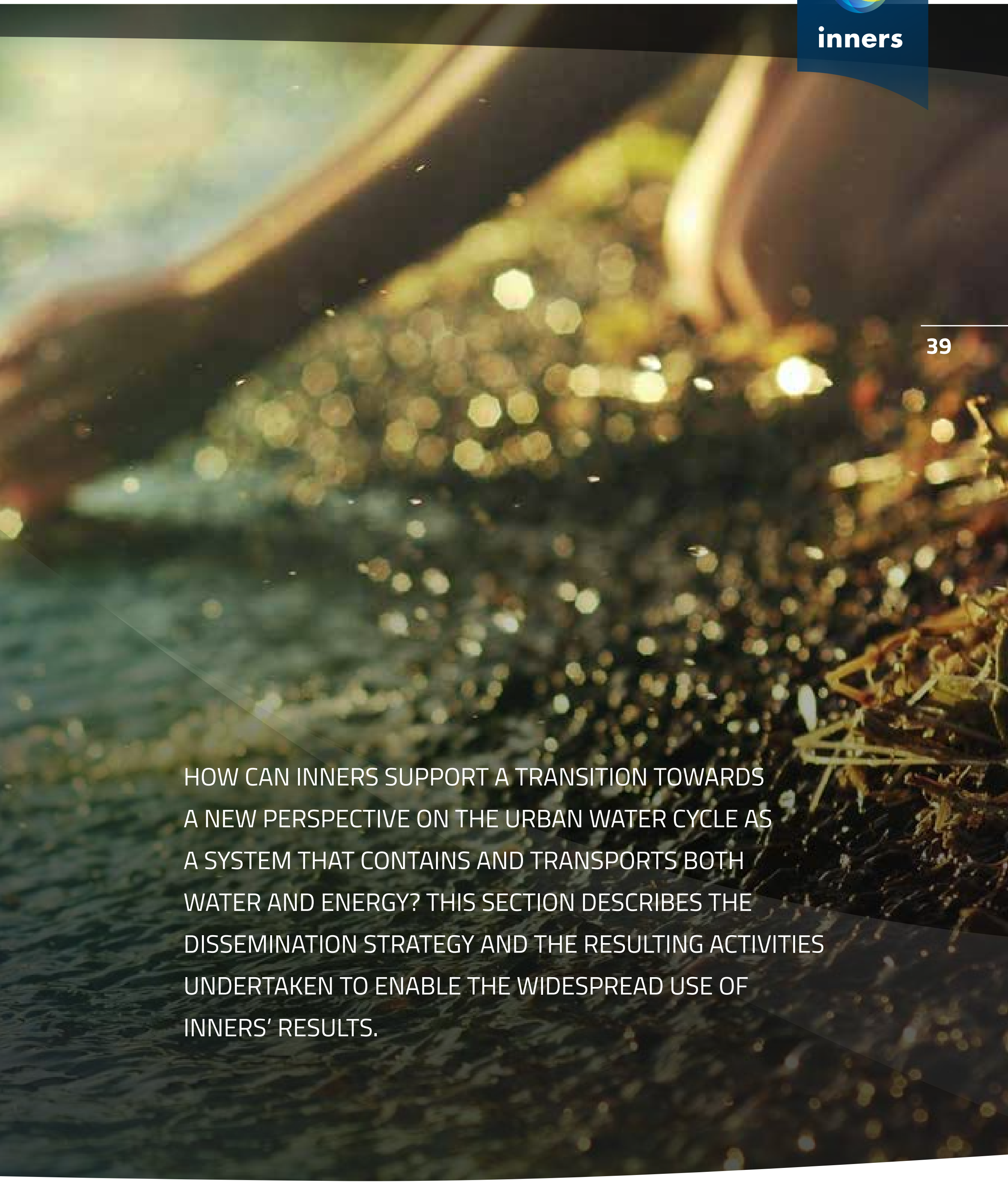
Currently, the financial feasibility of the diverted system came out to be poor as the calculated payback time is longer than the life time of the installations. Nevertheless, the major reason for not implementing the system in the studied housing area was the comparatively little experience with these systems in the Netherlands. Currently the Water Board Vallei en Veluwe is equipping a demonstration house with a vacuum toilet and kitchen waste grinder (macerator). Here, contractors and house owners can see how the system works and what the experiences are. The very high maintenance costs for the existing conventional sewer systems may open the way for implementation of this new approach within this century.

4.6 WHAT ARE THE "BIG" OUTCOMES AND FUTURE POSSIBILITIES?

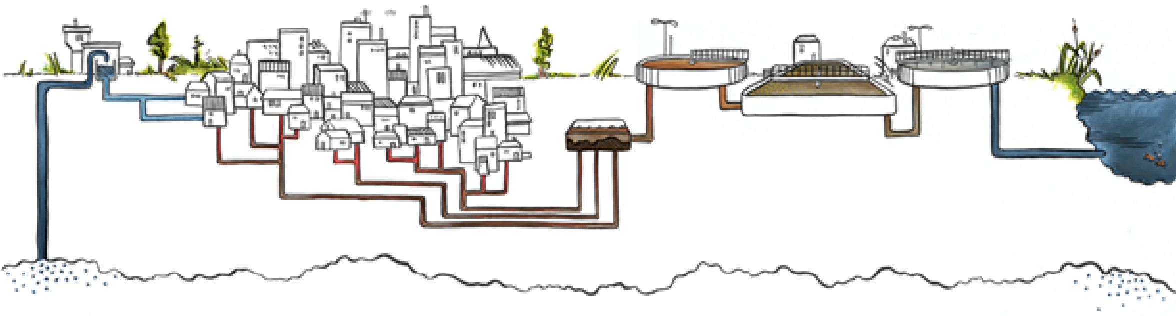
Currently there are still big gains that can be achieved by the energetic optimisation of WWTPs. Our estimation shows that Northwest European countries currently consume around 7 Terra Watt hours per year (TWh/year) on waste water treatment. If all these plants conform to the benchmarks, a saving of 3 0% is achievable (4.91 TWh/year). If subsequently all larger plants (capacity more than 50.000 people equivalents) would also implement a deammonification system, the possible saving would increase to 45 % (3.88 TWh/year, an overall saving of 3.14 TWh/year).

However, there is also, possibly, a need to further treat our waste water to remove micro-pollutants, such as pharmaceuticals and personal care products (a subject of other INTERREG NWE projects, such as the NoPILLS project). This would likely increase the energy consumption of all plants larger than 10.000 PE by 8KWh/(PE/year). The resulting impact would be that the total possible saving would be smaller, about 26 %. (5.19 TWh/year). Finally, in the future, consideration should also be given to integrate WWTPs into the overall urban energy system, because, in essence, WWTPs can store and release energy in the form of sludge and biogas and can also, possibly, in the short term, consume less or more energy if and when required.

5 Enabling implementation



HOW CAN INNERS SUPPORT A TRANSITION TOWARDS A NEW PERSPECTIVE ON THE URBAN WATER CYCLE AS A SYSTEM THAT CONTAINS AND TRANSPORTS BOTH WATER AND ENERGY? THIS SECTION DESCRIBES THE DISSEMINATION STRATEGY AND THE RESULTING ACTIVITIES UNDERTAKEN TO ENABLE THE WIDESPREAD USE OF INNERS' RESULTS.



5.1 WHY FOCUS ON ENABLING OF THE IMPLEMENTATION OF THE INNERS RESULTS?

An increasing number of studies have demonstrated that the urban water cycle has an enormous potential in terms of energy recovery and saving. However, this potential can only be used efficiently if it is implemented on a broad scale: preferably at European level. The implementation strategy that was created is based on the assumption that results need to be transferred to the right target groups and that the target groups will only use project results if they are tailored to them.

Projects undergo different stages of development: planning, realization, monitoring and evaluation (Fig 5.1). Although dissemination of (preliminary) results can take place during all project stages, most dissemination occurs during the monitoring and evaluation stages. The INNERS dissemination strategy, therefore, was active from the start of the project and intensified towards the final stages of the project. This ensures that the outputs from the activities and demonstration projects are of a sufficient quality and depth that they can be used by defined target groups so as to maximize the chances of the long term uptake of the INNERS results.

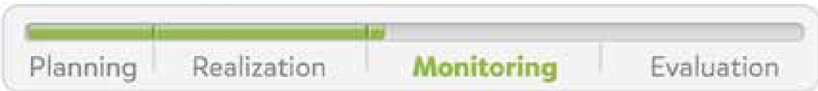


Figure 5.1 Sketch of typical project stages

5.1.1 TARGET GROUPS

Three groups of stakeholders were defined as key target groups; decision makers, technical specialists and students.

DECISION MAKERS

Without a European approach, the challenge to make the urban water cycle in North West-Europe energy efficient will be a time consuming process with lots of local initiatives repeating what has already been found out elsewhere, with little common learning. To achieve a common European approach, decision makers on all different levels need to be reached. Therefore this group has been defined as one of the main target groups of INNERS.

TECHNICAL SPECIALISTS

Technical specialists are a necessary group in the implementation strategy to continue to work on the INNERS results by having the new knowledge so as to start and implement similar initiatives.

STUDENTS

Students on technical courses are a key stakeholder group since they will be the future technical specialists and therefore also the future ambassadors of our work in INNERS.

Target group general public

Because of the mainly technical nature of the INNERS project the general public was not defined as key target group. However, since INNERS is funded with 'public money' (partly through the INTERREG IVB programme) it would not be right to ignore the general public. Therefore, the general public has been addressed during the project by i.e. open days, press releases, presentations, site visits and by creating visually attractive plaques at demonstration project sites.

5.2 STRATEGY

Key to the dissemination strategy was to tailor all INNERS outputs to the needs of the different target groups. One specific activity was formulated to tackle current barriers for the implementation of energy re-use and recovery solutions in the urban water cycle that are sustainable in terms of considering social, economic and environmental impact in the long term.

5.2.1 DISSEMINATION TO DECISION MAKERS

The approach for the target group decision makers is summarized with the following keywords:

- Keep it short and simple (KISS)
- Visualize information
- Show the short term and long term benefits (i.e. by showing the expected/ realized CO_2 reduction of a demonstration project)
- Use the demonstration project sites and their results as visible proof and evidence base

Figure 5.2 Examples of communication instruments in INNERS

5.2.2 DISSEMINATION TO (FUTURE) SPECIALISTS

Keywords for the approach to target (future) technical specialists are:
INNERS team members act as ambassadors
Visualize information combined with details in infographics and video's
Incorporate data from demonstration projects in student Masters projects.

Final dissemination work is focused on six final events, one event in each country that participates in INNERS. In this way we aim to reach more local, regional and national key target groups than we would have accomplished with one big centralized event.

5.3 OUTCOMES

The dissemination strategy has been evaluated and lead to the following conclusions:

- Visualizations helped to simplify the work which resulted in the possibility to reach a wider audience. However, no matter how inspiring they were, presentations about plans and ambitions did not seem to have a long lasting effect on policy makers.
- Dissemination started to work after tools and demonstration projects were completed. Videos and site visits of the realized demonstration projects provided "physical proof" and convinced our targeted groups that water and energy projects are not only possible in theory but can be implemented practically. Both presentations of results and site visits resulted in others starting to examine the feasibility of similar initiatives, for example the municipality of Urk in the Netherlands.

The projects in INNERS resulted in many presentations at congresses, conferences, workshops given at seminars and scientific articles. Results of INNERS were used by specialists in follow up projects and several publication citations proof that there is high interest on INNERS' work.

Students, at arrange of levels, have been introduced and contributed to the projects results that have been achieved. A number of knowledge transfer opportunities were developed and given to Master and Final Year Students e.g. many project students utilized INNER's facilities to undertake their research projects. Lectures on Energy within the Urban Water Cycle were delivered to Final year students.

5.4 BARRIERS FOR THE IMPLEMENTATION OF NEW TECHNIQUES

A strategy was elaborated to examine which barriers for the implementation of innovative techniques similar initiatives like INNERS can encounter. Based on experiences from the INNERS demonstration projects and studies, information on barriers was collected. The result is an overview of the types of barriers that were encountered during INNERS. Each type of barrier is illustrated with a practical example from INNERS.

5.4.1 TECHNICAL BARRIERS

Before making agreements to start a demonstration project it is important to investigate whether the technical conditions for such a project are right in the chosen area. One of the INNERS partners had to search for more than one year to find a proper location for their heat from sewage project. Project leader Wendy Francken from Vlario explains: "For the demonstration project all parameters had to be right. This means that a sufficient flow of waste water (the heat source) should be present *together* with a suitable building with a heat demand. Especially the heat demand part appeared to be difficult in Flanders. For the project we needed a collective heating system in the building and these were not common."

5.4.2 ORGANIZATIONAL BARRIERS

Permits may cause delays in project planning. This can be illustrated by the example of Water Board Vallei & Veluwe. Arjan Budding of the Water Board: "Our innovative projects give us, aside from the actual gains in KWh, a lot of energy! What we learned in INNERS is that energy projects alone won't be succesfull. Sometimes we need to be patient and accept that there are procedures that simply take time. And that these procedures are not to be taken lightly. As technicians we do seem te underestimate those procedures." The permit problem caused a delay of six months. In the UK, the innovative nature of the residential heat recovery system and the number of partners involved lead to several discussions on long term risk and compliance with current building standards. In this case the interest level of the various parties and their staff ensured that the demonstration project was delivered, however clearer mechanisms to address innovation risk and introduce flexibility into building regulations to encourage innovation would help.

5.4.3 FINANCIAL BARRIERS

One of the partners faced problems due to a decision of their Board not to continue with their demonstration project. Nicolas Prud'homme of the European Métropole of Lille (project leader): "after a feasibility study on 5 possible locations only one location came out to be legally and time-wise (within the time frame of INNERS) feasible. However, this location came out to have a very long return on investment time (16 years!) due to a very good existing heating system on the site. These outcomes lead to the decision of our Board to stop the project in July 2013." An alternative pilot project has been implemented successfully.

5.4.4 TRUST BARRIERS

When new techniques are implemented it is important to include go/no go moments with your stakeholders to be sure that everyone really wants to continue.

In the case of one of the partners their original demonstration project site, although technically perfect, was cancelled. "This was due to a decision of the project developer for the new apartment complex", Wendy Francken of Vlario explains. "In the end he did not have enough faith in the implementation of the new innovative technique to recover heat from the sewer system. So instead the choice for a conventional (quick to realize) system was made and we had to search for a new site for our demonstration project, which fortunately succeeded in the end."

But even when go/no go moments have been included and key stakeholders were involved the final outcome for implementation can still be a "no" due to a lack of trust in the technique. This happened in the case of Water Board Groot Salland. Herman Evenblij, project leader shares his experience: "In one of our demonstration projects we wanted to demonstrate a new concept for the separate collection of waste water streams. At first, the results from our feasibility studies seemed to be promising: the concept was technical feasible! As a next step we decided to make a business case to investigate the feasibility of making the step towards the implementation in 400 new houses in the city of Deventer. We made the choice to involve the project developers of the area and they helped us with the set-up of the business case. The conclusions from the business case were less positive unfortunately. Return on investment times were rather long, which did not help to convince the project decision makers to choose the concept. But especially the lack of proof that the concept worked on this scale in practice made that developers not want to implement this innovative concept yet."

5.4.5 TRANSNATIONAL BARRIERS

Next to barriers that we have encountered in the demonstration projects we also experienced that drawing overall conclusions for North West-Europe on the best strategies for energy recovery and reduction were sometimes hard. A few examples of barriers are listed here:

- how to make calculations of expected cost savings when energy prices and CO_2 emissions per unit of energy produced differ per country?
- the urban water cycle is managed differently in the different countries. Data from companies owned waste water treatment plants are not being shared that easily. How can we make a good benchmark?
- And last but not least: how to make waste water treatment plants comparable in North West-Europe when calculation methods for the plants characteristics differ?

5.5 FUTURE POSSIBILITIES IN THE URBAN WATER CYCLE AND TIPS AND TRICKS FROM INNERS

Increasing energy prices, the scarcity of fossil fuels: for blue energy the future seems promising. Some new devices have been designed to recover heat from grey water and to produce hot water. It could be interesting to study that kind of devices and to try to develop and to improve this technology in future projects. In the last four years the INNERS team pioneered in the world of blue energy from the urban water cycle. We definitely hope that our work inspired others to build further on our results. As a gesture of help we finalize this report with some tips and tricks.

1. STUDY, STUDY, STUDY...

A Feasibility study is one of the first steps when starting an innovative project. This prevents unexpected surprises and it helps build trust and in making the "go/ no go decision" with your key stakeholders.

2. COURAGE SELLS

Indeed, there is a lot of uncertainty about the financial and technical feasibility of innovative energy efficient measures in the urban water cycle. And if this is not within your team it is still there amongst your target groups whom you want to convince to make the urban water cycle more sustainable.

One thing that worked for us was to show that in INNERS also small organizations were active and made courageous decisions. One good example is the municipality of Raalte where we implemented the sustainable swimming pool project. There was a lot of attention for the way how this small municipality decided to become a pioneer in the topic of energy from waste water.

What we did not do, but what we believe will help in getting trust in projects like INNERS is to search for quick wins; physical proof in the form of realized demonstration projects in an early stage of your project.

3. ACCEPTANCE

Difficulties with permits should be expected. Allow for extra time and resources in any implementation plan. Extra discussion and analysis will be needed to provide the extra evidence to the permitting authority.

Improving the energy balance of the urban water cycle. That is the purpose of INNERS. 11 partners from the Netherlands, United Kingdom, France, Germany, Belgium and Luxembourg think in a new way about the urban water cycle as a potential source of energy.

Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

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