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NEREUS

Circular Economy

Energy Recovery Final Report

D2.6.1 Recovery & optimization of energy

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This project has received funding from the Interreg 2 Seas programme 2014-2020
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NEREUS FINAL REPORT

D2.6.1 Recovery & optimization of energy

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1 Introduction

The NEREUS (New Energy and Resources from Urban Sanitation) Project is an Interreg 2 Seas project with a consortium of 8 project partners across the United Kingdom, the Netherlands, Belgium, and France, working on the goal of recovering valuable resources from domestic wastewater. The working partners on this project were VITO NV, DuCoop CVBA, Waterlink, Agglomeration of Saint-Omer (CAPSO), HZ University of Applied Sciences, University of Portsmouth Higher Education Corporation, Southern Water Services Ltd and Evides Industrial Water B.V.

The project was born from a combination of global pressures, such as freshwater and finite resources scarcity, as well as the desire to increase the reuse of wastewater. To achieve this, it is aimed to encourage the adoption of technologies that recover important resources and enables the principal of a circular economy in the 2 Seas region[1].

The focus was to treat municipal/domestic wastewater, in order to transform it into valuable resources, and to efficiently remove micro-pollutants, resulting in reusable water as a final product. Hence, in order to achieve the desired objectives, NEREUS ran from October 2017 to December 2021, and during that time, focused on the recovery and reuse of water, resources (e.g. nutrients), and energy.

As domestic wastewater contains finite nutrients in its composition, such as phosphorus, nitrogen, potassium, and calcium, it offers significant potential for reuse. Additionally, it also contains energy and heat, that can be used as a sustainable source of energy in order to reduce CO_2 emissions. Therefore, wastewater treatment can lead to the recovery of these important environmental assets, besides water reuse as irrigation process, or even as drinking water. Thus, NEREUS partners have set up several demo cases to investigate and demonstrate these possibilities.

This report presents and discusses results achieved among project pilot partners, Evides and DuCoop, who aimed to recover energy from their wastewater streams. It also compares results regarding technologies used, recovered products, product quality and process optimization.

[1] 2Seas region: Covers coastal areas of England, France, Belgium (Flanders) and the Netherlands which are connected by the Channel and the North Sea (Interreg 2 Seas, n.d.)

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2 Pilot plants

As mentioned, this report will investigate the energy recovered by the project partners Evides (NL), and DuCoop (BE). In order to be able to recover resources from urban wastewater, each partner designed, built and operated a pilot scale wastewater treatment plant upon which they could perform their research. These particular pilot plants varied in size and focus; Evides has had two pilot plants over the course of the project which tested numerous technologies to recover many resources and DuCoop had a unique approach which was a treatment plant in the basement of an apartment building, treating and recovering resources from the wastewater produced by the apartments.

2.1 Evides Industry water

Evides is a Dutch water company involved in many aspects of water treatment, such as producing drinking and process water and treating domestic and industrial wastewater. Along with this, they develop, with their partners, sustainable solutions to recover valuable resources. In the NEREUS project, it was the branch Evides Industry Water who were a project partner and who ran the pilot plant.

Evides focused on the recovery of all three central products with their treatment train. The pilot was initially located in a commercial area in Rotterdam with the aim of delivering recovered resources and irrigation water back to an urban farming restaurant (*Uit Je Eigen Stad*). However, due to changes in circumstances involving the restaurant that were outside the control of Evides, the pilot location was moved to Harnaschpolder, Den Hoorn, where resources are recovered from a municipal wastewater treatment plant.

2.1.1 Stream profile

The term stream profile refers to the characteristics of the influent stream that is entering the pilot location and from which the resources will be recovered. As previously introduced, domestic wastewater was the chosen wastewater type to be treated. It can be divided into different streams according to their origin and composition: black water, which is water from toilets, and grey water, from showers laundry, and kitchen (de Graaff et al., 2010; Luostarinen et al., 2007).

According to de Graaff *et al.* (2010), these sources should be treated according to their quantity and composition, in order to achieve a successful resource recovery. Table 1 presents general compositions of both black and grey water. In this report, for each plant, the type of wastewater is identified, and its composition is presented.

Table 1 - Average characteristics of domestic wastewater, black water, and grey water

Parameter (mg/L)	Domestic wastewater	Black water	Grey water
BOD	350	300 – 600	100 – 400
COD	750	900 – 1500	200 – 700
Total nitrogen (TN)	60	100 – 300	8 – 30
Total phosphorus (TP)	15	40 – 90	2 – 7

Note. Adapted from Henze & Yves, 2008

The stream profile of the Evides pilot plant can be classified as domestic wastewater. The characteristics of the *Uit Je Eigen Stad* and Harnaschpolder streams can be found in Table 2 and 3, respectively. A view inside Evides' pilot plant, in Den Hoorn, is presented in Figure 1.

Table 2 - Uit Je Eigen Stad stream profile

Parameter	Unit	Value
Average Daily Flow	m^3/h	2.9
TSS	mg/L	25
COD	mg/L	58
BOD	mg/L	18
Total Kjeldahl nitrogen (TKN)	mg/L	15
Total nitrogen (TN)	mg/L	16
Total phosphorus (TP)	mg/L	1.4

Table 3 - Harnaschpolder stream profile

Parameter	Unit	Value
Average Daily Flow	m^3/h	2.9
TSS	mg/L	270
COD	mg/L	550
BOD	mg/L	240
Total Kjeldahl nitrogen (TKN)	mg/L	55
Total nitrogen (TN)	mg/L	67
Total phosphorus (TP)	mg/L	8

Figure 1 - Evides' pilot plant in Den Hoorn

2.1.2 Recovered resources

The Evides Industry Water pilot plant aimed to recover all central resources with their treatment train, but, for the benefit of this specific report; the pilot recovered energy in the form of biogas by using an anaerobic digestion unit. Within their treatment train, two different types of biomasses were available to be used for the digestion: sludge from a coagulation unit and algae. Biogas production using both fuel sources aimed to be tested, in order to analyse the recovery percentage of each. The produced biogas could then be burned to generate heat.

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2.2 DuCoop

DuCoop is a Belgium cooperative that provides sustainability services to the residents of *De Nieuwe Dokken*, an urban district in the city of Ghent. With their services, they contribute to climate ambition by closing loops: energy (heating, electricity and mobility), water and raw materials (waste treatment) (DuCoop, n.d.). The mentioned urban district, where the company's pilot plant is located, is presented in Figure 2. This figure also highlights the location of the biogas burner of the plant, which is a technology involved in the energy recovery; the focus of this report.

Within the NEREUS project, DuCoop focused on recovering water and energy with innovative technologies. They aimed to demonstrate a scalable design for use in sustainable urban districts, and also, to contribute to the development of new sustainable business models with smart energy management (NEREUS Project, 2018). Figure 3 shows a photograph of the biogas burner, which is located on the rooftop of a building at *De Nieuwe Dokken.*

Figure 2 - De Nieuwe Dokken district

Figure 3 - Biogas burner

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2.2.1 Stream profile

DuCoop treated two different types of effluent: black water, from sanitary and kitchen waste, and grey water from residential washing machines, shower, etc. The black water was not treated within the scope of the NEREUS project, however, the treated black water was used as part of the influent of the treatment train covered in this report and the NEREUS project, as seen in *section 3.3.1*. Therefore, the characteristics of black water stream can be found in Appendix A, Table A1, and the characteristics of grey water stream is presented in Table 4.

Table 4 - Nieuwe Dokken's (grey water) stream profile

Parameter	Unit	Value
Average Daily Flow	m^3/d	11.4
pH	-	7.4
COD	mg/L	1439.0
Total Nitrogen (TN)	mg/L	149.0
Total Phosphorous (TP)	mg/L	43.0

Note. Data concerns the influent quality during August 2021.

2.2.2 Recovered resource

Figure 4 shows a visual representation of the resources DuCoop aimed to recover and from which stream at *De Nieuwe Dokken*. Their specific goal for energy was recovery in the form of heat and biogas. Biogas was recovered outside of the scope of the NEREUS project, however, the reuse of the gas itself is accounted for in the project. It is meant to be burned, in order to produce heat, and used for central heating and sanitary hot water demand for housing units, offices and a city building at *De Nieuwe Dokken* district.

DuCoop also aimed to recover heat from two sources; their own treatment plant and from a nearby company, *Christeyns*. At their treatment plant, they've used a heat pump and heat exchange system at the end of the treatment train, as at this point the water had a temperature of about 30°C. For the remaining heat demand, they aimed to provide it by recovering waste heat (>70°C) from the nearby industry (NEREUS Project, 2018).

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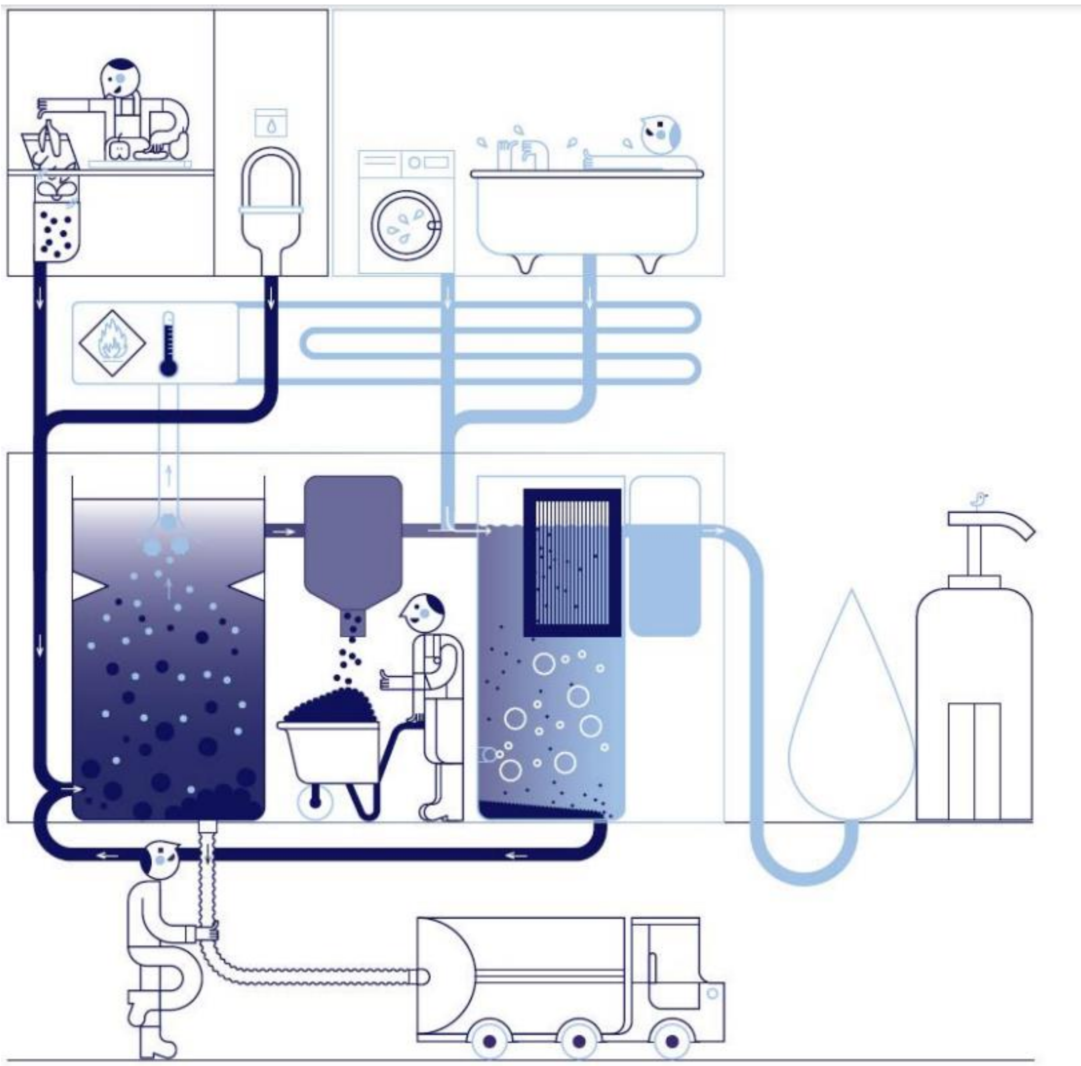

Figure 4 - Illustration of the resources being recovered at De Nieuwe Dokken

Note. The figure shows the different sources of wastewater and their use for resource recovery. Black water is treated together with kitchen waste for nutrient and energy recovery (biogas). Grey water is converted into process water, where the waste heat of the process is also recovered.
(DuCoop, 2018)

3 Methods

In order for the intended resources to be recovered from the source wastewater, a treatment train made up of various technologies was designed and installed at each pilot plant. The complexity of the treatment train was dependent on the resource or in some case number of resources to be recovered. In this chapter, a process flow diagram and technology description per pilot partner is reported.

3.1 Evides Industry Water

3.1.1 Process flow diagram

Figure 5 shown below contains Evides' process flow diagram involved in the energy recovery route (highlighted in the diagram):

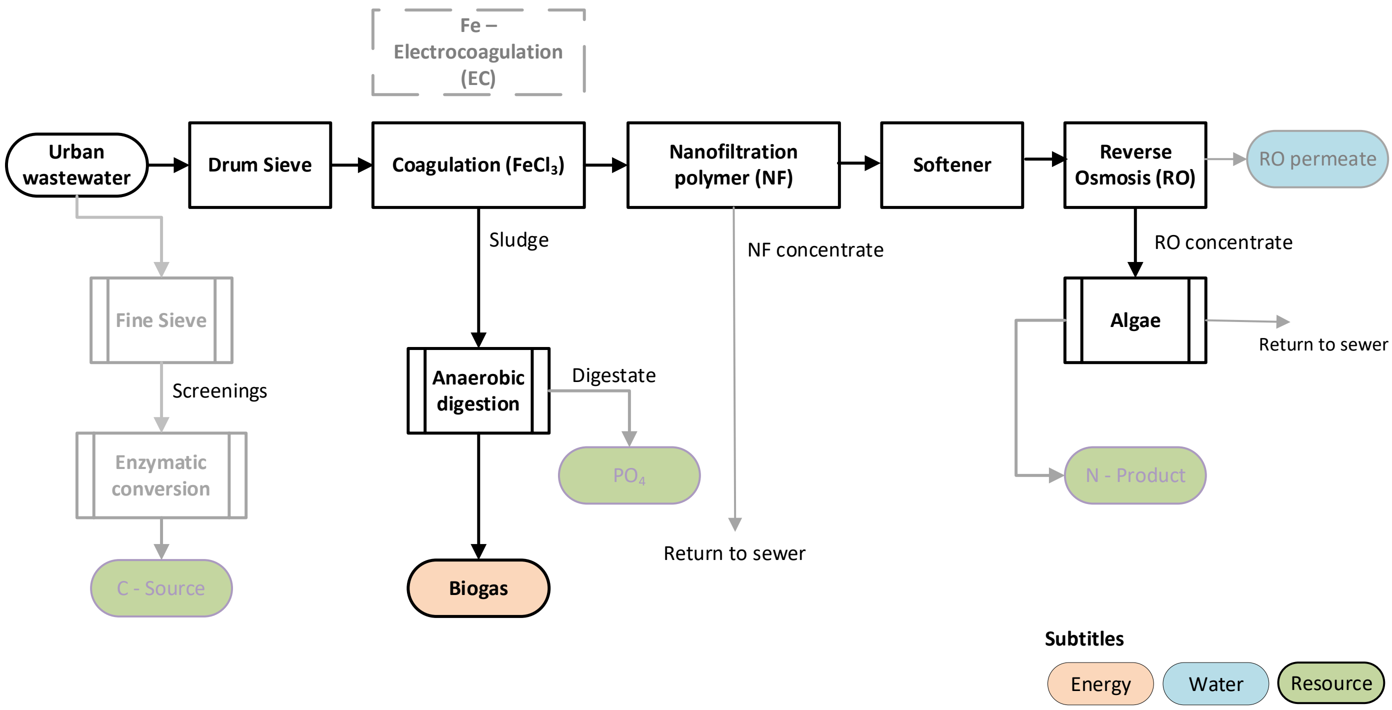

Figure 5 - Evides' energy recovery process flow diagram

3.1.2 Technologies

A treatment train containing various technologies was used for energy recovery, as shown in Figure 5. These technologies are described below:

- Electro-coagulation (EC): Consists of pairs of metal sheets called electrodes, that are arranged in pairs of anodes and cathodes, made of iron (Fe) (Naje & Abbas, 2013; Rodrigues, 2019). To achieve the coagulation, a metal with positive charge is required, as it will neutralize the negative charge of dissolved and suspended particles in the water (Safe Water, n.d.). When using the EC, the electrochemical reactions needed to achieve the coagulation are induced by a direct current electric field applied to the electrodes (Naje & Abbas, 2013; Rodrigues, 2019). Therefore, the particles will attach to each other and form large agglomerates that settle to the bottom.

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The coagulated particles, in the EC unit, form a sludge containing nutrients and organic matter. Therefore, for the energy recovery route, part of this sludge was used to feed the anaerobic digestion unit. Along with that, this process also produces hydrogen (H_2) , which could be used as an energy source.

After a period of testing running the pilot with EC, Evides decided to change it to a traditional coagulation process with iron (III) chloride ($FeCl_3$) dosing.

- Chemical coagulation ($FeCl_3$): Coagulation is a conventional process, in which chemicals are added, and react with colloidal particles to form large aggregates. These, can then be more easily and rapidly removed by flocculation or membrane filtration (Oriekhova & Stoll, 2014). According to Racar et al., (2017), some conventional coagulants are ferric or aluminum salts, that enable the formed aggregates to be removed as sludge.

  This process was applied in order to replace the EC unit, by dosing $FeCl_3$, as coagulant. Although following a different method, it was still used to remove the colloidal particles that form the sludge that was later digested to recover energy.

- Algae: Microalgae are photosynthetic organisms that grow rapidly and live in harsh conditions due to their unicellular or simple multicellular structure (Barbera et al., 2018; Rodrigues, 2019). They can be used in wastewater treatment for a different range of objectives: removal of coliform bacteria, reduction of both chemical and biochemical oxygen demand, removal of N and/or P, and also for the removal of heavy metals (Abdel-Raouf et al., 2012). Algae are also related to energy saving, since they use solar energy, because of their photosynthetic capabilities, to biodegrade organic pollutants and transform them into useful biomasses, such as biogas substrate, biofuels, fertilizers, and biopolymers (Abdel-Raouf et al., 2012; Arashiro, 2016).

  Besides being used for nitrogen recovery, algae biomass was also meant to be tested at the Evides pilot as a source of energy recovery. In order to do so, the algae was fed into the anaerobic digestion unit, in order to produce methane (biogas).

- Anaerobic digestion: An anaerobic[2] digestion process consists of the degradation of natural polymers and soluble organic compounds into methane (CH_4) and carbon dioxide (CO_2) (Aiyuk et al., 2006) which can be used to produce electricity and heat (de Graaff et al., 2010).

  This unit was used for methane (biogas) production in order to recover energy. Evides tested the anaerobic reactor with two different sources of biomass; sludge, from the coagulation unit, and algae.

[2] A process that occurs in the absence of oxygen.

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3.2 DuCoop

3.2.1 Process flow diagram

Figure 6 presents DuCoop’s process flow diagram for energy recovery.

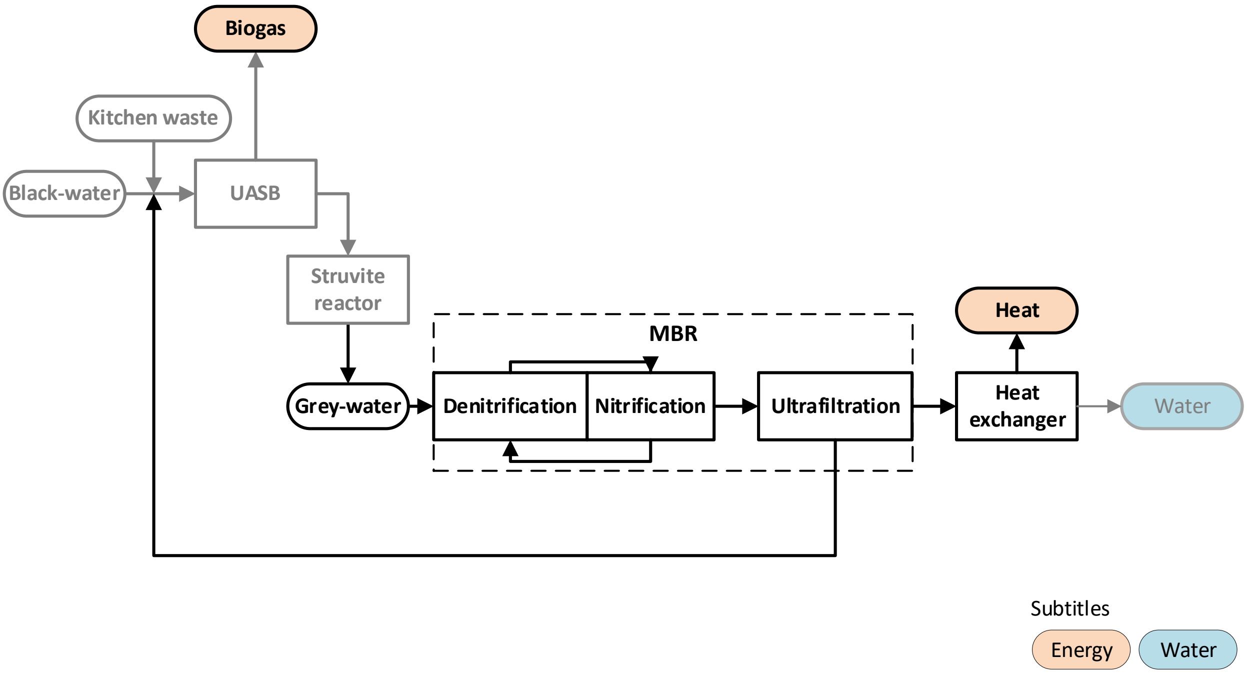

Figure 6 - DuCoop's energy recovery process flow diagram

3.2.2 Technologies

The set of technologies used to recover energy, in DuCoop treatment train, are explained below:

- Upflow Anaerobic Sludge Blanket (UASB) Reactor: UASB is a high-rate anaerobic digester used to treat sewage, designed to be operated with a short hydraulic retention time (HRT[3]) (Chong et al., 2012). This type of reactor has a very dense sludge bed, and above it, a sludge blanket zone, enabling the biological reactions to take place between them. As this process happens, soluble organic compounds in the influent are converted to biogas, consisting of mainly methane and carbon dioxide (Aiyuk et al., 2006). This technology has a high removal efficiency, except for pathogen and nutrients, therefore, requiring a post-treatment to reach discharge standards (Chong et al., 2012).

  The UASB reactor is used as a primary treatment, in DuCoop’s treatment train, and also for biogas production. Its influent is black water and kitchen waste, and it aims to produce a biogas, that is 60% CH_4 and 40% CO_2 for combustion and heat production. It should be noted that the UASB was not covered by the scope of the NEREUS project, however, the effluent from the UASB was fed into the rest of the treatment train which was covered by the NEREUS project and therefore had an impact on the rest of the process.

[3] Represents the average time that components stay inside the reactor.

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- Heat pump and heat exchanger system: A heat pump's objective is to recover and reuse energy that is being dissipated as a large amount of heat waste, causing severe energy misuse and sometimes, environmental pollution (Xu et al., 2020). This source of energy can be partially or fully reused or recovered economically and can be either used on the same or different processes for the same system (Baradey et al., 2015).

  The heat recovery system in DuCoop's treatment plant was placed as the last unit in the water production process. It aimed to recover energy from the effluent of the water treatment plant (20-30°C, depending on seasonal conditions), that would be used to partially fulfil the central heating demand of the district (approximately one third).

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4 Results

This chapter focusses on the results obtained by each pilot partner when recovering the aimed energy type, as well as the recovery amount and quality of the end product. It also presents the process optimization applied in each plant and the conditions chosen to be the best for achieving their targets.

4.1 Evides Industry Water

4.1.1 Recovery

Evides recovered biogas through an anaerobic digestion process of iron sludge. These tests were done in a lab scale and, based on achieved results, represented a potential production rate of methane of 5.8 m^3/d in the pilot setup.

4.1.2 Recovered product

Evides' general target was to recover energy as gas via digestion (biogas, measured as CH_4) and via electrocoagulation (H_2). For biogas production, they aimed to test iron sludge, from the precipitation unit, and algae biomass as a feed for the aerobic digestion unit. Tests were done in a lab scale setup, and showed that in a continuous mode, the recovery of biogas out of iron sludge is satisfactory and feasible.

Concerning the digestion of the algae biomass, Evides believe that, with the tests already performed, they do not have enough results to draw conclusions for its feasibility. The recovery of hydrogen gas was not possible due to the replacement of the electrocoagulation unit for a conventional chemical precipitation unit.

4.1.3 Process optimization

The process optimization of Evides in the energy recovered route was focused on the anaerobic digestion of iron sludge from the precipitation unit. Table 5 presents the amount of methane produced per amount (mass) of sludge. The samples tested were iron sludge in different pH values, and also primary sludge of the Harnaschpolder WWTP.

Table 5 - Methane production from sludge digestion

Sample	**Average yield from substrate (mL CH_4/g VS)**
Iron sludge, pH 7	362
Iron sludge, pH 8	479
Iron sludge, pH 9	586
Iron sludge, pH 10	0
Harnaschpolder sludge	329

Based on Table 5, it's possible to conclude that the digestion of iron sludge in a pH between 8 and 9 had a higher methane production when compared to the primary sludge digestion.

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4.1.4 Full scale design

According to Steenbakker & van den Brink, 2021, the plant should be a full scale in order to be economically feasible. It was concluded that resource recovery can reach a full scale design depending on the stream, source and application. However, they do not intend to go full-scale with this same setup.

4.2 DuCoop

4.2.1 Recovery

DuCoop recovered waste heat on two locations at their treatment train: after grey water treatment with a heat exchanger and heat pump, and from burning biogas produced at the UASB.

An important way of analysing the effectiveness of the heat pump is the coefficient of performance (COP). In the heating mode, the COP is the ratio of the heat output (produced heat) of a heat pump to its electrical energy input. Table 6 presents the COP achieved by using the average heat production during cold and warm seasons in 2021, and also an extrapolation for what is believed to happen when the plant is fully operational.

It is important to note that, according to DuCoop, due to some problems faced on the unit, the amount of heat that could be recovered in the summer and spring was lower than winter. This was later solved but still had an impact on the results shown in Table 6.

Table 6 - Average operational measurements of the heat pump

	Cold seasons	Warm seasons
Electricity usage heat pump (kWh)	5900	3880.5
Heat production heat pump (kWh)	19300	9200
COP total	3.27	2.37
COP when (fully) operational	2.8 – 3.5	3.4 – 4.1

Note. Adapted from NEREUS Deliverable D5.7.6 Test results heat pump (Seuntjens, 2021).

Therefore, it is expected that the heat pump delivers an average of 3.15 and 3.75 times more energy than it consumes, for cold and warm seasons respectively.

DuCoop's plant also recovered energy as biogas, with a production rate of 4.05 m^3/d, and a methane concentration of 75.3%. Based on a mass balance of the UASB, done by DuCoop over a period of one year, this achieved production corresponded to a COD recovery of about 44%. Additionally, by burning the biogas, they have a potential heat recovery of 11.329 kWh.

4.2.2 Recovered product

The heat recovered by DuCoop comes from two different sources but aims to serve the same purpose: to be used to cover part of the heat demand of *De Nieuwe Dokken* district and the nearby soap factory *Christeyns*. In Figure 7, the potential heat available from the water treatment plant and the district heat demand are illustrated over a whole year. This data was extrapolated to represent the district when fully inhabited (Seuntjens, 2021).

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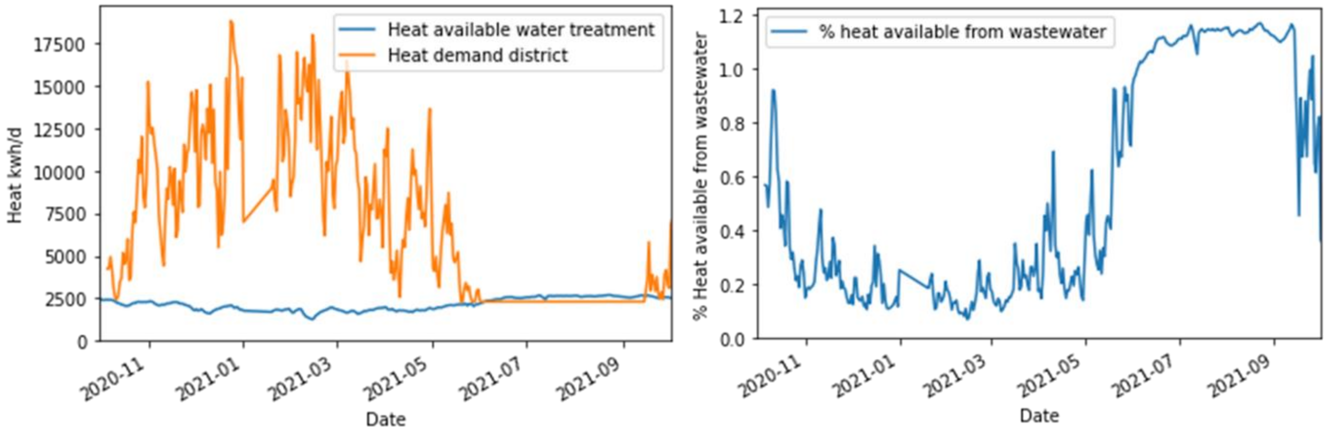

Figure 7 - Potential heat production and demand

(Seuntjens, 2021)

In Figure 7, is possible to see that, in the warm seasons, the recovered heat would be sufficient to cover the demand. However, during winter, the amount of heat recovered is not enough. Also in Figure 7, it's illustrated that they expect an overall heat recovery of 2500 kWh/d, when accounting all the values of the year. According to Seuntjens, 2021, DuCoop estimates that 25-30% of the heat demand of the district can originate from the wastewater treatment plant.

Concerning the biogas produced, it is burned and also reused as a heat source. However, due to the fact of limited gas buffering capacity, there is not a control optimization. This means that when sufficient gas is produced, it is automatically burned. Therefore the heat production is non controllable, but the generated heat is still used by the district when there is a time match between demand and production. The biogas boiler was able to increase the temperature of the heat departing the district from 55°C to < 90°C. This limit temperature was chosen in order to avoid condensation in the boiler and corrosion due to H_2SO_4.

The combination of these two heat sources is expected to be enough to cover a third of the district demand, and two thirds of the demand of nearby fabric *Christeyns*.

4.2.3 Process optimization

The process optimization of DuCoop's plant was focused on finding the appropriated conditions for incorporating the heat pump and the biogas burner, in order to be used as a heat source. As heat is a product that cannot be stored, as it'll be dissipated, and therefore lost, the focus was on finding a smart control system. In other words, there should be a match between the time when heat is recovered and when it is needed to be used by the district.

Thus, DuCoop established some operational boundaries for heat recovery from the effluent (Seuntjens, 2021, p.3):

- *The heat pump can only work when effluent of wastewater treatment plant is available*
- *The heat pump can only provide heat to the district when there is sufficient heat demand*

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- *The heat pump can only provide heat to the district when other heat sources are not placing already too much heat on the district heating; i.e. biogas burner and waste heat from the soap factory.*
- *The heat pump preferentially uses cheap power from solar panels or battery stored power.*

Concerning the biogas burner, as explained in *section 4.2.2.,* it did not have an optimized control, due to the limited gas buffering capacity of the design. However, with the combination of the two energy sources and the smart management, it is estimated that this heat source will be enough for covering 25-30% of the district demand.

4.2.4 Full scale design

The plant is already full scale and designed for operating 90 m^3/d of grey water, collecting wastewater from 400 apartments and 1200 PE. As already explained, until the end of the NEREUS project, the plant operated with a maximum of 17% of the capacity, because the complex at De Nieuwe Dokken was not completely built. It is expected that by the end of 2022 there will be an acceptable load which would give more representative numbers for the plant.

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5 Discussion

During this report, characteristics of the different energy types recovered, along with the technologies used and the obtained results have been presented per pilot partner. In order to enable a discussion about all of these recovery processes, this chapter will focus on comparing the main aspects and results of their processes; their technologies, recovered product and achievement of initial goals and targets.

5.1 Technologies and process conditions

As all of the technologies involved have already been presented per pilot partner in *chapter 3,* the aim here is to provide a better view and comparison of them. Therefore, Table 7 presents the overall and most relevant process conditions that have been presented in this report.

Table 7 - Overall process overview per recovered resource

	Evides	**DuCoop**	
	Biogas	Heat	Biogas
Main technologies	• Anaerobic digestion	• Heat exchanger • Heat pump	• UASB • Biogas burner
External dosing	• No	• No	• No
Operational variables	• Temperature	• Smart heat control	• Flow • Temperature
Barriers	2	2	1

The two pilot plants involved aimed to get to the same end product: heat, either by its direct recovery from waste heat or by biogas production, that could then be burned. In terms of similarity, both partners recovered biogas by an anaerobic digestion process. However, Evides used the sludge from the precipitation unit as a source for the digestion, while DuCoop fed a mixture of black water and kitchen waste into an UASB. Besides the biogas production, DuCoop also invested in recovery of waste heat from the water of their treatment plant, by using a heat exchange and heat pump system.

In terms of barriers, it's possible to see in Table 7 that there was not a need for a lot of technologies involved. This is the case as the anaerobic digestion process only requires a feed that is rich in organic matter: DuCoop had this with the black water and the kitchen waste, and Evides needed one other process to obtain the influent sludge. For the heat recovery, the heat system is enough for recovery, but, it's important to have a cleaner water for this, in order to not cause damage to the system. Therefore, the biological treatment (MBR), was counted as a needed barrier.

5.2 Recovery

Table 8 presents the amount of energy recovered by the pilot partners.

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Table 8 - Energy recovery per pilot partner

Evides	DuCoop	
Biogas as CH_4 (m^3/d)	Heat (kWh/d)	Biogas (m^3/d)
5.8[a]	2500.0	4.03 as CH_4: 3.03

[a] potential methane production based on lab scale trials

5.3 Quality of recovered products

Table 9 contains the main aspects of the recovered energy sources at the pilot plants. It aims to provide the characteristics of the products in order to discuss whether it is suitable or not for the end use.

Table 9 - Quality of recovered products per pilot partner

	Evides	**DuCoop**	
	Biogas	Heat	Biogas
Overall characteristics	• From precipitation sludge	• 20-30°C from effluent • > 70°C from industry	• From black water and kitchen waste
Impurities	• n.a.[a]	• n.a.[a]	• n.a.[a]
Suitable for end use	• Yes: Can be burned for heat source	• Yes: Heat source	• Yes: Burned to get a heat source

[a] n.a.: (data) not available

Both Evides and DuCoop obtained biogas through an anaerobic digestion process, respectively from digesting the sludge from the precipitation unit and a mixture of black water and kitchen waste. DuCoop also recovered heat from waste heat sources: the effluent of their wastewater plant and from the industry *Christeyns.* The temperatures of both of these streams are presented in Table 9.

In terms of suitability for end use, all of the resources were able to be reused, as seen. In effect, the heat recovered by DuCoop is already being used to cover part of the demand of De Nieuwe Dokken district and the nearby soap factory. Concerning Evides, there was no final user for their product, but the biogas generated in the process is suitable for being burned, and therefore, to be converted to heat.

5.4 Initial goals and targets

An assessment of the pilot plants' end products was done by comparing the initial goals and recovery targets with the achieved ones. This assessment is presented in the form of a table containing a color coded conclusion, per recovery percentage and other goals. Table 10 contains this color code definition, and the assessment is covered in Table 11.

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Table 10 - Color code definition

Color	Definition
Green	• Recovery target achieved • Goals achieved
Yellow	• At least 50% of recovery target achieved • Goals partially achieved
Red	• Less than 50% of the recovery target achieved • None of goals achieved

Table 11 - Comparison of the initial and achieved targets and goals

	Evides	DuCoop	
	Gas (m^3/d)	Heat (kWh/d)	Biogas (m^3/d)
Recovery target	-	2330.0	-
Achieved	**CH_4: 5.8** (green)	**2500.0** (green)	**4.05** (green)
Goals	• Biogas production • H_2 gas production	• Heat from waste heat of GW	• Burn biogas for heat generation
Achieved	(yellow)	(green)	(green)

As seen in Table 11, both partners achieved their recovery target for energy with the designed processes. Concerning the goals stablished, Evides successfully produced biogas through the digestion of precipitation sludge and could draw some initial conclusions. The aim was also to recover H_2 as a by-product of the electrocoagulation unit, due to its spontaneous release. Although there was indeed H_2 production, this specific unit was no longer used due to operational challenges and was replaced by a conventional precipitation process. Therefore, H_2 gas was no longer recovered, explaining why the goals were partially achieved.

DuCoop successfully achieved their proposed goals for energy recovery in the form of heat. Although there were some difficulties within the biogas burning control, that did not enable it to be burned according to demand, the combination of two heat sources in order to partly supply heat for the district and a factory was successful.

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6 Conclusion

This report covered the experiences, among project partners Evides and DuCoop, on energy recovery from wastewater, during the NEREUS project. Two types of energy were recovered within the pilot plants; biogas and heat, from different waste sources and using a variety of technologies, enabling discussions concerning the recovery process. These involved several trials and optimization tests in order to find appropriate conditions for recovering products with high quality suitable for re-use.

Both pilots produced biogas in their plants through an anaerobic digestion unit. Different types of waste can be used in the digestion process, as long as it carries a high load of organic matter and colloidal particles. In effect, Evides used the sludge from the precipitation unit as the feed whilst DuCoop used a mixed stream of black water and kitchen waste; both presented considerable gas production. This demonstrates that biogas can be produced from different waste sources, however, trials and optimization tests are important to attest if the source is feasible for it. Biogas can later be burned and transformed into another source of energy: heat.

Heat was also directly recovered in DuCoop's plant. They've used a heat system composed of a heat exchanger and a heat pump. The sources for the recovery were waste heat from different locations: the effluent of their own treatment plant and from process water from a nearby factory. It is estimated that, when fully operational, this recovered heat would be enough for covering a third of the demand of the district where the plant is located and two thirds of the energy needed by the nearby factory. An important remark about the reuse of heat is the necessity of designing a smart control of its use; as heat cannot be stored, the timing of its recovery must meet the timing of its demand, so losses can be minimized.

Therefore, this report aimed to present and discuss the processes and results obtained at the pilot plants, in order to verify the possibilities of energy recovery from wastewater. As seen, energy can be recovered from different waste sources and, in general, does not require various units in the process, enabling a more compact plant. Although it is likely that the recovered energy won't fulfil the complete demand, it can be a complimentary supply and have a positive impact on cost reductions. Thus, energy is an important resource that can be reused, although a smart control might be necessary to avoid losses and increase efficiency. Therefore, research should continue in order to improve the processes, the feasibility and acceptability of energy recovery.

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Appendix A

Extra influent quality data

Table A1 – Nieuwe Dokken's (black water) stream profile

Parameter	**Unit**	**Value**
Average Daily Flow	m^3/d	3.10
pH	-	7.4
COD	mg/L	7283

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