Interreg Baltic Sea Region

Co-funded by the European Union

SUSTAINABLE WATERS

NURSECOAST-II

MAPS FOR THE TOURISTIC SEASONALITY AREAS AND TECHNOLOGY CRITERIA FOR PILOTS

DELIVERABLE D.1.1

NURSECOAST-II REPORT

January 2024

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Glossary

BOD_5 - Biological oxygen demand - the amount of oxygen which microorganisms consume in a wastewater sample during the period of 5 days at a certain temperature

BOD_7 - Biological oxygen demand - the amount of oxygen which microorganisms consume in a wastewater sample during the period of 7 days at a certain temperature

COD - Chemical Oxygen Demand

EPA - Environmental Protection Agency

N - Nitrogen

NUTS - Nomenclature of territorial units for statistics

NUTS 3 - small regions for specific diagnoses

P - Phosphorus

PE - Population equivalent

Qdtavg - Average amount of treated wastewater per day

Qdwavg - Average amount of wastewater discharged to the wastewater treatment plant per day

RZGW – Regionalny Zarząd Gospodarki Wodnej (Regional Water Management Board in Poland)

SS - Suspended Solids

TN - Total nitrogen

TP - Total phosphorus

TSS - Total suspended Solids

WIOŚ – Wojewódzki Inspektorat Ochrony Środowiska (Voivodship Inspectorate for Environmental Protection in Poland)

WWTP – Wastewater treatment plant

WWTS – Wastewater treatment system

This report titled 'Maps for the touristic seasonality areas and technology criteria for pilots' was published on 31st of December 2023 (period 2 of the project) on the project website. The report is part of the activity A1.1 'SEASONALITY MAPPING & ANALYSES' in NURSECOAST-II project.

31 December 2023

Introduction

During the summer, many tourists come to the coastal areas around the Baltic Sea. This puts pressure on the coastal wastewater treatment systems designed for the average year-round population. Thus, several problems may occur as untreated or poorly treated wastewater can cause harmful effects on human health, the environment or economic activity, e.g., spoiling the hygienic and ecological quality of the water in its catchments, causing eutrophication and worsening the water's oxygen situation and fish populations in the delicate Baltic Sea. Tourism in the coastal areas of the Baltic is connected to the state of the sea. Clean beaches and safe and clear water attract tourists, but at the same time, the environmental impacts of tourism must be considered, for instance, proper treatment of wastewater from tourist destinations. The high load during the tourist season and on the other hand the too low utilization rate outside the tourist season is causing challenges to wastewater treatment, area's environment, and the Baltic Sea.

Wastewater discharged from the near-coast Baltic regions is often from very small treatment plants (<2000 population equivalent, PE). In addition, a large variability of wastewater flows occurs due to seasonality. Such conditions make it difficult to obtain the required effluent quality parameters continuously and may endanger the overall quality of the touristic place and the satisfaction of the clients. Finding a different wastewater technological solution, especially adapted to tourist areas, would reduce the nutrient inputs to the sea across the Baltic Sea Region. To achieve sustainable development, along with technological and economic factors, environmental and social aspects should be taken into consideration when selecting suitable wastewater treatment solutions.

Along with increased/more efficient wastewater treatment capacity, there is a need to consider and raise awareness about responsible water consumption. Tap water is consumed in many ways, e.g., cooking, showering, or actual drinking. Most of the household water consumption comes from washing. Regarding the touristic business, hotels and other types of accommodation, restaurants and other service providers consume millions of litres of water and produce wastewater. The European Environment Agency (EEA 2023[1]) estimates that about a third of the EU's territory is exposed to water stress, either permanently or temporarily. Climate change is expected to increase the frequency of water shortages in the future. In addition, drought periods are rising, and precipitation occurs less frequently. Increased extreme water conditions (floods, drought) will put pressure on the infrastructure in the cities and rural areas also in the northern parts of Europe.

[1]EEA 2023. Water scarcity conditions in Europe, 13 Jan 2023. https://www.eea.europa.eu/en/analysis/indicators/use-of-freshwater-resources-in-europe-1?activeAccordion=ecdb3bcf-bbe9-4978-b5cf-0b136399d9f8

This report is written in the project NURSECOAST-II which is funded by the Interreg Baltic Sea Region 2021-2027 programme and co-funded by the European Union.

Project approach

The circular economy has been proposed as an effective framework for sustainable water management. The concept of circular water management adopts the 5R approach- reduce, reuse, recycle, restore, recover (Figure 1). In this project, 5Rs are adopted as the NURSECOAST-II project focuses on small-scale wastewater treatment (<2000 PE) as well as other measures and technologies that aim to recirculate or reduce nutrients, particularly in the touristic regions. The high load during the tourist season and on the other hand the too low utilization rate outside the tourist season is causing wastewater treatment, and this causes extra load on the area's environment and the Baltic Sea.

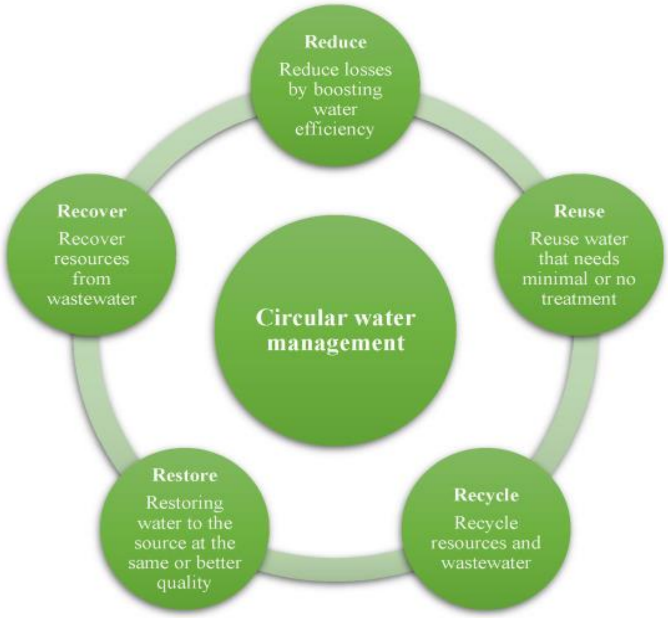

Figure 1. Circular water management- 5R principles (UN 2020)[2].

The project specific aim is to tackle particularly the problem with the seasonality in 6 pilot cases in Latvia, Finland, Denmark and Poland. Methods, nanobubbles, constructed wetlands, and package plants demonstrated in the pilot sites aim to increase treatment capacity as a solution to the challenge caused by seasonality (Figure 2). The project takes lessons from other projects and builds up an added value towards sustainable solutions dedicated to near-coast tourism. A tool about 2000 PE wastewater treatment plant distribution, technology reviews, pilot selection criteria and risk assessment will be developed.

[2] UN 2020. UN World Water Development Report 2020. https://www.unwater.org/publications/un-world-water-development-report-2020

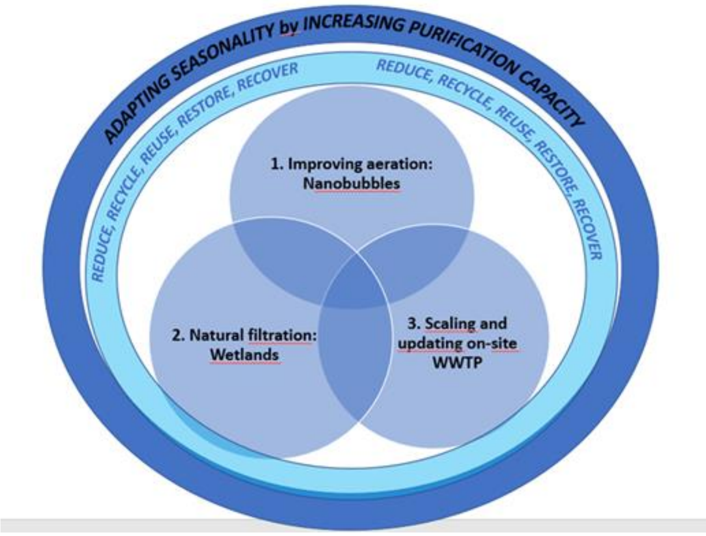

Figure 2. The framework of the project.

This report combines the projects preliminary actions and report summaries including 1) GIS analyses of current small scale WWTP in chosen regions 2) Identification of technological boundaries for selected pilots, 3) Survey of water use and possible water saving solutions in selected pilots, 4) Options analysis: nutrient reducing and recycling, from wastewater to resource and 5) Final <2000 PE WWTP wastewater seasonality examination in the partnering countries for given touristic locations and pilots.

Aim of the Project

The project´s goal is to find an alternative wastewater treatment solution for tourist areas that could reduce nutrient inputs to the Baltic Sea. NURSECOAST-II is a pioneering project that unites 17 partner organisations from 8 countries in the Baltic Sea Region, aimed at mitigating the seasonal increase in wastewater production and nutrient discharges in tourist areas around the Baltic Sea. The Project will conduct six pilots in Denmark, Poland, Latvia, and Finland, testing innovative wastewater solutions that can be used in the Baltic Sea region. Additionally, the Project will conduct three regional surveys in Sweden, Estonia, and Latvia, supported by a pan-Baltic Sea Region GIS-based mapping.

NURSECOAST-II comprises three work packages, namely WP1 - Preparing Solutions, WP2 - Piloting and Evaluating Solutions, and WP3 - Transferring Solutions. The WP1 will include seasonality mapping and analyses, pilots' technical preparation, socio-economic considerations' analysis, and transnational co-creation workshops. This coverage describes the process of collecting and visualising the data needed in the first work packages – WP1 - Preparing Solutions. The collected data constitutes the basis for future analyses.

Terms used in the coverage:

Project - "Model Nutrients Reduction Solutions In Near-Coast Touristic Areas (NURSECOAST-II)"

Partner Countries - Baltic Sea countries participating in the Project (Figure 3).

Project Partners – The Szewalski Institute of Fluid-Flow Machinery Polish Academy of Sciences (IFFM PAS), Kaunas University of Technology (KTU), Natural Resources Institute Finland (LUKE), SYKLI Environmental College (SYKLI), Keep the Archipelago Tidy Association (KATA), Aalborg Univesity (AAU), The Bogdan Janski Bure Misie Community Foundation (BMCF), Stockholm Environment Institute Tallinn Centre (SEI Tallinn), Jurmala Udens Water Utility (JU), Municipality of Söderhamn, Municipality of Ingå, Danish Nature Fund, NK forsyning, Association of Polish Communes Euroregion Baltic, EUCC - The Coastal Union Germany, VNK serviss Ltd.

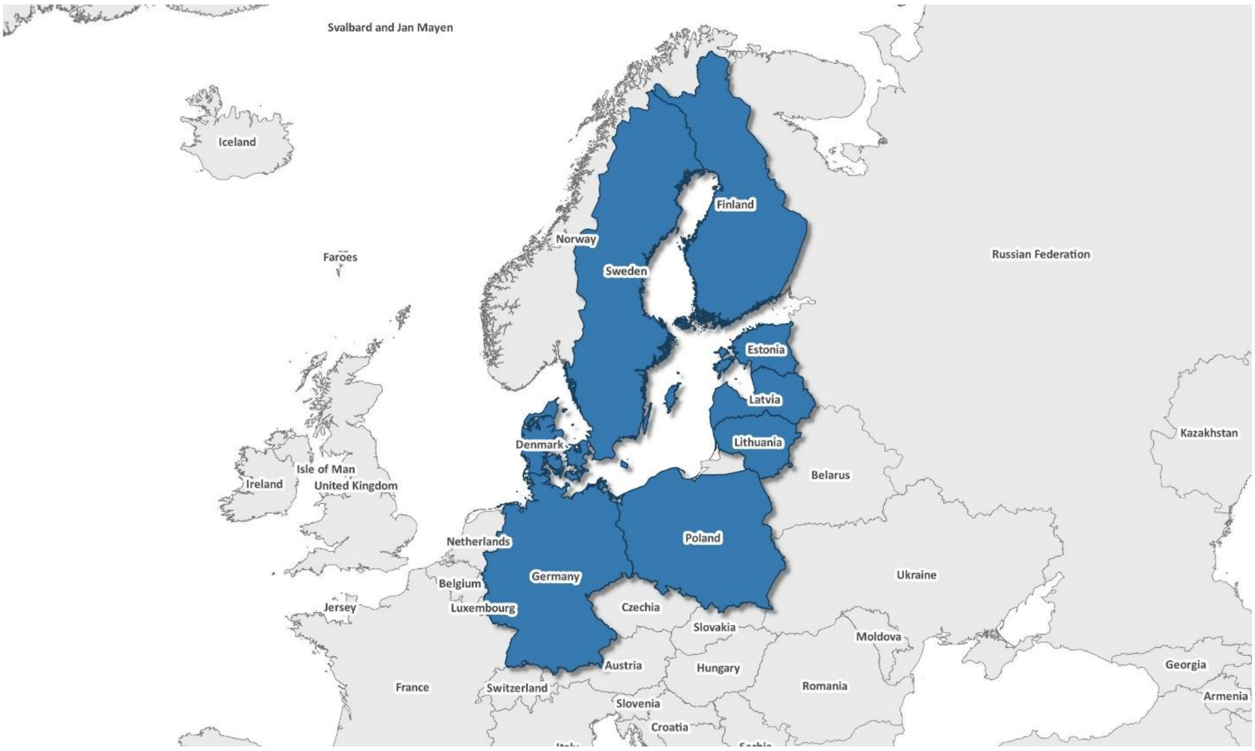

Figure 3. Partner Countries

1. GIS analyses of current small scale WWTP in chosen regions

Authors: Joanna Małuj, Piotr Szafranowicz, Magda Ciepły, Joanna Łyżwa, Magdalena Goławska, Izabela Konkol, Ksawery Kuligowski

Methodology

Project criteria

WWTPs from the Baltic Sea region that meet the following criteria were selected for the Project:

1. Location within the distance of 100 km from the coastline of the Baltic Sea (Figure 4);
2. PE below or equal to 2000;
3. operating in 2019 and 2021;
4. the Baltic Sea is the end receiver of the treated wastewater.

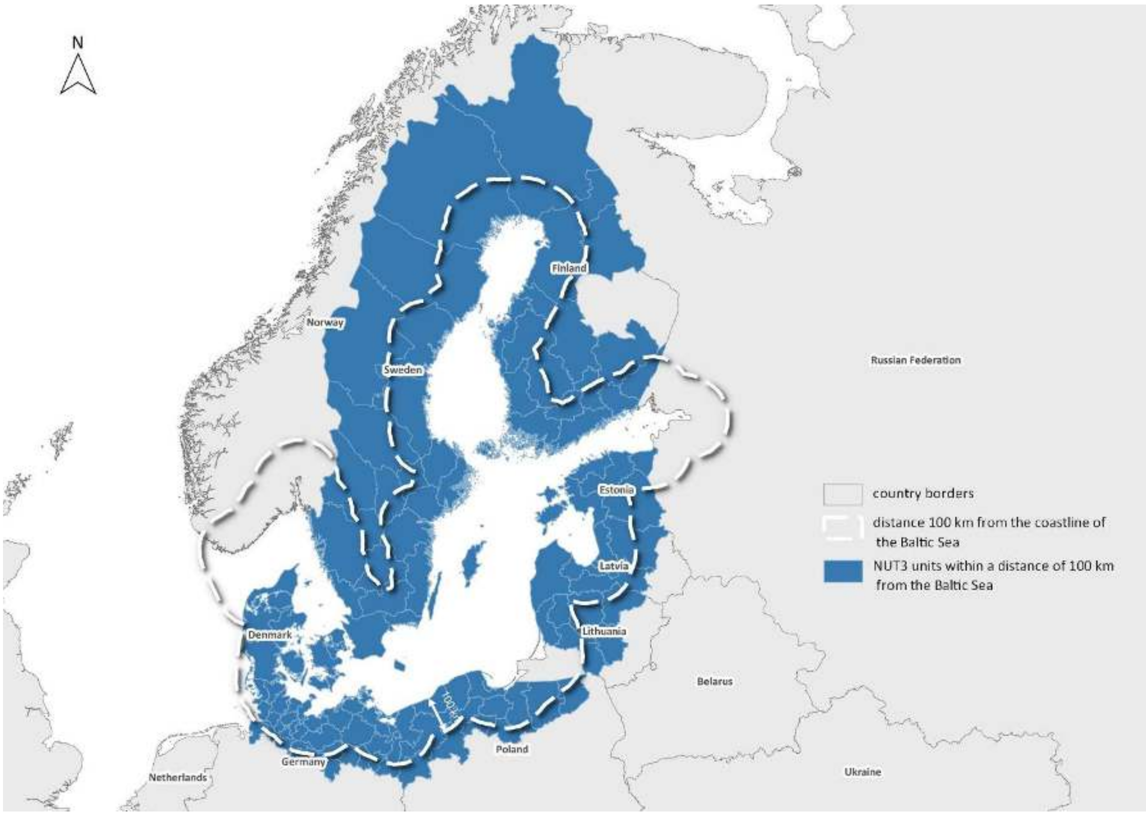

Figure 4. Distance of 100 km from the coastline of the Baltic Sea

This report is written in the project NURSECOAST-II which is funded by the Interreg Baltic Sea Region 2021-2027 programme and co-funded by the European Union.

The distance of 100 km from the coastline of the Baltic Sea was determined based on the coastlines of all the Baltic countries including countries not participating in the Project (Russia and Norway). It should be emphasized that the obtained result will vary depending on the geometry of the source layer. For example, the borderline of 100 km from the coastline of the Baltic Sea will be different when the source layer is the coastline of one country, and different when the source layer is the coastline of all the Baltic countries. Figure 5 below shows the impact of considering the coastline of Russia (Kaliningrad) and Lithuania on determining the distance of 100 km in Poland. Lastly, the designated boundaries have been adjusted to the boundaries of NUTS 3 territorial units.

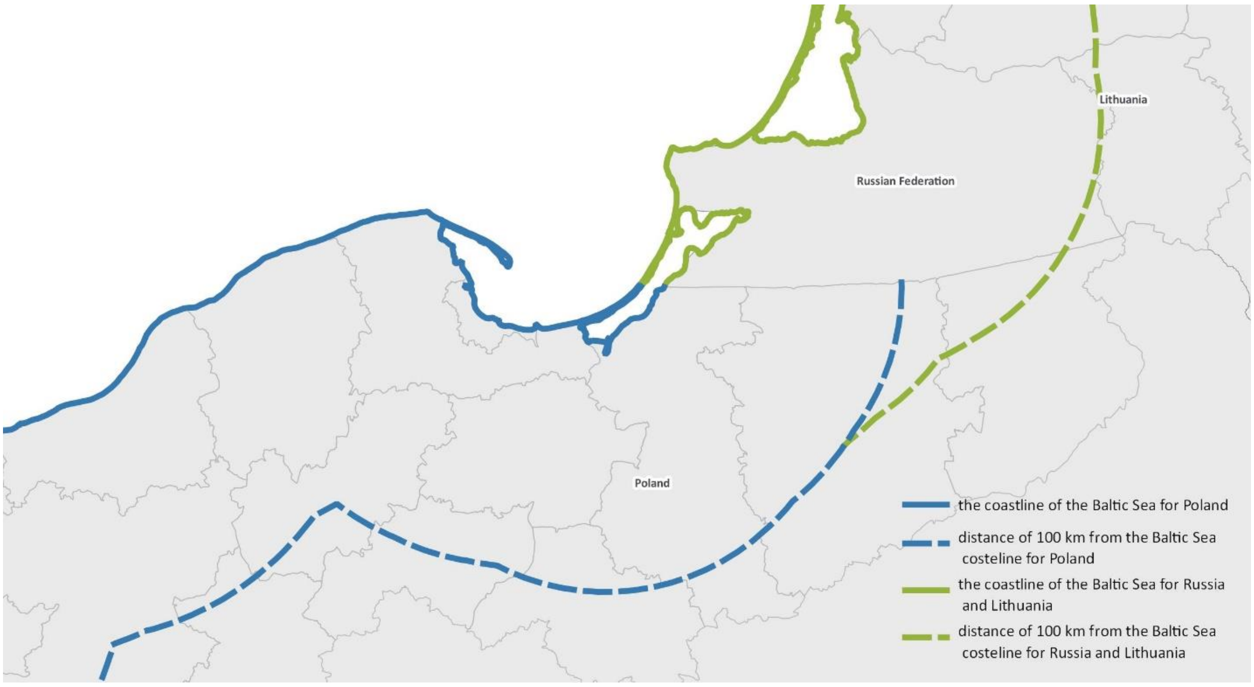

Figure 5. The impact of taking into account the coastline of Russia (Kaliningrad) on determining the distance of 100 km in Poland

The second criterion was met if, in at least one of the analysed years, the WWTPs had a value equal to or below 2000 PE. This means that WWTPs that were redeveloped during the analysed period were also included in the Project.

The 2020 omitted in the Project was the year of the Covid-19 pandemic, during which countries imposed significant restrictions on domestic and foreign travel. Due to the smaller number of tourists visiting the Baltic Sea regions, the measurements from 2020 would most likely differ significantly from those from 2019 and 2021. The years selected for the Project were considered the most reliable.

The fourth criterion concerns the end receiver of treated wastewater. In Denmark and Germany, some WWTPs located 100 km from the coastline of the Baltic Sea discharge treated wastewater to the North Sea, which is closer than the Baltic Sea. Such treatment plants were not included in the Project.

Even though the Project focuses on the impact of tourism on increasing wastewater production, in most Partner Countries, it is not possible to select WWTPs that treat wastewater from tourist entities only. Moreover, when analysing wastewater from municipal WWTPs, not only domestic sewage but also industrial sewage is taken into account. Therefore, until a consistent data collection system is introduced in all Partner Countries, selecting treatment plants based on the origin of wastewater is impossible.

Key Features of the legal system in the analysed countries

Based on the information provided by Project Partners, it can be concluded that the wastewater legislation systems in the analysed countries are structured similarly. The Water Act is the main legal act in water management. It specifies the conditions for the use, treatment and disposal of wastewater. In most cases, the construction of a WWTP requires obtaining a water permit, which specifies treated wastewater quality standards, treated wastewater discharge locations and the PE of the treatment plant. However, the Swedish system is an exception to this rule. In Sweden, in addition to the water permit (tillstånd), there is a notification obligation (anmälningsplikt). The first one is required for WWTPs in the range of 5 PE to 199 PE. For WWTPs over 200 PE there is an obligation to notify.

Significant differences exist in how wastewater quality is monitored in the analysed countries. Typically, the differences concern the number of measurements per year and the types of parameters that are measured. Regarding WWTPs under 2000 PE in the analysed countries, neither monthly nor quarterly data is collected. The number of measurements per year is determined based on the size of the WWTP, assuming that small plants can carry out fewer measurements. It should be emphasized that some countries do not monitor the smallest WWTPs. In Finland, there is no obligation to monitor sewage treatment plants below 100 PE. Therefore, the data provided from Finland do not include WWTPs below this value.

Data collection procedure

A universal form (spreadsheet) was prepared in cooperation with the Project Partners. The form was divided into three parts: basic information about the wastewater treatment plant, characteristics of the wastewater discharged to the wastewater treatment plant and characteristics of the treated wastewater. These sections contain the following data:

1. Basic information about the WWTP:
    a. location (place and geographical coordinates);
    b. managing institution (name of the institution, contact details, institution type);

c. characteristics of the wastewater treatment plant (PE, wastewater treatment technology, name of the receiver, treated water receiver).

2. Characteristics of the wastewater discharged to the WWTP - the average amount of wastewater discharged to the WWTP per day [m^3/day].

3. Characteristics of the treated wastewater:
   a. average amount of treated wastewater per day [m^3/per];
   b. BOD_5 [mgO2/l];
   c. COD [mgO2/l];
   d. total suspended solids [mg/l];
   e. total nitrogen [mg/l];
   f. total phosphorus [mg/l].

The data in the second and third parts was collected on an annual, quarterly, and monthly basis, depending on the data available to the partner countries (Figure 6). Partner Countries have been given the option to include additional data at the end of the table.

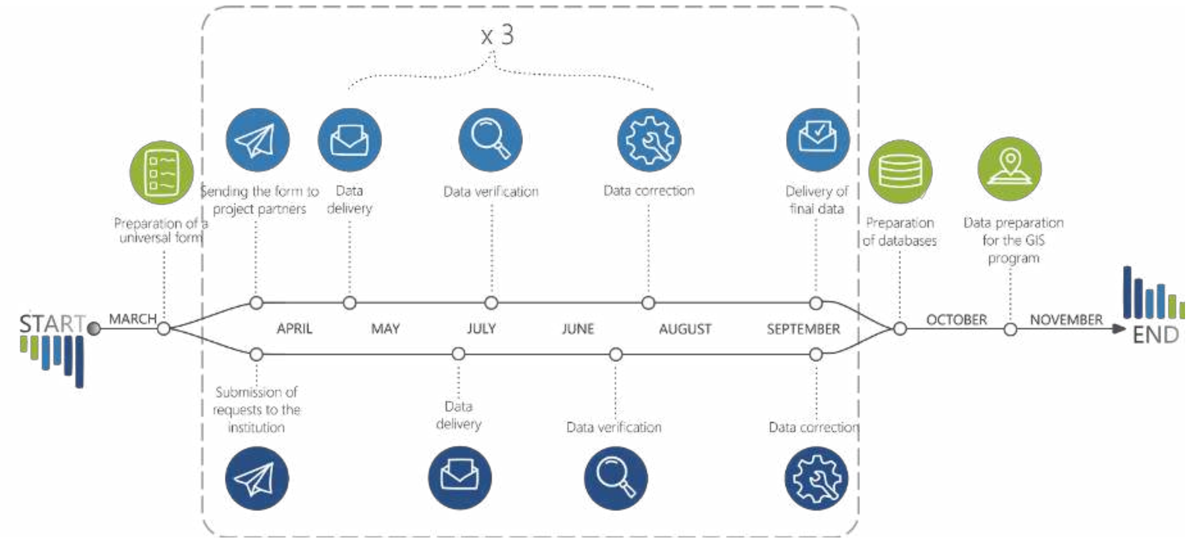

Figure 6. The process of preparation of the study. The area marked in the centre shows the data collection procedure.

After preparing and sending the form to the Project Partners, the process of individual data collection began. The Project Partners submitted requests for the data to national or municipal authorities responsible for collecting the data on WWTPs. In Poland, requests for the data were submitted to two types of regional authorities - WIOŚ (Voivodship Inspectorate for Environmental Protection) and RZGW (Regional Water Management Board part of Polish Waters). The areas which are under the administration of each of the two authorities do not square with each other. While WIOŚ is working within the administrative borders of voivodship, the RZGW administrates areas which borders are suited to the water catchment areas. So, there are 7 RZGWs and 6 WIOŚs within 100 km from the coastline of the Baltic Sea, to with requests were submitted.

Data collection in Poland took place between April 13, 2023 and November 15, 2023. Two institutions required the submission of supplements, one of which refused to provide the data after submitting the supplement. RGZW Wrocław informed about the lack of WWTPs meeting the Project criteria in the territory indicated in the request. The data collection process in Poland was completed after the last authority submitted the requested data.

While waiting for the data in Poland, Project Partners collected data in their countries. The first set of data was sent by Lithuania on April 11, 2023. The last one was sent by Sweden and Finland on June 13, 2023. In the meantime, questions from Project Partners were answered and minor corrections were made. The actual process of verifying the provided data started in mid-June after the data was provided by each of the foreign Project Partners. It has been observed that there are many discrepancies in the way data is collected in partner countries. In Poland, most data received came from water law permits specifying the upper limit of parameters - normative values, not measurement values. Bearing in mind the concern for the integrity of the final database, the partners were asked to make the necessary corrections and additions to the submitted data, including normative data. After sending the corrected data on August 24, 2023, verification was carried out again. After detecting errors in the data sets sent by partners, they were sent e-mails with a list of changes to be made. The last data verification was based on the geographical coordinates of the WWTPs. After entering the data into the GIS program, it turned out that there were large areas without WWTPs. The Project Partners were obliged to re-check the submitted data and make any necessary corrections.

Data processing procedure

After delivering the final data sets to the Project Partners, two databases were created: one for Poland and one for the Project Partners. The databases were processed for compatibility with the spatial data visualization program. This process consists of changes in notation to match the notation used in the GIS program and reorganisation of the table structure so that each column has a unique name (Figure 7).

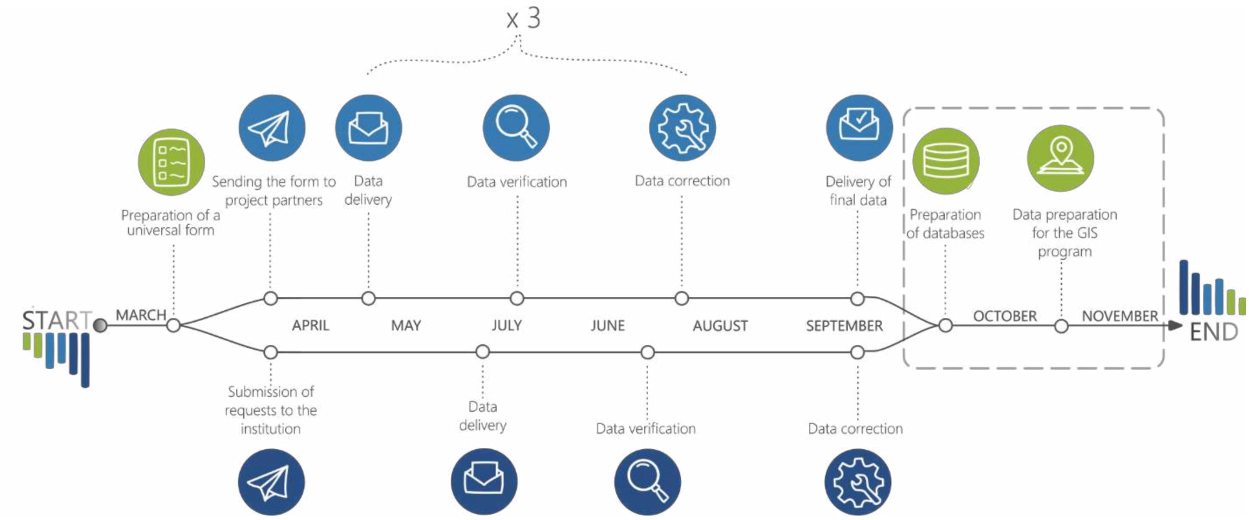

Figure 7. The process of preparation of the study. The area marked on the right shows the data preparation procedure.

Further steps of the data processing procedure were carried out in the GIS program and included, among many others:

- verifying the format in which the geographical coordinates were provided by the Project Partners;
- changing the field type for all columns containing numerical data to enable their visualization on a numerical scale;
- changing the notation of some values (for example, a value given as "<4" was rewritten as "3.9");
- data verification (e.g. checking whether the location of the point corresponds to the name of the town indicated in the form or with the plot number).

Due to errors in geographical coordinates, some of the WWTPs were not transferred from the Excel file to the GIS program. When incorrect notation occurred or when coordinates were missing, the program did not include the object in the GIS project. Therefore, in order to include this object, it must have been transferred manually. In such cases, the location of WWTP was determined based on publicly available data, such as satellite photos or maps of technical infrastructure.

Data characteristics

None of the authorities, to which the request had been submitted, provided monthly or quarterly measurement data and only a few of them provided annual measurement data. Despite the obligation to carry out at least two measurements yearly, access to these data is significantly limited. Most of the authorities did not provide a completed database for WWTPs under their authority. Typically, measurement data is collected in paper form in archives, and making it available requires scanning and forwarding thousands of copies. Authorities refuse to provide this type of data due to excessive workload and provide only water law permits or summary tables available on the Internet, both of which contain only normative data. As a result, data on WWTPs below 2000 PE collected in Poland is mostly normative and does not reflect seasonal changes.

During the data collection process, significant differences were noticed between the data provided by the authorities. The differences concerned not only the values of parameters or characteristics of the WWTPs, but also the number of declared WWTPs. Which considering the legal obligation to report these measurement data to both WIOŚ and RZGW, should be the same. Presumably, the differences resulted from the lack of updating and verification of the data, but it is not possible to clearly determine the reasons for the discrepancies. As a result, it is not possible to collate and compare the received data from the two authorities. To ensure the consistency of the final database, it was decided to show the data from two sources separately.

A significant difficulty in preparing the database for Poland was the lack of a coherent data collection system. Despite the obligation to collect the same data, individual authorities use different methods. For example, authorities in Poland collect location data in six different ways:

- geographical coordinates of the WWTP in the Polish coordinate system (ETRF2000-PL / CS92);
- longitude and latitude of the WWTP;
- plot number of the WWTP;
- geographical coordinates of the wastewater discharge location in the Polish coordinate system (ETRF2000-PL / CS92);
- longitude and latitude of the wastewater discharge location;
- number of the plot where the wastewater is discharged.

The process of verifying location data for several hundred WWTPs would require a significant amount of time, going beyond the Project schedule. For this reason, it has been decided to present the location data in the form in which it was provided by the authorities, without any significant changes. Moreover, only one dataset will be used for further analysis and visualisations – a dataset from RZGW. The database from WIOŚ has significant deficiencies and is not suitable for comparing data between countries.

In addition to inconsistencies between authorities described above, there are also inconsistencies in the individual data sets. There were cases in which the values of one parameter were given in different units for each WWTP (e.g. the average amount of treated wastewater was given in m^3/day, in m^3/year or in m^3 without a time unit). There were also inconsistencies in the form of notation. For instance, the data concerning the receiver of the treated wastewater is presented in an unclear manner, making it impossible to determine which of the listed receivers is the final one. Such cases required selection and additional verification based on publicly available data.

Last issue is the inaccuracy of providing PE data. For many small WWTPs the exact PE value is unknown. The only information available is the declaration of individual WWTPs managers on whether the facility exceeds 2000 PE. If a given WWTP does not exceed 2000 PE, the authorities only provided information "below 2000 PE" without the exact value.

All Project Partners provided annual measurement but only a few of them provided monthly and quarterly data. Due to the limited amount of monthly and quarterly data, seasonal changes in measured parameters will only be shown based on the data from Danmark, Latvia, Poland and Sweden. After verifying the data, the partners supplemented data sets with normative data.

Since legal systems in the analysed countries are not coherent, the following discrepancies occurred in the final database:

- Lack of data from Finland on wastewater treatment plants below 100 PE;
- Lack of data from some Swedish municipalities that did not provide data;
- BOD_7 in Finland, Estonia and Sweden, BOD_5 in rest of the countries,
- Some of the values do not represent average values, but the value from one measurement.

Some data providers did not provide annual data, so Project Partners were asked to calculate annual averages from monthly or quarterly data. This decision has been made in order to obtain a parameter that could be used to compare the results from all countries, since most of the partners provided annual data. Unfortunately, this process introduced the risk of computational errors. Some of the values differ significantly, which indicates an error when calculating the averages. In such cases, extreme values were omitted from the visualizations and left in the Excel database.

Status of collected data

The tables below present the status of data collection (Tables 1-4). The number in the table should be understood as number of objects for which the type of data specified in the column has been provided. These objects will be presented in the project database. The following assumptions have been made in the database:

- for the parameters: average amount of wastewater discharged to the WWTP per day [m^3/day] and average amount of treated wastewater per day [m^3/per], the value "0" was interpreted as lack of data. Such a value implies that there was an interruption in the operation of a WWTP and as a significantly different value is not taken into account in the database.

- if approximate values were provided (for example “<30” or “6,5 – 6,7” the upper value of the limit was taken).
- for the PE parameter, when the value has not been precisely determined (e.g. "<2000"), it is considered as lack of data, but the WWTP is qualified for the project. When the value "<2000" is not provided in the table and the field is left empty, this case is considered as a declaration of the Project Partner that the PE value for the WWTP is below or equal to 2000 PE, and the WWTP is qualified for the project.

As described in chapter "2.1. Project criteria", the PE values for 2019 and 2021 may differ, thus the number of sewage treatment plants in the analysed years may as well. In table 3. Analysed parameters on a quarterly basis and table 4. Analysed parameters monthly, the values for a given parameter are put in two columns. The left column (on a white background) shows the number of objects with complete dataset (for all quarters or months). The right column (on a blue background) shows partial data set (data only from some quarters or months).

Table 1. Basic information about the WWTP

country	WWTPs	place	coordinates	name	Type	PE	technology	name	type
2019									
Denmark	155	155	155	150	11	155	150	154	155
Estonia	216	216	216	216	216	193	216	216	216
Finland	108	108	108	108	108	92	107	9	9
Germany	102	102	102	102	0	102	30	0	0
Latvia	504	504	504	504	504	504	504	4	4
Lithuania	49	49	49	49	49	49	49	49	49
Poland	486	466	118*	461	254	299	382	249	484
Sweden	73	73	73	73	73	70	73	72	73
2021									
Denmark	155	155	155	150	11	155	150	154	155
Estonia	10	10	10	10	10	9	10	10	10
Finland	110	110	110	110	110	91	9	9	9
Germany	159	159	159	159	0	159	0	0	0
Latvia	4	4	4	4	4	4	4	4	4
Lithuania	50	50	50	50	50	50	50	50	50
Poland	491	471	113*	468	259	303	387	249	491
Sweden	73	73	73	73	73	70	73	72	73

* The value shows the number of WWTPs for which the facility coordinates were given, for 415 WWTPS in 2019 and for 413 WWTPs in 2021 the wastewater discharge locations were given

Table 2. Analysed parameters on an annual basis.

country	WWTPs	Qdwavg	Qdtavg	BOD_5/BOD_7	COD	TSS	TN	TP
				2019				
Denmark	155	137*	0	36*	123*	136*	147*	147*
Estonia	216	216	0	216	216	216	216	216
Finland	108	104*	12*	104*	100*	102*	102*	103*
Germany	102	46	0	46	46	0	46	46
Latvia	504	490*	490*	312*	0	313*	0	0
Lithuania	49	49	49	49	49	49	49	49
Poland	486	0	27	49	49	49	0	0
Sweden	73	50*	30*	63	52	41	58	57
				2021				
Denmark	155	149*	0	137*	112*	125*	155*	150*
Estonia	10	9	0	9	9	9	9	9
Finland	110	102*	11*	104*	103*	103*	104*	104*
Germany	159	108	0	107	107	0	103	17
Latvia	4	4*	4*	4*	4*	4*	4*	4*
Lithuania	50	49	50	50	50	48	50	50
Poland	491	0	27	46	46	45	0	0
Sweden	73	53*	29*	71	59	37	64	65

*values calculated based on monthly data, or the total quantity in the year

Table 3. Analysed parameters on a quarterly basis.

country	WWTPs	Qdwavg		Qdtavg		BOD_5/BOD_7		COD		TSS		TN		TP	
							2019								
Denmark	155	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Estonia	216	214	2	0	0	213	3	213	3	213	3	215	1	213	3
Finland	108	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Germany	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Latvia	504	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poland	486	0	0	14	0	38	1	38	1	38	1	0	0	0	0
Sweden	73	40	0	25	0	25	1	21	1	21	1	21	1	26	1
							2021								
Denmark	155	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Estonia	10	9	0	0	0	9	0	9	0	9	0	9	0	9	0

Finland	110	0	0	0	0	1	0	1	0	1	0	1	0	1	0
Germany	159	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Latvia	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poland	491	0	0	14	0	31	8	33	10	33	10	0	0	0	0
Sweden	73	42	0	24	0	26	4	21	5	25	2	25	2	31	2

Table 4. Analysed parameters on a monthly basis.

country	WWTPs	Qdwavg		Qdtavg		BOD_5/BOD_7		COD		TSS		TN		TP	
2019															
Denmark	155	25	112	0	0	0	28	16	107	18	118	26	121	26	121
Estonia	216	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Finland	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Germany	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Latvia	504	0	0	0	0	1	199	1	3	1	197	1	3	1	3
Lithuania	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poland	486	0	0	0	1	0	8	0	8	0	8	0	0	0	0
Sweden	73	40	0	24	1	13	37	5	33	6	34	5	36	9	40
2021															
Denmark	155	20	99	0	0	2	23	24	88	20	105	24	103	21	109
Estonia	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Finland	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Germany	159	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Latvia	4	0	0	0	0	1	3	1	3	1	3	1	3	1	3
Lithuania	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poland	491	0	0	0	0	0	3	0	3	0	3	0	0	0	0
Sweden	73	40	2	23	1	10	37	9	31	8	32	8	36	12	36

Status of collected data based on data type and year:

- 45,18 % - annual data for 2019;
- 39,00 % - annual data for 2021;
- 6,80 % - quarterly data for 2019;
- 2,76 % - quarterly data for 2021;
- 6,05 % - monthly data for 2019;
- 6,46 % - monthly data for 2021.

Status of collected data by country:

- 38,11 % - data from Denmark;
- 46,14 % - data from Estonia;
- 26,36 % - data from Finland;
- 15,56 % - data from Germany;
- 23,47 % - data from Latvia;
- 34,77 % - data from Lithuania;
- 14,51 % - data from Poland;
- 45,40 % - data from Sweden.

Report

WWTPs that meet the Project criteria

There are 1694 WWTPs in 2019 and 1052 WWTPs in 2021 that meet the Project criteria and are presented in the final database. However, some of them were not shown in map analyses due to the lack of data on the location of the objects. The maps below show locations of WWTPs in 2019 and 2021 (Figure 8 and Figure 9).

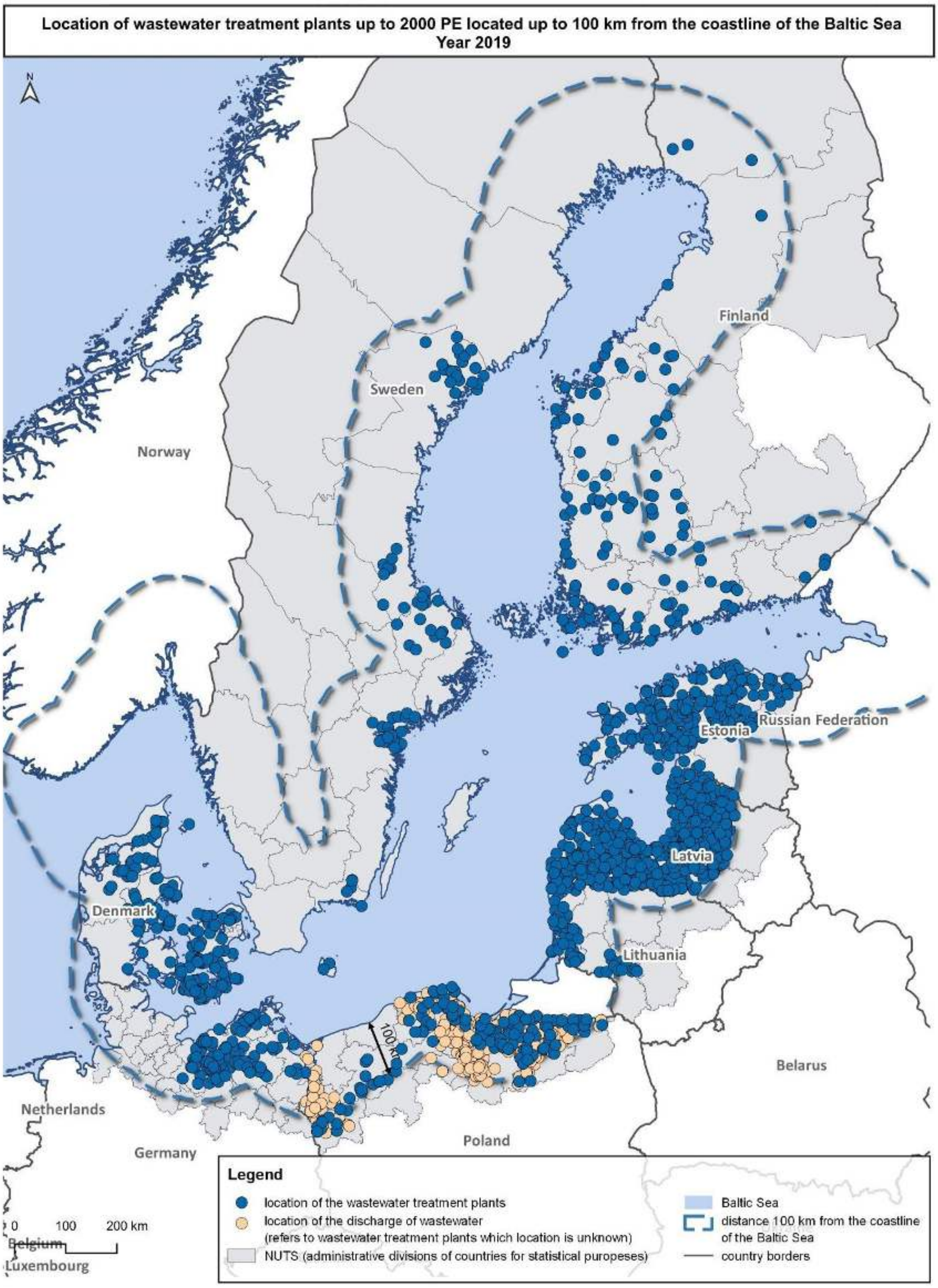

Figure 8. Locations of WWTPs in 2019.

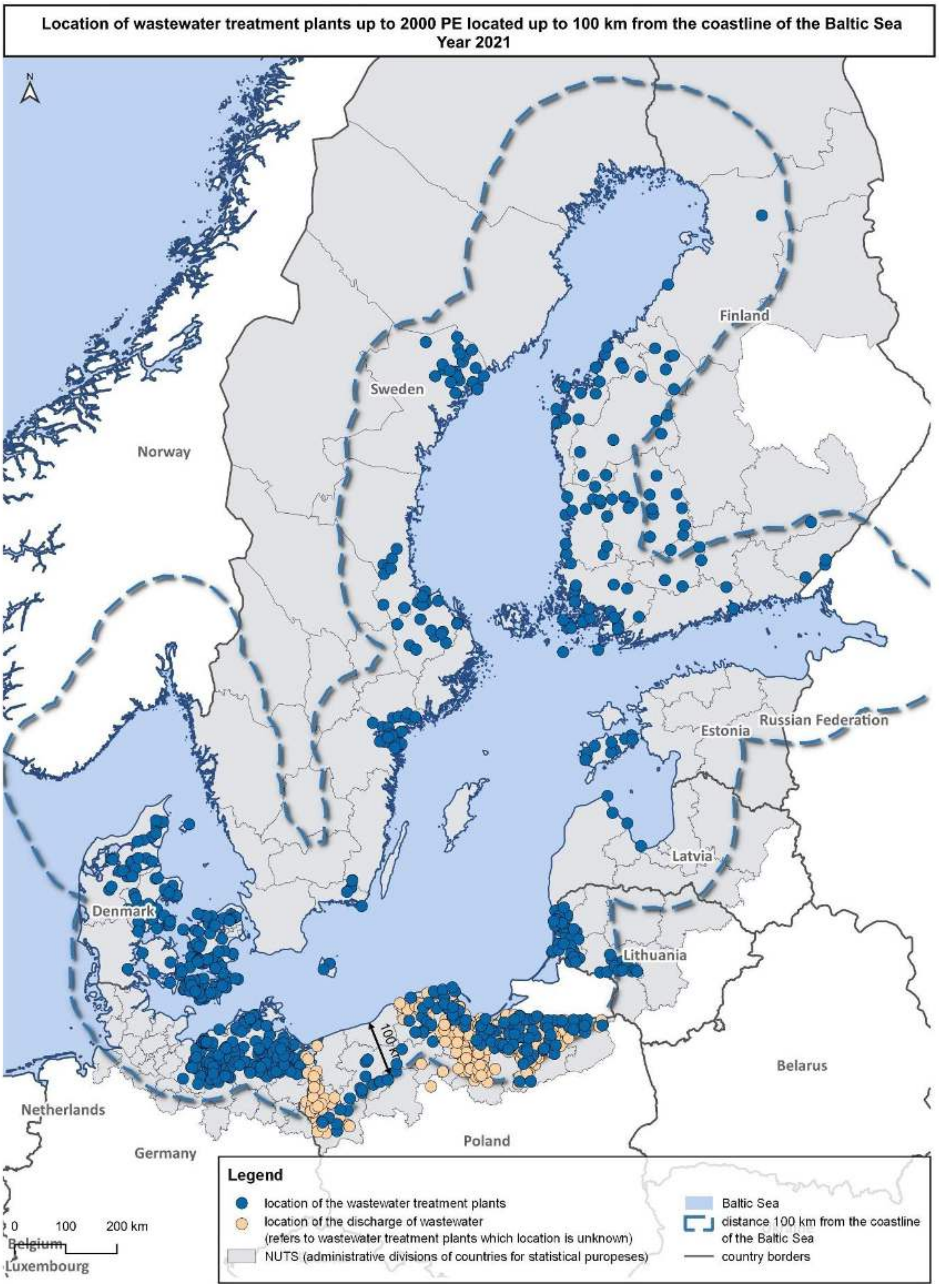

Figure 9. Locations of WWTPs in 2021.

Map analyses

A set of maps illustrating the analysed parameters was prepared for each of the Partner Countries. Information about the PE value for a given WWTP was compared with information on the type of receiver. Other parameters - average amount of treated wastewater per day, BOD_5, COD, total suspended solids, total nitrogen and total phosphorus – were compared with data on technology. Data for 2019 and 2021 for each Project Courtiers were presented on separate maps. Maps with the letter "m" at the end of the file name present measurement data, and maps with the letter "n" present normative data.

Particular maps presenting wastewater parameters (BOD, COD, Total N, Total P, suspended solids, flowrate, receiver, type of technology for both 2019 and 2021) for each out of 8 BSR countries can be found on project website. They were not included here intentionally due to too high resolution and large area in the text that they would occupy.

Conclusions and recommendations

The quantity and quality of data collected for the project clearly indicates the lack of resources of environmental protection authorities in examining the impact of small WWTPs on the natural environment of the Baltic Sea. Due to the lack of data, it is not possible to estimate the real impact of small WWTPs on the environment. It is even more challenging to study seasonal changes in the efficiency of WWTPs, because of lack of monthly or quarterly data.

The Council Directive of 21 May 1991 concerning urban wastewater treatment (91/271/EWG) regulates the rules regarding treatment of wastewater and monitoring of WWTPS above 2000 PE. The introduction of the Directive was a step in the right direction, but it requires stricter regulations. It should be noted that in October of 2022 European Commission made a proposal for a Directive concerning urban wastewater treatment (recast) which is lowering the limit of 2000 PE for wastewater agglomerations to 1000 PE. Thus, WWTPs between 2000 and 1000 PE, which have not yet been covered by the regulations of the Directive, would be subject to monitoring and control. The most beneficial solution from an environmental perspective would be to include all WWTPs. However, taking into account the costs of implementing those regulations, this approach that's spreads costs over time should be considered reasonable. The proposal has not yet been adopted.

The rules for carrying out measurements and collecting data should be uniform in all European Union countries. It would also be beneficial to maintain a common database, which would significantly facilitate conducting scientific research. This database should be intended for both specialists and citizens to enable easy access to public information.

2. Identification of technological boundaries for selected pilots

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The selection of a suitable wastewater system, or the upgrade of an existing system, depends by the type of the system, the size and location and the quantity and quality of the wastewater flow. The key to system selection, sizing and placement is identifying the desired level of performance and ensure that the effluent quality at the performance boundaries corresponds to the expected legislative treatment requirements. In this chapter, is presented the possible technological changes in the wastewater systems that is needed to improve the treatment result even during the busiest tourist season in the project's pilot sites in Denmark, Finland, Latvia and Poland.

Pilot descriptions

Latvia -pilot 1. Nanobubbles

Jūrkalne is located on the Baltic Sea coast and has the highest coastal steep shores in Latvia, visited by many tourists and visitors during the tourist season. This creates seasonal problems in wastewater treatment due to changing pollution levels and the inflow of wastewater into the Jūrkalne wastewater treatment plant. In these changing conditions, "VNK serviss" is currently looking for adaptive solutions for wastewater treatment, as the existing solution is currently no longer satisfactory. The pilot plans to use a nanobubble solution in the biological part of the wastewater treatment, potentially allowing the wastewater treatment plant to be scaled down current size and more efficiently delivering dissolved oxygen to the micro-organisms that treat the polluting nutrients. This is particularly important with changing pollutant loads in untreated wastewater during tourist seasons. For more information about the pilot can be found here.

Finland- pilot 2. Scaling and updating on site WWTS

Bärosund marina is in the Bärosund strait in Ingå, between the islands of Barölandet and Orslandet. The port area and its functions have been developed over the past few years and the area will be further developed. As a result, the capacity of the current wastewater system has become small during the high season. In the surroundings of the Bärosund harbour area, there is a shop, a cafe, a restaurant, a clubhouse, a boat pier, as well as accommodation, a padel court, and meeting activities.

Barösund water cooperative's wastewater is treated in its small treatment plant, which was completed in 2005 (Wehoputs 30). 11 properties have joined the Barösund water cooperative's water supply, four of which are in year-round use (about 20 residents). During the summer, 100-200 tourists visit the area every day. The highest number of visitors are on weekends. The amount of wastewater generated during the tourist season exceeds the capacity of the treatment plant, so the water has been led to a holding tank and transported from there for further treatment. The area's water use is about 1000 m^3 per year, but the monthly variation is large and most of the water use is in the summertime. For more information about the pilot can be found here.

Denmark- pilot 3. Improved aeration at already existing plant – improvement of capacity

The pilot-scale setup is situated at Næstved Renseanlæg, in Næstved southern Sjælland. The test comprises three IBC tanks, which collect raw wastewater from the main plant, while the treated wastewater is recycled back into the system. The primary concept involves utilizing a nanobubble generator for aerating a wastewater treatment biological tank, aiming to enhance oxygen transfer and increase the tank's capacity. Idea is to implement it at small WWTP where wastewater load exceeds the capacity of the tank continuously or at given period of the year. Depending on the test results, the plan is to establish nano bubble generator as an external unit at smaller plant e.g., Vallensved (700 PE) at Vallensved – NK forsyning which are responsible for several smaller plants. For more information about the pilot can be found here.

Denmark-pilot 4. Constructed wetland at Danmarks Naturfond

Skovsgaard is on countryside in an island of Langeland located in the south of Denmark. It is popular tourist destination due its beautiful nature and activities. A constructed wetland has been designed and installed at Skovgaard Gods and it's designed to accommodate up to 500 population equivalents (PE) during the summer and 1-2 PE during the winter. This fit well with the constructed wetland where grow is most active during the summer period. Using treated wastewater for irrigation will be tested in the pilot and utilizing phosphorus and nitrogen present in the treated wastewater as a resource of nutrients. In such cases, achieving high removal rates for phosphorus and nitrogen may not be critical. However, for plants where irrigation is not a possibility, alternative strategies for phosphorus removal are essential. For more information about the pilot can be found here.

Poland- pilot 5. Constructed wetland, nanobubbles and reuse of treated wastewater for irrigation

The pilot facility is in Poland, at the Bure Misie Settlement which includes six residential family houses (ultimately seven - the last to be built in 2024), a chapel, a farm, a small cheese factory and soon also a small bakery. The Settlement also includes an agritourism building, wooden camping cabins and a campsite - these facilities are used during the tourist season, which runs from the end of June to the end of August. The Bure Misie Settlement has an average of 160 people during the summer and an average of

58 people during the rest of the year. As a result, the amount of wastewater produced at the Bure Misie Settlement is characterized by high seasonal variability.

The mechanical-biological wastewater treatment plant (75 PE) that has existed in the area since 2006 needs to be expanded and modernised to ensure a high level of wastewater treatment, considering the high variability of the volume of wastewater. A design for a new wastewater treatment plant, which will include a constructed wetland, is currently under construction. After treatment, the wastewater is to be filtered and disinfected, and the resulting water can be used to irrigate green areas. These processes will reduce the total amount of water used at the Bure Misie Settlement. Additionally in the biological part of the WWTP, nanobubbles' technology will be tested. For more information about the pilot can be found here.

Latvia -pilot 6. Constructed wetland as a post-treatment solution.

The pilot project is planned to be implemented in Blāzma village in such a way as to minimise the potentially reduced efficiency of the existing wastewater treatment plant BIO-100 with capacity of 100 m^3/d and the emission of pollutants into the environment (as determined by the Polluting Activities Permit) caused by seasonal fluctuations in wastewater flows. The solution foresees the creation of an constructed wetland downstream of the existing wastewater treatment plant to serve as a post-treatment solution, with the prospect that this solution could become a future core process that is much less affected by seasonal fluctuations in wastewater flows than the traditional approach used to date.

Under high seasonal hydraulic loads, the wastewater flow rate results in high suspended solids discharges to the WWTP outlet. Therefore, the design of the constructed wetland may need to include a hybrid solution, where part of the flows should be directed horizontally and part vertically. This would allow an assessment of which approach would work more effectively. In any case, the appropriateness of such an approach will need to be initially justified during design. For more information about the pilot can be found here.

Legislation in pilot countries

Wastewater treatment systems (WWTS) must be designed according to legislation and standards. In some cases, also environmental permit is needed. Once the permit is issued, the process must be inspected and approved by a local authority. The European Union (EU)'s legislation on urban wastewater requires all agglomerations with a population equivalent (PE) above 2000 people to undergo a secondary (mechanical/physical and biological) wastewater treatment. Agglomerations below 2000 PE, though, fall outside the scope of the current EU's legislation. As such, their regulation is heterogeneous across the various EU member states. Table 5 summarizes the Danish, Finnish, Latvian and Polish legislative requirements and permits that are required to build a new under 2000 PE wastewater system or to update an existing one.

Table 5. Legislative requirements for wastewater treatment in pilot sites.

	Denmark		FINLAND			
Small-scale WWTP (<2000 pe)	>=2000 PE	<2000 PE	<100 PE		100-1999 PE	
Unit/Parameter	mg/l		g/pers/d	%	mg/l	%
BOD_7		not regulated*		not regulated*	30	70
COD	75	not regulated*		not regulated*	125	75
Organic matter	15	not regulated*	50	80 % min reduction (sensitive area 90%)	not regulated*	not regulated*
TP	1,5	not regulated*	2,2	70 % min reduction (sensitive area 85%)	3	80
TN	8	not regulated*	14	30 % min reduction (sensitive area 40%)	not regulated*	not regulated*
Suspended solids		not regulated*			35	90
pH		not regulated*	not regulated*			

	Poland	Latvia			
Small-scale WWTP (<2000 pe)	<2000 PE	<200 PE		200-2000 PE	
Unit/Parameter	mg/l	mg/l	%	mg/l	%
BOD_7	BOD_5 40 **		BOD_5 appropriate treatment		BOD_5 appropriate treatment 50-70%
COD	150 **		appropriate treatment		appropriate treatment 50-75%
Organic matter	not regulated*		not regulated*		not regulated*
TP	5 mgP/l (Values required only in wastewater discharged to lakes and their tributaries and directly into artificial water bodies located on flowing waters.)		appropriate treatment (<2000pe)		appropriate treatment (<2000pe)
TN	30 mgN/L (Values required only in wastewater discharged to lakes and their tributaries and directly into artificial water bodies located on flowing waters.)		appropriate treatment (<2000pe)		appropriate treatment (<2000pe)
Suspended solids	50 mg/l **		not regulated (35 mg/l, 90% reduction for WWTP <1000 pe)		not regulated (35 mg/l, 90% reduction for WWTP <1000 pe)
pH	6,5-9				

*not national regulated

** In Poland, it is necessary to obtain a water permit issued by State Water Management Authority [org. Wody Polskie]). For each wastewater treatment plant the permit is issued individually and it specifies what the maximum allowable levels are for that particular plant, but they are never higher than BOD5, 40 mg/l, etc.

Oxygen Nanobubbles

Using the nanobubble technology in wastewater treatment is tested in the project in three different pilot places in Denmark, Latvia and Poland.

In Denmark, Næstved Renseanlæg, the pilot plant focuses on the controlled production and characterization of oxygen nanobubbles in an experimental environment to optimize wastewater treatment processes. If the results are positive, the plan is to establish nano bubble generator as an external unit at smaller plant e.g., Vallensved (700 PE). For all experiments, was employed a nanobubble generator from Anzai (ANZAIKANTETSU CO LTD, Japan, AZ-UFB-Generator, AZ-015-0286).

In Latvia, the nanobubble device will be tested in the biological wastewater treatment plant, model BioM-30 (manufacturer "Kombi D Ltd."). The nanobubble generator will be supplied from TECHRAS Nano ApS.

In Poland the nanobubbles will be tested in the mechanical-biological wastewater treatment plant (Bioekol Mini 75 model, manufacturer Ecol-Unicon Sp. z o.o.). The nanobubbles generator is the OZ-NM 2 device from AOZ Quingdao Aozengnier Purification Equipment Co, China.

Nanobubbles are miniature gas bubbles in liquids with a diameter smaller than 200 nm. This ultrafine bubble size provides unique physical properties that can enhance wastewater treatment. They remain stable in water for a long time due to their negatively charged surface, whereas larger bubbles rise quickly and burst on the surface of the water. In the same volume of water, the contact area between bubbles in water filled with tiny bubbles is much larger than water filled with bigger bubbles. The increase in the contact area enhances i.e. the aerobic bacteria activities in the liquid by using oxygen gas or anaerobic activities by creating nitrogen bubbles, moreover the efficiency of chemical reactions is increased between the supplied gas and liquid ingredients. In addition, the collapse of bulk nanobubbles forms free radicals which promote oxidation process (Jia et. al. 2023[3], Selihin & Tay 2022[4]). Table 6 lists the advantages of nanobubble technology in wastewater treatment.

Table 6. Pros of using nanobubble technology in wastewater treatment.

Increased Oxygen Transfer	Nanobubbles have a high oxygen transfer efficiency, improving aerobic biological processes in wastewater treatment plants. This enhances the breakdown of organic matter and pollutants.
Enhanced Nutrient Uptake	Nanobubbles can help in the delivery of nutrients, such as nitrogen and phosphorus, to microorganisms, facilitating better nutrient uptake and wastewater treatment.
Reduced Chemical Usage	Improved oxygenation and nutrient delivery might reduce the need for additional chemicals in the treatment process, leading to cost savings and environmental benefits.

[3] Mingyi Jia et.al. (2023). Nanobubbles in water and wastewater treatment systems: Small bubbles making big difference, Water Research, Volume 245.

[4] Nurhafizah Mohd Selihin, Meng Guan Tay (2022). A review on future wastewater treatment technologies: micro-nanobubbles, hybrid electro-Fenton processes, photocatalytic fuel cells, and microbial fuel cells. Water Sci Technol 85 (1): 319–341.

Improved Settling and Filtration	Nanobubbles can assist in flocculation and particle agglomeration, aiding in the settling of solids and enhancing filtration processes.
Energy Efficiency -> reduced climate impact	Nanobubble technology can potentially be more energy-efficient due to its ability to transfer oxygen more effectively into the water, reducing the energy required for aeration. Nanobubble systems can have a smaller footprint compared to conventional aeration systems. If we lose only minimal amount of oxygen then we might also lose very little nitrous oxide (N_2O) and minimize a climate problem.
Versatility	Nanobubble technology can be applied in various stages of wastewater treatment, offering versatility in its applications. Technology is also suitable for installations where space is limited.

However, while nanobubble technology offers promising benefits, its widespread adoption might still be limited by factors like initial costs, maintenance requirements, and the need for further research to optimize its application in diverse wastewater treatment scenarios. Addressing all technological boundaries will be needed in harnessing the full potential of nanobubble technology for wastewater treatment, making it more efficient, cost-effective, and suitable for practical large-scale implementation (Wu et.al. 2021[5]).

The following system boundaries are the goal of testing in pilot sites, so that the benefits of nanobubble technology can be maximized in wastewater treatment (Table 7).

Table 7. System boundaries to test nano bubble technology in wastewater treatment.

	Latvia, pilot 1	Denmark, pilot 3	Poland, pilot 5
Treatment efficiency vs Legislation	Increase capacity of the existing WWTP and increase the nutrient removal ensuring appropriate treatment (<2000 PE)	Increase nutrient removal and reuse, increase capacity of already existing plant for biological treatment, no regulation <2000 PE. Nanobubbles will potentially result in better removal of micropollutants.	Increase the treatment efficiency in the biological section of WWTP.
Energy Consumption	Comparison to conventional bottom aeration system	Comparison to conventional system for aeration (surface aeration and bottom aeration)	Comparison to conventional system (bottom aeration)
Cost-Effectiveness	Equipment, maintenance, and operational costs compared to conventional treatment methods	Equipment, maintenance, and operational costs compared to conventional treatment methods	Thanks to the sensors in the bio-reactor, it will be possible to automatically control the switching. The nanobubbles generator will therefore not be more complicated or time-consuming to run than conventional treatment methods.

[5] Wu, J., Zhang, K., Cen, C. *et al.* (2021) Role of bulk nanobubbles in removing organic pollutants in wastewater treatment. AMB Expr 11, 96.

Scaling Up	Seasonal variation - 100 PE to 500 PE or even more (WWTP is designed for 175 PE)	Transitioning nanobubble technology from small-scale experiments to large-scale wastewater treatment plants (700 PE) presents engineering challenges and risk for destroying sludge floc structure	Seasonal fluctuations in the number of people from 58 to 160 and also wastewater from a small cheese factory and in the future a home bakery. Total fluctuations between 70 and 220 PE.
Other concerns/ requirements	Optimization of current WWTP process to be capable to catch and treat seasonal fluctuations of wastewater flow and pollution load in worst case scenario	-Does it work with 100% nanobubble or should it be combined with traditional aeration. -Do nanobubble reduce the settling capability of the sludge? -Do nanobubble give problems with denitrification process - toxic substances?	Optimization for current WWTP Choosing the most optimal ratio of traditional aeration and nano aeration.

Constructed wetland

The effectiveness of constructed wetlands in wastewater treatment and the possibilities of water reuse, e.g. irrigation is being tested in Denmark and Poland.

In Denmark a constructed wetland has been designed and installed at Skovgaard Gods, Denmark. It's designed to accommodate up to 500 population equivalents (PE) during the summer and 1-2 PE during the winter. The design incorporates 1.0 m^2 of constructed wetland per PE, and the design has been based on the anticipated peak-period PE. The plant is situated above an infiltration unit. Aeration is employed in the constructed wetland to enhance mineralization processes, and thereby reducing the necessary area per PE. The operating mechanism of a constructed wetland involves wastewater flowing into a plant filter bed, inhabited by specific plant species such as Phragmites australis or Typha latifolia. These plants promote a process called Phytoremediation (from Greek Phyto: plant and Latin Remedium: restoring; so, cleaning with plants), which removes pollutants and nutrients from water bodies, and it is aided by microorganisms that live on plant's roots and in the substrate. The output of this process is cleaner water, ready to be reused or safely discharged into the environment.

The biological wastewater treatment plant (75 PE) in Poland needs to be expanded and modernised to ensure a high level of wastewater treatment, taking into account the high variability of the volume of wastewater. A design for a new wastewater treatment plant includes vertical and horizontal constructed wetlands. After treatment, the wastewater is to be filtered and disinfected, and the resulting water can be used to irrigate green areas.

Constructed wetlands offer a natural and cost-effective method for treating wastewater (Vymazal, J. 2010[6], Ketema et.al.[7]). Table 8 lists the advantages of constructed wetlands in wastewater treatment.

Table 8. Pros of using constructed wetlands in wastewater treatment.

Natural Treatment	Constructed wetlands use natural processes involving vegetation, soil, and microbial activity to treat wastewater, mimicking natural wetland ecosystems. This reduces the reliance on energy-intensive processes and chemicals, making them environmentally friendly.
Cost-Effectiveness	Compared to traditional treatment methods, constructed wetlands can be more cost-effective to build and maintain over the long term. They require less infrastructure and lower operational costs.
Biodiversity and Habitat	Constructed wetlands provide habitats for various plant and animal species, promoting biodiversity and ecological balance.
Aesthetic and Recreational Value	Constructed wetlands can enhance the aesthetic appeal of an area, offering recreational opportunities such as bird watching, hiking, or educational programs.
Nutrient Removal	They effectively remove nutrients like nitrogen and phosphorus through plant uptake and microbial processes, aiding in pollution control. in many cases, properly designed and maintained constructed wetlands can meet regulatory standards for water quality, providing a compliant solution for wastewater treatment. After treatment, the purified water can be reused for irrigation or other non-potable purposes.

While constructed wetlands offer these advantages, their effectiveness may vary based on factors like design, climate and extreme weather events, type of contaminants, and maintenance. They might not be suitable for all types of wastewaters or in areas with limited space or specific regulatory requirements. Regular maintenance, including monitoring plant growth, sediment accumulation, and potential clogging of the system, is necessary for optimal performance. This can add to operational costs (Hassan, I. et.al. 2021[8]).

The following system boundaries must be examined so that the benefits of constructed wetlands can be maximized in wastewater treatment (Table 9).

[6] Vymazal, J. (2010). Constructed Wetlands for Wastewater Treatment. Water, 2, 530-549.

[7] Ketema, S. et.al (2021). Systematic review on constructed wetland for removal of nutrient from wastewater. Asian Journal of Advances in Research, 4(1), 475–481.

[8] Hassan I, Chowdhury SR, Prihartato PK, Razzak SA. (2021). Wastewater Treatment Using Constructed Wetland: Current Trends and Future Potential. Processes; 9(11):1917.

Table 9. System boundaries to the constructed wetlands.

	Denmark, pilot 4	Poland, pilot 5	Latvia, pilot 6
Climate Sensitivity	Climates or temperature fluctuations can affect the efficiency of constructed wetlands. Colder climates might decrease microbial activity, impacting treatment effectiveness, while hotter climates can increase evapotranspiration rates, affecting water retention.	Cold temperatures might decrease microbial activity, impacting treatment effectiveness. The Kashubian Lake District, where Pilot 5 is located, is one of the coldest regions in Poland. The coldest month is January, with the average temperature below zero. Hotter summer temperatures can increase evapotranspiration rates, affecting water retention	Extreme climates or temperature fluctuations can affect the efficiency of constructed wetlands. Colder climates might decrease microbial activity, impacting treatment effectiveness, while hotter climates can increase evapotranspiration rates, affecting water retention.
Space Requirements	Constructed wetland area can be repurposed for recreational or educational uses. After treatment, the purified water can be reused for irrigation. Aerated wetland will be tested as a method to reduce the required area for the sludge beds.	Constructed wetlands typically need more space compared to some other treatment technologies Pilot 5 has enough area for constructed wetlands.	Limited land availability in urban areas or densely populated regions can hinder their widespread implementation. They need more space comparing to conventional wastewater treatment systems.
Design Variability	Vegetation type, wetland depth, size, hydraulic loading rates, aeration intensity and frequency testing treatment effectiveness	Design optimization is crucial for effectiveness. In pilot 5 there will be vertical and horizontal constructed wetlands. Wastewater, after treatment, will be disinfected and reused for irrigation.	Design optimization is crucial for effectiveness of treated wastewater quality; therefore, combination of different flow approaches of constructed wetlands (horizontal and vertical) have to be considered.
Treatment Time	Constructed wetlands often require longer retention times for effective treatment compared to some conventional treatment methods. Aeration of the wetland and recycling of the water is tested as method to reduce the required retention time	The project provides appropriate solutions for high volume wastewater treatment in tourist season.	This slower treatment process might not be suitable for situations requiring rapid or high-volume treatment, therefore, combination of different flow approaches of constructed wetlands (horizontal and vertical) have to be considered.
Maintenance Needs	Managing vegetation, removing sediment, and ongoing monitoring, as neglecting maintenance can reduce treatment efficiency over time.	Regular monitoring and removing sediment is necessary for constructed wetlands to ensure consistent performance.	Regular maintenance is necessary for constructed wetlands to ensure consistent performance. It's related to vegetation management and frequent monitoring.
Nutrient Removal Efficiency – Water reuse	Might have limitations in removing certain nutrients like phosphorus under specific conditions, affecting overall water quality goals, method to adsorb phosphorus can be implemented	Might have limitations in removing certain nutrients like phosphorus under specific conditions, affecting overall water quality goals. Wastewater, after	Might have limitations in removing certain nutrients like phosphorus under specific conditions, affecting overall water quality goals as stated in pollution

	– It will be tested whether water can be reuse for irrigation	treatment, will be disinfected and reused for irrigation.	permit. But this pilot is not meant for usage of reclaimed water.
Regulatory Compliance, Legislation	Increase nutrient removal and reuse, appropriate treatment (<2000pe)	Increase nutrient removal and reuse. (in accordance with the water permit issued by State Water Management Authority [Wody Polskie])	Increase nutrient removal, SS <50 mg/l, TP < 5 mg/l, TN <30 mg/l

Small-Scale wastewater treatment plant

In situations where improving wastewater treatment is not enough, the entire wastewater system must be renewed. During the high season, the amount of wastewater handled by the Barösund marina's water supply exceeds the capacity of the local small-scale treatment plant. Eleven properties have joined the Barösund water cooperative's water supply, four of which are in year-round use (about 20 residents). During the summer, 100-200 tourists visit the area every day. Based on the results of the July 2023 wastewater sampling, greywaters do not cause wastewater dilution, but the wastewater was quite concentrated. Based on the sample of the WWTP outlet, the amount of organic matter removed by the treatment plant was almost equal to the required level, but only half of the phosphorus was removed. The amount of suspended solids were high and nitrogen removal was minimal. Based on the results, the size of the new wastewater system must be dimensioned over 100 PE and the Barösund treatment plant therefore needs an environmental permit.

Various small-scale on-site wastewater treatment systems are available on market (Vorne *et al.* 2019[9]). Package plants are a good choice if space, rapid deployment, and initial costs are crucial. However, their efficiency and suitability depend on the specific wastewater characteristics, required treatment levels, and adherence to operational and maintenance requirements. Ensuring proper installation in suitable locations and addressing site-specific conditions (such as soil type, groundwater levels, or available space) can be critical for their effective operation (Heinonen-Tanski and Matikka 2017[10], Vidal *et al.* 2019[11]). Package wastewater treatment plants have clear advantages, which are listed in Table 10.

[9] Vorne, V., Silvenius, F., Česonienė, L., Eymontt, A., Hamunen, K., Pachel, K., Räsänen, K., Sinkko, T., Urtāne, L., Vieraankivi, M.-L. and Virtanen, Y. (2019). A survey of available wastewater treatment technologies for sparsely populated areas, User's manual – Version 2.1, Natural Resources Institute Finland (Luke).

[10] Heinonen-Tanski, H., Matikka, V. (2017). Chemical and microbiological quality of effluents from different on-site wastewater treatment systems across Finland and Sweden. Water 9, 47.

[11] Vidal, B., Hedström, A., Barraud, S., Kärrman, E., Herrmann, I. (2019). Assessing the sustainability of on-site sanitation systems using multi-criteria analysis. Environ. Sci. Water Res. Technol. 5, 1599.

Table 10. Pros of package plants in wastewater treatment.

Treatment efficiency	When properly designed and maintained, package plants can meet regulatory standards for wastewater treatment, providing efficient and effective treatment of various pollutants. Package plants can help prevent pollution by treating wastewater locally, reducing the risk of untreated or poorly treated effluents being discharged into the environment.
Compact and Modular Design	Package plants are pre-designed and compact. Package plants are available in various sizes and configurations, making them adaptable to different wastewater treatment needs. They're easy to install and can be expanded or relocated if necessary.
Quick Deployment	These plants can be quickly deployed and operational, minimizing downtime for wastewater treatment compared to larger, conventional plants that may take longer to construct.
Customization and Scalability	They offer a degree of customization and scalability to meet specific treatment needs, allowing for modifications to accommodate changes in wastewater volume or quality.
Lower Capital Costs	Package plants often have lower initial capital costs compared to larger centralized treatment plants, especially for smaller-scale applications.
Operation	Many package plants are designed for ease of operation and maintenance. They often come equipped with automated systems and remote monitoring capabilities, reducing the need for constant on-site attention.
Reduced Footprint	They require less space compared to conventional treatment plants, making them suitable for areas with limited available land.

The following system boundaries must be examined so that the benefits of package plants can be maximized in wastewater treatment (Table 11).

Table 11. System boundaries to the package plants.

	Finland, pilot 2
Technology selection	Change SBR to continuously flowing small scale package plant to improve treatment during seasonal load.
Treatment efficiency vs Legislation	Remove 90% of the suspended solids, 80% of the phosphorus, 70% of the BOD and 75% of the COD in untreated wastewater.
Energy Consumption	Usually low
Cost-Effectiveness	Equipment, maintenance, and operational costs can be high
Climate Sensitivity	Colder climates (like wintertime in Finland) might decrease microbial activity, impacting treatment effectiveness
Space Requirements	Also requires underground space
Maintenance Needs	Requires maintenance and chemicals, sludge removal
Nutrient Removal Efficiency - Water reuse	Good cleaning results when used correctly. High load of detergents, disinfectants etc. may reduce treatment efficiency. Advanced treatment methods may be used to further remove pollutants and improve the quality of the treated water. Purified water can be used for irrigation

Conclusions of used technologies

When choosing a wastewater system or planning a system renovation, different technologies have their strengths and limitations, so they are suitable for different scenarios based on factors such as scale, available space, budget, and the specific quality of the wastewater being treated.

Nanobubble technology effectively removes contaminants due to the high oxygenation and increased surface area of nanobubbles. It can be implemented in small spaces. Nanobubble technology may have the potential to be more energy-efficient compared to traditional aeration methods.

Constructed wetland utilizes natural processes, such as plant and microbial actions, for effective water treatment. It can be considered to be eco-friendly choice, providing habitat and sustenance for diverse flora and fauna, supporting biodiversity. Constructed wetland systems can be cost-effective compared to conventional treatment methods because it generally requires less energy compared to mechanical treatment methods.

Package plants can easily be installed to clean wastewater efficiently in scattered dwelling areas. They are cost-effective and, if used and maintained correctly, the treatment efficiency meets the requirements of the legislation.

In all wastewater treatment technologies, the most important thing is correct use and regular maintenance. Combining technologies can offer the best solution, and different methods of improving wastewater treatment should be utilized even more.

3. Survey of water use and possible water saving solutions in selected pilots

Authors: Anu Reinikainen, Virpi Vorne, Marta Płuciennik, Morten Lykkegaard Christensen, Jānis Zviedriss

As a preparatory work in this project a survey of the project pilots water use/wastewater discharge was conducted. In addition, water saving solutions were explored. The seasonality effect, that needs to be tackled in the pilot sites, was demonstrated.

National level of daily water use and wastewater parameters

In the national level, in Estonia, Finland, Latvia, Lithuania, Poland and Sweden (the projects partner countries), the average daily water use per person is between 120-150 l/daily/per person. Regarding wastewater parameters (polluting substances) BOD values are between 0,05-0,06 kg, COD 0,110 kg/daily/person, SS 0,07 kg/daily/person and P 0,002 kg/daily per person in each pilot countries, N g/daily per person is between 0,010-0,014 kg (Table 12).

Table 12. National level variations of water use per person (l/d), wastewater parameters per person (kg/d)(2019, Village waters, 2019[12], updated 2023 by project partners)

Country name	Water use l/d/ per person	BOD kg/d/per person	COD kg/d/per person	SS kg/d per person	P kg/d/person	N kg/d/ per person
Estonia	150	0,05	0,11	0,07	0,002	0,014
Finland	150	0,05	0,11	0,07	0,002	0,014
Latvia	150	0,06	0,11	0,07	0,002	0,010
Lithuania	120	0,05	0,11	0,07	0,002	0,014
Poland	120-150	0,06	0,12	0,06	0,002	0,012
Sweden	150	0,05	0,11	0,07	0,002	0,014

[12] https://villagewaters.eu/Project_reports_994

This report is written in the project NURSECOAST-II which is funded by the Interreg Baltic Sea Region 2021-2027 programme and co-funded by the European Union.

Water consumption and wastewater amounts

Latvia -pilot 1

Jūrkalne biological wastewater treatment plant (WWTP) is built 2015, with hydraulic capacity of 30 m^3/d. According to data from 2022 person equivalent (PE) of Jūrkalne WWTP is 287. Jūrkalne WWTP provides centralized wastewater treatment for about 150 permanent residents daily. In Jūrkalne village there are properties with decentralised sewerage systems, the contents of which are periodically also received at Jūrkalne WWTP. Figure 10 presents the sold water and incoming wastewater amounts in Jūrkalne 2021-2023.

Figure 10. Wastewater received to pilot WWTP Jūrkalne (m^3) 2021-23.

However, the figures are not entirely comparable due to different calculation method that was being used in the beginning 2022. In addition, regarding year 2023 the reason that there are cases when there is more water sold than wastewater received is that in those months' inconsistencies were found in the meter readings given to customers and an additional calculation was made for the water received in previous periods and also there are clients to whom VNK serviss is delivering water, but who do not have central sewerage.

Finland- pilot 2

Barösund water cooperative takes water from its well. Water consumption is about 1000 m^3 per year. The largest user in the area is the marina and water use is focused on summer time (June-August). Barösund's water consumption data is described in Figure 11 and Figure 12. Part of the water consumption goes to filling the water tanks of the boats, as well as the water tanks of summer cottages, and thus does not burden the wastewater treatment plant. Water consumption in the summertime exceeds the capacity of the wastewater treatment plant on several days, even though some of the water is not returned to the wastewater treatment plant. As the average daily consumption varies so significantly from month to month, the daily consumption shown on an annual basis should not be used in sizing. The water consumption has increased from year 2019. The highest water use is on weekends when water is consumed well beyond the capacity of the current wastewater treatment plant. Part of the water is also used to fill boats and cottagers' water tanks. In 2019, the biggest water consumers were the restaurant, shop, and cafe buildings.

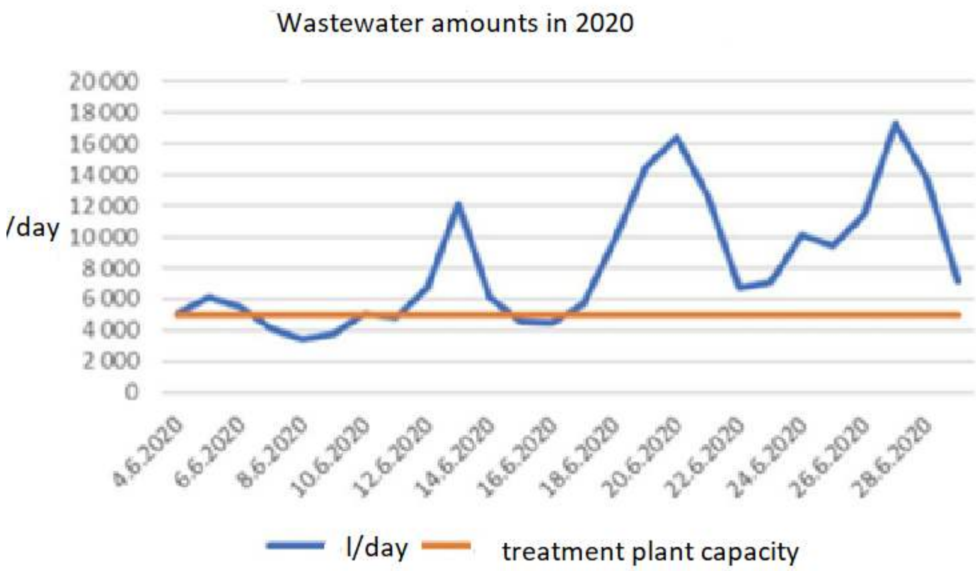

Figure 11. Water use in July 2020 and the capacity of the current treatment plant.

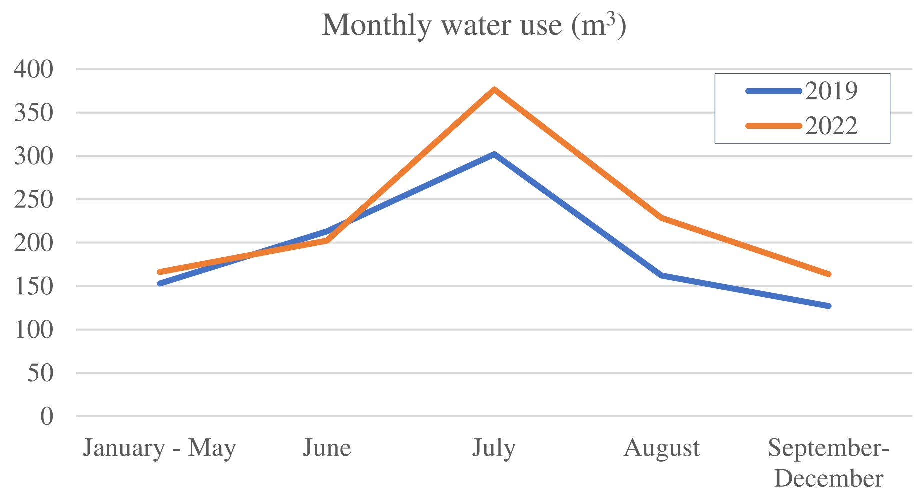

Figure 12. Monthly water use (m^3) in Barösund in 2019 & 2022.

The seasonal water use of the Barösund marina and the correspondingly variable amount of wastewater present challenges for wastewater treatment. In terms of the area's development, quality, and securing its domestic water supply, wastewater treatment must be controlled and avoid wastewater enter the terrain directly. A special feature of the wastewater generated from the operation is a significant proportion of grey water, which in part brings challenges, but can be managed with technical solutions. In addition, the purpose of sufficient wastewater treatment capacity is to ensure that wastewater does not end up directly to the Baltic Sea increasing the eutrophic load, which is a problem in coastal areas in Finland.

Denmark- pilot 3

Pilot 3 Improved aeration at already existing plant – improvement of capacity

The wastewater discharged (m^3/day) in Vallensdev WWTP (700 PE) is presented in Table 13. The high amounts during winter months are due to the rainwater/snowmelt etc. as it is not separation the system for wastewater and rainwater.

Table 13. Wastewater discharge (m^3/day) Vallensved WWTP.

	January	February	March	April	May	June	July	August	September	October	November	December
2019		162		102		134	55			135		135
2022		517		120		72	54			73		112

Denmark- pilot 4

Constructed wetland at Danmarks Naturfond, Skovsgaard Estate, produces almost zero wastewater during winter month. e.g., during winter period as there are only 1-3 employees at the location during daytime (not weekend). During summer period up to 500 visitors during daytime. There is also a possibility to stay overnight usually around 20 persons (three guest houses for 4 persons, 12 persons and 12 persons, respectively) and shelters. In addition, there is a café serving lunch, snacks etc. Wastewater comes from toilets, café and guest house.

Skovsgaard Gods site's café has an annual water consumption of approximately 344 m^3/year. This is expected to increase to around 500 m^3/year within a few years. Guest toilets have a consumption of about 100 m^3/year, and the residential section consumes about 100 m^3/year. This totals approximately 700 m^3/year, practically equivalent to around 20 PE. However, the primary consumption will occur during the summer months. Therefore, assuming a consumption of about 500 m^3 over approximately 3 – 4 months, this would correspond to about 2000 m^3/year (dimension-wise), which is approximately 55 PE. Based on the above, it is recommended to establish a facility for 60 PE. This way, the facility is dimensioned with a good buffer well into the calculations, in case the future consumption exceeds the current estimates. Moreover, there is no local treatment for the wastewater, it is being transported with wastewater trucks to nearest WWTP, which is expensive and not very climate friendly. The planned new technology, intensified constructed wetland, is designed to 60 PE. Further the water and nutrients are planned to reuse in irrigation. In general, the water use for toilet, bath etc. is expected to be relatively low at the place.

Poland - pilot 5

The Bure Misie Settlement includes six residential family houses (ultimately seven - the last to be built in 2024), a chapel, a farm, a small cheese factory and soon also a small bakery. The Settlement also includes an agritourism building, wooden camping cabins and a campsite - these facilities are used during the tourist season, which runs from the end of June to the end of August. The average water consumption in The Bure Misie Settlement is 11 255 l/day - this water consumption data apply to the entire farm, i.e., the residential houses (58 people), the cheese factory and the water used for watering the animals (cattle). There is a separate water meter for the two residential buildings, where the average amount of water consumed per person per day is 104 litres. The Bure Misie Settlement has an average of 160 people during the summer and an average of 58 people during the rest of the year. As a result, the amount of wastewater produced at the Bure Misie Settlement is characterized by high seasonal variability (Figure 13).

The mechanical-biological wastewater treatment plant (75 PE) that has existed in the area since 2006 needs to be expanded and modernised to ensure a high level of wastewater treatment, considering the high variability of the volume of wastewater. A design for a new wastewater treatment plant, which will include a wetland, is currently under construction. After treatment, the wastewater is to be filtered and disinfected, and the resulting water can be used to irrigate green areas. These processes will reduce the total amount of water used at the Bure Misie Settlement.

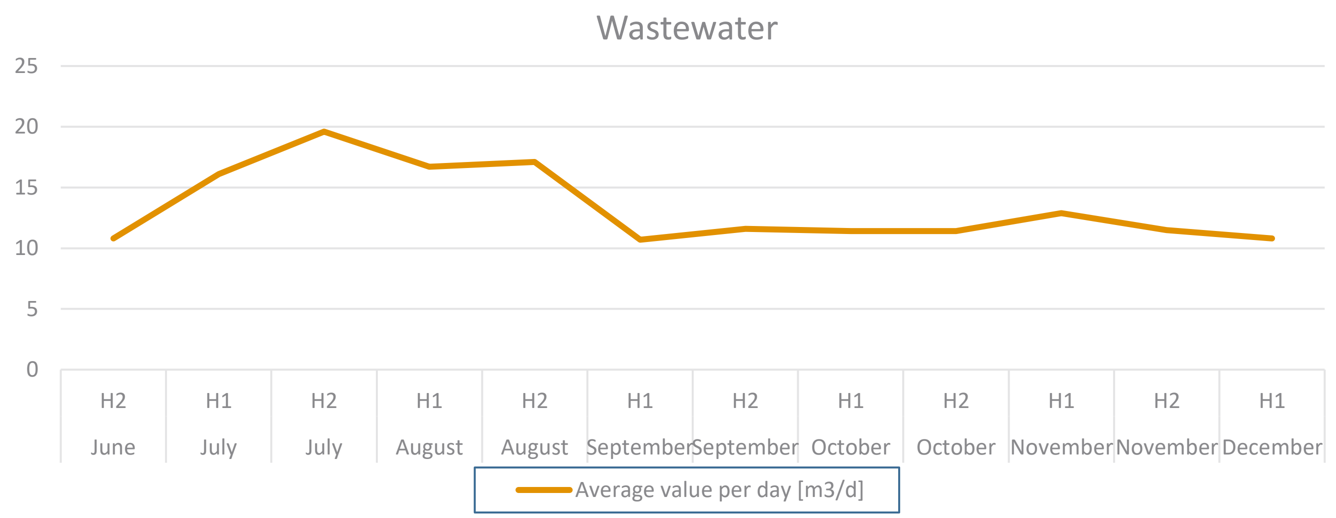

Figure 13. Wastewater quantity for half-month periods (H1, H2) in Bure Misie Settlement in 2023.

Latvia – pilot 6

The pilot project is planned to be implemented in Blāzma village in such a way as to minimise the potentially reduced efficiency of the existing wastewater treatment plant BIO-100 with capacity of 100 m^3/d and the emission of pollutants into the environment (as determined by the Polluting Activities Permit) caused by seasonal fluctuations in wastewater flows. The solution foresees the creation of a constructed wetland downstream of the existing wastewater treatment plant to serve as a post-treatment solution, with the prospect that this solution could become a future core process that is much less affected by seasonal fluctuations in wastewater flows than the traditional approach used to date.

Under high seasonal hydraulic loads, the wastewater flow rate results in high suspended solids discharges to the WWTP outlet. Therefore, the design of the constructed wetland may need to include a hybrid solution, where part of the flows should be directed horizontally and part vertically. This would allow an assessment of which approach would work more effectively. In any case, the appropriateness of such an approach will need to be initially justified during design.

Water saving solutions- households, tourism companies

The water saving solutions aim to more efficient water uses and for instance municipality of Ingå (Inkoon kunta 2023[13]) gives some instructions for households regarding wastewater treatment and efficient water use outside sewer network. The wastewater treatment method is not specified in the regulation, but it is determined according to the amount of wastewater, the load, and the surrounding conditions during the planning phase. When choosing the system, the characteristics of the area must be considered (soil, groundwater areas, coastal areas, general plan regulations). A professional designer must be used in the design of the wastewater system. Closed tanks cannot be considered a sustainable wastewater treatment solution. Low-water WC systems or compost toilets should be preferred in sparsely populated areas. Separation of grey water (washing water) and toilet water is recommended. A dry toilet is a highly recommended solution. Nowadays, several options are also suitable for indoor spaces. A properly implemented dry toilet is easy to use, odourless, and does not pose a risk of environmental pollution if the generated waste is handled appropriately. Gray wastewater (washing water) can be treated in a two-part septic tank and a shallow ground filter or packet filter. In low-water WC systems, the toilet water can be led to a closed tank, for example.

Households have the potential to reduce water consumption (Mayer *et al.* 1999[14], Vickers 2001[15], Willis *et al.* 2010[16], EEA 2017[17]). General guidance can be applied when it comes to saving drinking water, for instance dripping and/or broken taps can lead to long-term losses, measured in cubic metres of resource wasted so keeping an eye on the water fixtures and fixing potential leaks is important. In addition, water saving devices and more efficient household appliances can be applied. Turning off the tap while brushing teeth, shampooing hair are common sense advice to prevent water to go down the drain unused. Capturing rainwater and reusing it directly for irrigation is one of the most popular and recommended ways to use water resources efficiently. Having a bath, shower, sinks, washing machine, dishwasher in households creates so-called grey water (water that does not come into contact with faeces). These waters can certainly be collected and, with a little preparation, reused at least for flushing the toilet bowl.

Tourism sector may regionally be an important water use sector even though the tourism sector does not represent a key water use sector in Europe overall. Technical water saving measures are in line with the households. (Dworak *et al.* 2007[18]). Regarding companies in the tourism sector, the entrepreneurs can

[13] Inkoon kunta (2023). Jätevesi. https://www.inkoo.fi/asuminen-ja-ymparisto/ymparisto-ja-luonto/lupa-ja-ilmoitusasiat/jatevesi/

[14] Mayer, P. W., DeOreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B., & Nelson, J. O. (1999). Residential end uses of water.

[15] Vickers, A. L. (1999). Handbook of water use and conservation.

[16] Willis, R. M., Stewart, R. A., Panuwatwanich, K., Jones, S., & Kyriakides, A. (2010). Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. *Resources, Conservation and Recycling*, *54*(12), 1117-1127.

[17] EEA (2017). Water management in Europe: price and non-price approaches to water conservation https://www.eea.europa.eu/publications/water-management-in-europe-price

[18] Dworak, Thomas; Maria Berglund; Cornelius Laaser (2007). EU Water saving potential (Part 1 –Report). ENV.D.2/ETU/2007/0001r. Berlin.

take several steps regarding sustainable water use (e.g Sustainable Hospitality Alliance 2018[19], Visit Finland 2023[20]): measure current and future water use, identify its sources, ensure adequate wastewater treatment, reduce pressure on freshwater resources by reducing water use and recycling water. It is important to involve staff to water stewardship measures and engage customers, educate, and inform the customers about the importance of saving water and encourage them to embrace eco-friendly behaviours such as shorter showers, using towels and bed linen more than once, etc. Moreover, what is needed is to analyse products and services of highest spend and engage with suppliers on their water stewardship to better identify and address also indirect impacts on water in basins where they are operating. For example, many of the food ingredients have significant environmental impacts (impacts of the water use) outside Finland as many of them are imported from the water scarcity areas. Moving towards holistic water stewardship requires taking into consideration of the whole value chain.

Conclusions

Water consumption (l/d) in the national level is like all project countries. The pilot cases vary (e.g., small & larger settlements, restaurant, guest harbour) and the water consumed, and wastewater generated. In addition, not all the information about the water consumption in the pilots were available. However, the seasonality effect was described indicating increased water consumption during the summer months.

Leakage reduction of the water supply system, water saving devices and efficient household appliances are efficient water saving measures for both households and tourism entrepreneurs. It is more about raising awareness and changing habits that is needed to appreciate water as expensive and valuable resource. Moreover, companies need to address the whole value chain of their operations to achieve sustainable water use.

[19] Sustainable Hospitality Alliance (2018). Six simple steps for hotels to embed water stewardship. https://sustainablehospitalityalliance.org/six-simple-steps-for-hotels-to-embed-water-stewardship/

[20] Visit Finland (2023). https://www.businessfinland.fi/48e735/globalassets/finnish-customers/02-build-your-network/visit-finland/julkaisut/vf_tool-for-sustainability-and-communication-a5_eng.pdf

4. Nutrient reducing and recycling, from wastewater to resource

Author: Morten Lykkegaard Christensen, Pasi Korkalo, Tiia Pedusaar and Jolanta Dvarionienė

In this chapter, we present an overview of nitrogen (N) and phosphorus (P) mass balance for wastewater treatment plants (WWTPs) with a capacity of less than 2000 Population Equivalent (PE) and with a specific focus on those serving tourist areas around the Baltic Sea Region. The primary goal is to provide a detailed information on the quantities of N and P in the outlet of these treatment plants, shedding light on the efficiency of wastewater treatment in this ecologically sensitive region.

Furthermore, we will identify technologies employed for the recovery and reuse of N and P. This involves an examination of existing methods currently deployed in smaller WWTPs across the Baltic Sea Region, alongside the identification and discussion of new technologies that have been tested in pilot-scale.

By giving insights from traditional practices and emerging innovations, this chapter aims to contribute to a nuanced understanding of nutrient management in wastewater treatment within the Baltic Sea Region, discussing possible optimization of resource utilization.

Nitrogen and phosphorus in outlet of small treatment plants (<2000 PE)

Monitoring of nitrogen and phosphorus data in the effluent after wastewater treatment is routinely done for large treatment plants, and less frequently for smaller plants. These statistical data have been gathered and utilized to compare effluent data across various technologies and plant sizes.

The concentrations of nitrogen, phosphorus, and BOD for plants with a capacity below 2000 PE have been compared with the average effluent concentrations for all plants. Table 14 reveals that the concentrations of nitrogen and phosphorus in the effluent from plants below 2000 PE are 6-8 times higher compared to the average values. This indicates a significant potential for reducing nitrogen and phosphorus discharges from smaller plants.

Table 14: Data for nitrogen, phosphorus, and BOD amount and concentrations in treated wastewater for Denmark. The factor between these concentrations has been calculated by dividing the concentrations for small plants (2000 PE) by the concentrations for large plants.

	All plant	<2000 PE	Factor
Nitrogen	3127 tons/year	13.9 tons/year	
Phosphorus	297 tons/year	1.8 tons/year	
BOD	2199 tons/year	15.2 tons/year	
Water	614 mill m^3/year	0.47 tons/year	

This report is written in the project NURSECOAST-II which is funded by the Interreg Baltic Sea Region 2021-2027 programme and co-funded by the European Union.

Nitrogen	5.1 mg/L	29.5 mg/L	5.8
Phosphorus	0.48 mg/L	3.83 mg/L	7.9
BOD	3.58 mg/L	32.1 mg/L	9.0

Variability in Nitrogen and Phosphorus Levels Across Different Wastewater Treatment Technologies

Various wastewater treatment technologies exist, and the selection of a specific technology is influenced by the volume of wastewater to be treated but also other factors such as construction time and geographical location. Denmark provides a comprehensive breakdown of treatment plant types, encompassing nine installations: M for mechanical treatment, C for chemical treatment, B for biological treatment, BS for biological treatment with a sand filter, R for root zone treatment, L for lagoons, S for sand filters, and F for filtration. Additionally, N and D represent nitrification and denitrification, respectively. Thus, these data have been chosen for the comparison of technologies.

Advanced technologies are predominantly employed in wastewater treatment plants exceeding 500-1000 PE, frequently combining mechanical and biological treatment including nitrification and denitrification. In contrast, smaller plants below 500 PE typically utilize simpler technologies such as root zone treatment, sole mechanical treatment, sole biological treatment, or a combination of mechanical and chemical cleaning or biological treatment and sand filters (Figure 14).

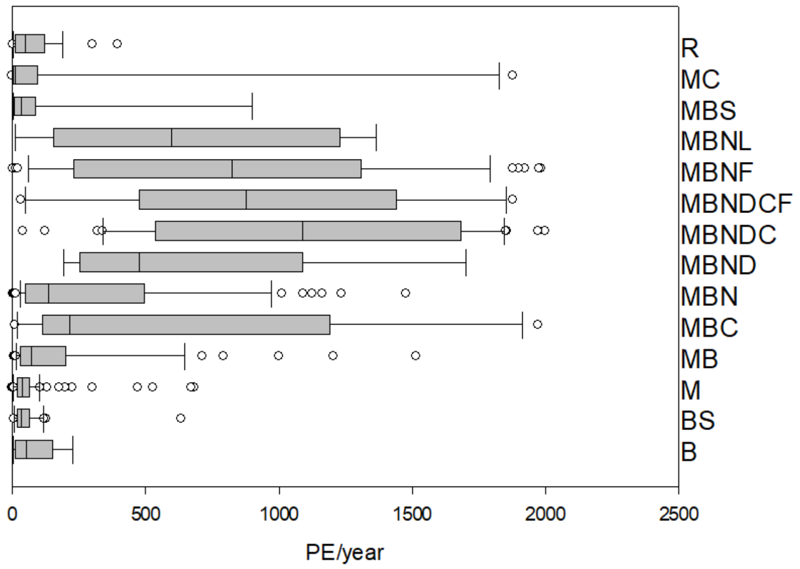

Figure 14: Load of wastewater treatment plant

The nitrogen concentration measured in the plant effluents show a significant correlation with the selected treatment technology (Figure 15). The lowest concentrations were measured in the effluent from the more advanced systems, i.e. biological wastewater treatment with nitrification and denitrification. The highest nitrogen concentrations were observed for plant with mechanical-chemical treatment of the wastewater.

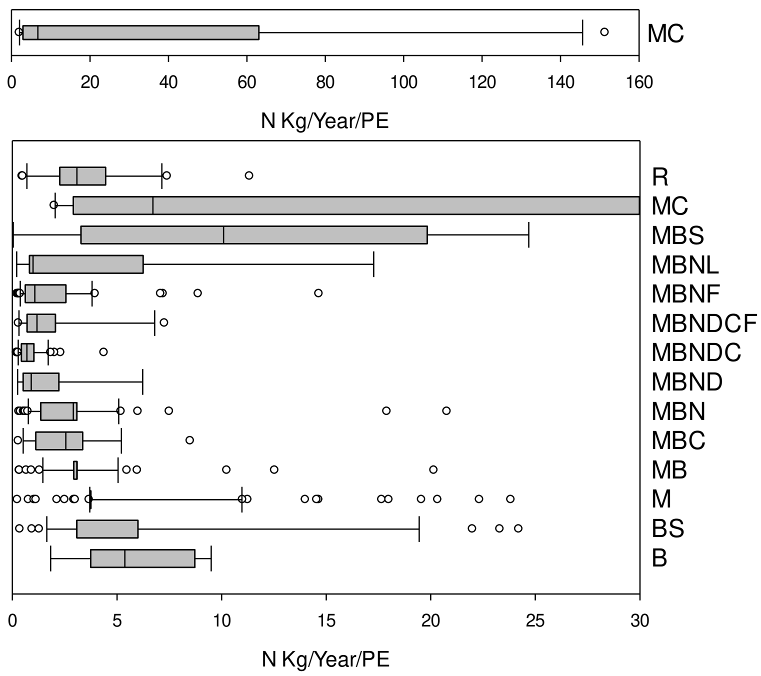

Figure 15: Nitrogen in outlet for wastewater treatment plant in Denmark (<2000 PE). Please note that mechanical-chemical treatment is presented twice – once with concentrations ranging from 0-160 to encompass all data points and a second time alongside other technology.

A comparable trend is observed when examining the phosphorus concentration in the effluent, where more advanced systems yield the lowest concentrations in the effluent (Figure 16). Among the simpler technologies, root zone treatment performs relatively well in terms of both nitrogen and phosphorus.

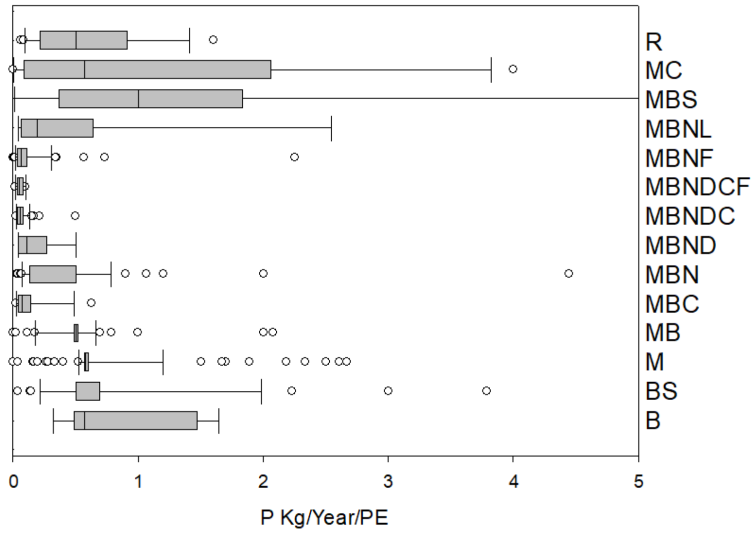

Figure 16: Phosphorus in outlet for wastewater treatment plant in Denmark (<2000 PE).

Seasonal Fluctuations in Nitrogen and Phosphorus Levels Throughout the Year

The water volume can fluctuate throughout the year, influenced by factors such as increased tourist activity in specific periods and variations in incoming rainwater. Tourist influx contributes to an elevated load, while rainfall primarily increase the overall water volume, thereby diluting the constituent substances.

Various plants were analyzed to identify trends between the flow of raw wastewater (input flow) and effluent concentrations of phosphorus and nitrogen. No distinct pattern was observed, but increased variability in the measured data was observed at lower loads. An illustrative example of a mechanical-biological treatment plant with nitrification is presented in Figure 17.

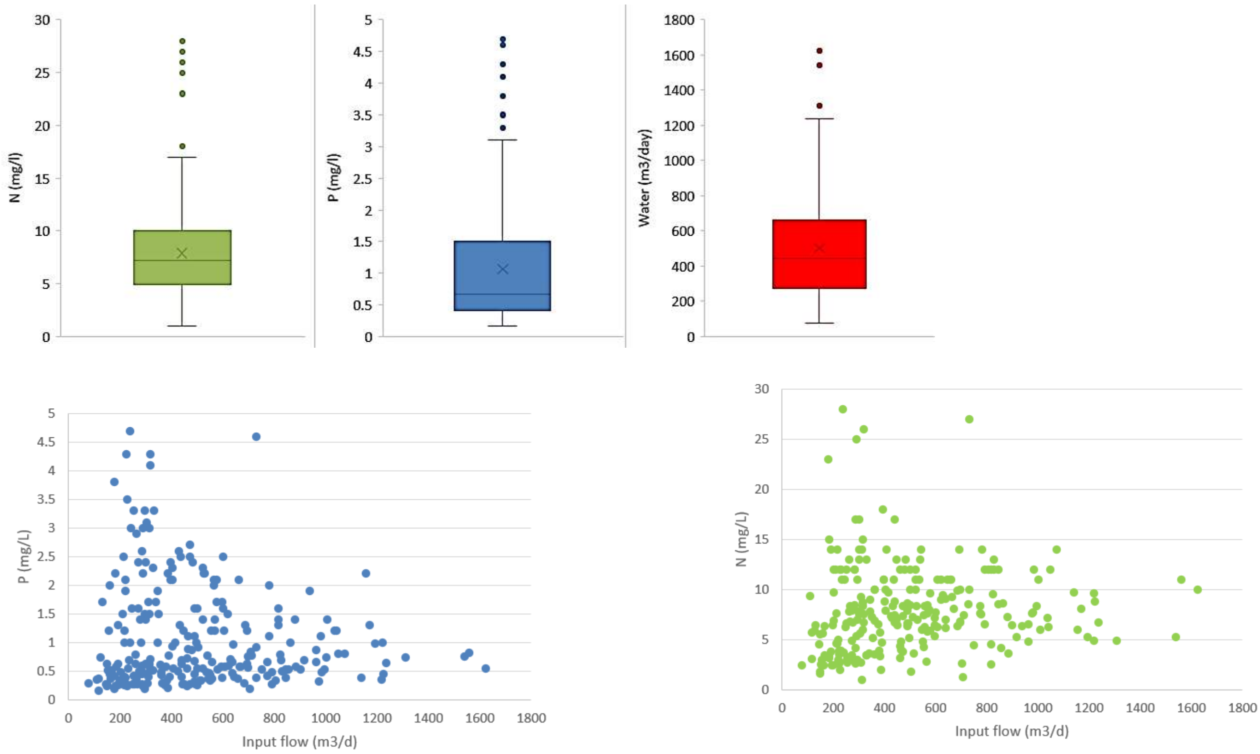

Figure 17: Effluent concentration of phosphorus and nitrogen.

Reuse of N and P from small treatment plants (<2000 PE)

Various wastewater treatment technologies are used for treating wastewater in tourist area, but the treatment of wastewater typically resulting in two to three distinct outlet streams: 1) treated wastewater, 2) sludge comprising biomass and particles separated from the wastewater, and 3) in certain instances, emitted gases (Figure 18). Phosphorus is directed exclusively to the sludge and treated wastewater, while nitrogen may also be present in emitted gases, such as N_2 and N_2O. Nitrous oxide (N_2O) has a significant greenhouse gas potency, however, further discussion on this matter is not done in this report.

At well-operated large wastewater treatment plants around 96% of the phosphorus is removed from the wastewater and end in the sludge (Dagerskog and Olsson 2020[21]). On average, smaller plants with a capacity of less than 2000 PE exhibit a lower phosphorus removal efficiency, approximately 72%. Furthermore, approximately 68% of the nitrogen is removed from the treated wastewater and end, either in the sludge or released back into the atmosphere. For larger plant 40% of the total nitrogen is returned

[21] Dagerskog, L. and Olsson, O. (2020). Swedish sludge management at the crossroad. Stockholm Environment Institute.

to the atmosphere (Dagerskog and Olsson 2020). No specific data were found for smaller plants, but the removal efficiency is expected to be lower, given that many smaller plants lack a biological process for nitrification and denitrification.

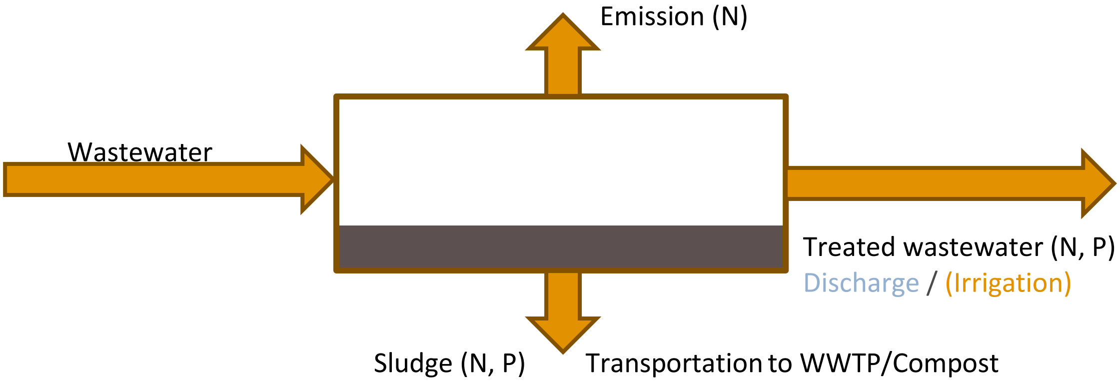

Figure 18: Sketch of wastewater treatment plant.

Nearly all small wastewater treatment plants direct their treated wastewater either to rivers or directly into the sea. Consequently, the discharged water, along with its nitrogen and phosphorus content, contributes to the overall nutrient load in the Baltic Sea.

Sludge is often conveyed and managed in larger plants, undergoing processes such as digestion to generate methane and eventually recycle phosphorus. The potential methods for utilization include:

1. Direct application of sludge in agricultural fields. Biological removal of phosphorus gives the best phosphorus availability compared to chemical removed phosphorus and phosphorus from digested sludge (Glæsner *et al.*, 2016[22]).
2. Incineration of sludge is another used solution, where efforts have been made to recover phosphorus from the ash (although nitrogen may be lost in the process).
3. In addition to these, sludge can find purpose in the production of materials for green construction, contributing to sustainable building practices.
4. Additional technologies, such as struvite precipitation, offer alternatives for phosphorus recovery and utilization.

[22] Glæsner, N., Lemming, C., Magid, J., Jensen, L.S. (2006). Review af eksisterende viden om plantetilgængelighed af fosfor i forskellige slamprodukter. Rapport for Miljøstyrelsen udgivet af Institut for Plante- og Miljøvidenskab, Københavns Universitet, www.plen.ku.dk

At small plants, an alternative approach involves retaining the sludge or removed solids from wastewater for compost, allowing the nutrients to remain compost rather than being removed.

Direct application of sludge is often the most cost-effective method for phosphorus reuse. The limited utilization of sludge is attributed to its quality, including factors such as the risk of heavy metals, the presence of pathogens, and organic pollutants (Rantanen *et al.*, 2008[23]). There are also local differences in nutrient needs; hence, transportation costs may be excessively high for many wastewater treatment plants (Miljøstyrelsen, 2013[24]), leading to biases against sludge. Furthermore, the insufficient availability of phosphorus for plant uptake may reduce its use as a fertilizer in agriculture. The destiny of sludge in larger plants is well-documented and varies across countries, as summarized in Dagerskog and Olsson 2020. For instance, in Germany, over 55% of the sludge undergoes incineration, while Sweden, Lithuania, and Latvia utilize 30-40% directly on the agricultural field. In Denmark, around 80% is applied to agricultural fields, with 13% is incinerated and 4% is landfilled (Miljøstyrelsen 2020[25]). In Finland, 40% is used on the agricultural field, and 50% contributes to green constructions (Pöyry Finland Oy, 2018[26]).

In the Moonsund Archipelago of Estonia, flow-through activated sludge treatment plants are prevalent. Sludge is gathered and subsequently transported to a larger wastewater treatment plant, often to the Kuressaare wastewater treatment plant, which is the only facility with a capacity exceeding 2000 PE on the island. The treated sewage sludge is made available at no cost to farmers or individuals for use in landscaping. It is important that the sewage sludge complies with the requirements outlined in the Water Act. While some larger wastewater treatment plants (WWTPs) in Estonia do sell treated sewage sludge, the commercial uptake has been hindered by public scepticism. Presently, there is limited commercial value for treated sewage sludge in Estonia and other countries.

The first survey in Estonia was initiated in 2023 (Körgmaa *et al.* 2023[27]) examining the possibilities of wastewater reuse in agriculture and industry. The investigation was started as a response to the implementation of a new regulation (EU 2020/741) outlining minimum requirements for water reuse in agricultural irrigation. Notably, the focus of this study was on large wastewater treatment plants, as the economic viability of water reuse is more pronounced with these facilities, ensuring sufficient wastewater volumes throughout the year. The findings indicated a notable interest in wastewater reuse within the industrial sector, while interest in agriculture was scarce. The study underscored the need for technological advancements in wastewater treatment plants to ensure the safety of treated wastewater for recycling purposes.

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[23] Rantanen, P., Valve, M., & Kangas, A. (2008). *Lietteen loppusijoitus -esiselvitys*. https://core.ac.uk/download/pdf/14928375.pdf

[24] Miljøstyrelsen (2013). Innovationspartnerskab for anvendelse af fosfor fra spildevand og spildevandsslam fra spildevandsforsyninger.

[25] Miljøstyrelsen (2020). Affaldsstatistik.

[26] Pöyry Finland Oy. (2018). *Lietteen hyödyntäminen ilman maatalouskäyttöä - hankkeen loppuraportti*.

[27] Kõrgmaa, V. *et al.* (2023). Heitvee taaskasutuse potentsiaali ning mõjude analüüsimine. https://kliimaministeerium.ee/media/12122/download

Innovative Technologies for Nitrogen and Phosphorus Reuse in Small Treatment Plants (<2000 PE)

Various development and demonstration projects have been conducted for wastewater treatment and nutrient recovery. This include both pilot-scale test and documentation of novel technologies at full scale. Various pilot-scale studies have been done to recover phosphorus and nitrogen from wastewater for use it as fertilizer in agricultural fields, involving the utilization of sludge, or both the spread sludge on the field and use the effluent for irrigation. Some of these projects specifically target smaller wastewater treatment plants (<2000 PE) with a simpler setup compared to studies conducted for larger plants.

Published project of pilot-scale or full-scale have been identified and will be listed in the chapter. It includes reports from the Baltic Sea area that look at phosphorus and nitrogen removal and recovery. The chapter will examine data on the removal and recovery of nitrogen and phosphorus where available. Furthermore, the discussion will include the identification of barriers, such as logistical challenges and other factors.

Direct concentration of wastewater for biogas production (DOGAS)

In the DOGAS project, wastewater was concentrated by direct filtration with ultrafiltration (0.02 µ) or microfiltration membrane (0.1 µ) and used for biogas production. The wastewater effluent was further treated by ozonation and sand filters. The refined wastewater effluent was evaluated for irrigation purposes, while the sludge, generated after biomass production, was utilized as fertilizer (Figure 19). The test was done at Nordby Wastewater plant (2000 PE) and financed by the MUDP program under Ministry of Environment and Food of Denmark. Nordby Wastewater plant is located the Island of Samsø as test location. Samsø has the ambition of becoming a model island for a circular bio economy, where all the biological resources are kept in close loops, among them the resources in the wastewater (Heinen *et al.* 2018[28]).

[28] Heinen, N., Joncquez, E., Mikkelsen, N., Kragh-Müller, K., Lindholst, S., Rickers, C.K. (2018). DOGAS Direct concentration of wastewater for biogas production. The Danis Environmental Projection Agency.

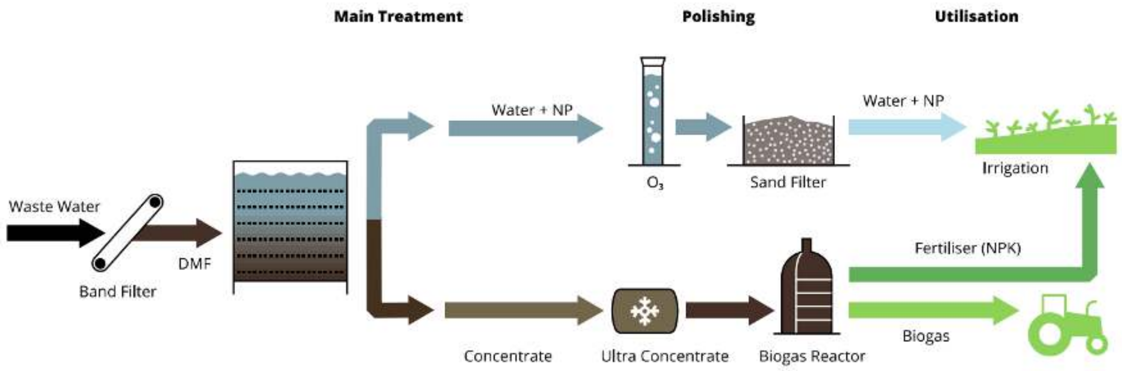

Figure 19: Sketch of wastewater treatment plant (Heinen et al. 2018).

In the report it was concluded that direct filtration with a membrane is suitable for wastewater concentration. The primary challenge is to maintain a minimal retention time to prevent biological activity, which could otherwise reduce biogas production. This challenge can be addressed through proper plant design. Nitrogen and phosphorus permeate the membrane, contributing to the treated wastewater (effluent), which becomes a valuable resource for agricultural production. The membrane effectively removes organic xenobiotics and heavy metals, even at peak concentrations in the inlet water (up to 10 times higher than normal). The Sludge Act, which regulates the use of treated wastewater for irrigation, shows that's these concentrations are a factor 10-1000 below. As such the permeate is suitable for irrigation (Heinen *et al.* 2018).

The technology appears promising but necessitates continuous irrigation throughout the year, or in tourist areas with varying seasonal loads during the periods with many tourists. Roughly 60-70% of the nitrogen is directed into the irrigation water, while the remaining portion is retained in the sludge. It is expected that only a small amount of nitrogen is lost to the atmosphere since direct filtration was used in the process instead of aerobic degradation. Therefore, most nitrogen from wastewater can be effectively reused at the agricultural field.

Resource container project

As part of the projects within the Nutrient Recycling ecosystem under Tekes' BioNets program, VTT (Technical Research Centre of Finland) has worked with new solutions for wastewater treatment and nutrient recovery and for better usability of the recycled products. A mobile wastewater treatment unit has been developed to enhance the usability of recycled products by recovering phosphorus, nitrogen, and carbon (Figure 20). Various methods have undergone testing for the recovery of phosphorus and nitrogen.

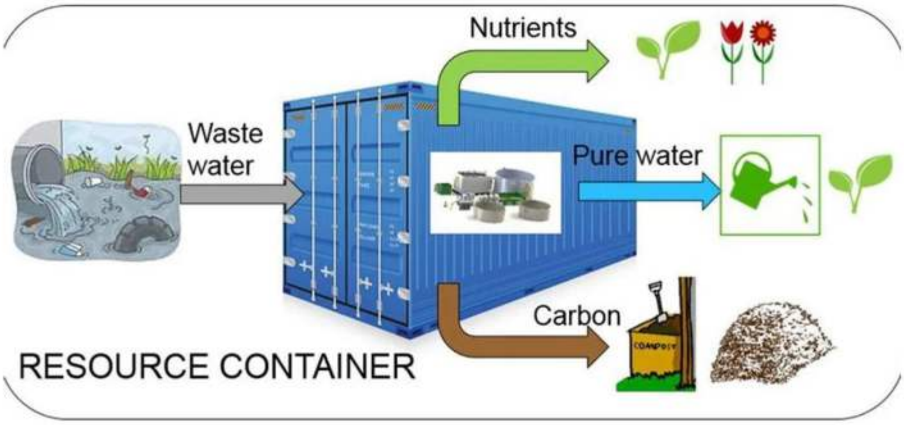

Figure 20: Resource container project (Kyllönen et al. 2020[29]).

For phosphorus, the explored technologies include: 1) Precipitation using calcium products, 2) Nanofiltration and reverse osmosis, 3) Evaporation and 4) Adsorption using adsorbent and granular activated carbon.

For nitrogen, tests were conducted with and without pH adjustment, employing the following technologies: 1) Evaporation and stripping, 2) Nanofiltration and reverse osmosis, 3) Membrane contactor, and 4) Adsorption using adsorbent and granular activated carbon.

Two pilots for water purification and resource recovery were conducted in two scenarios for treating industrial wastewater from Chipsters Food (Åland) or septic tank wastewater (PSS ry). The primary challenge for the wastewater from Chipster food being the elevated concentration of COD. The removal rate was 99% for COD, nitrogen and phosphorus. In the Resource Container pilot involving septic tank wastewater, key components included a belt filter, cartridge filter, and RO system, achieving recovery rates of 98% for COD, 95% for nitrogen, and 96% for phosphorus. Organic bioflocculant was employed, and the use of iron coagulant was avoided to mitigate potential challenges in nutrient reuse associated with the use of iron.

The finale concept is a commercial solution for solid/liquid separation that was assisted by flocculation, prioritizing that the nutrients stay in the liquid phase. The process involves phosphorus recovery through precipitation, nitrogen recovery via membrane contactor, and the production of pure water through

[29] Kyllönen, H., Heikkinen, J., Järvelä, E., Grönroos A. (2020). Resource Container, Concepts for nutrient recovery. Jätevesien ravinteet kiertoon -webinar October 23rd, 2020. https://ym.fi/documents/1410903/42721411/4_Resurssikontti_Kyll%C3%B6nen.pdf/af97978f-a7c4-8385-849b-683f7ca6139d/4_Resurssikontti_Kyll%C3%B6nen.pdf?t=1603875132817

reverse osmosis. The resulting solids can be effectively utilized, for example, in biogas or biochar production (Kyllönen 2020).

Source separation for nutrient recovery

A comprehensive study was conducted to collect scientific data on source separation, focusing on urine and blackwater source separation. The objective was to assess the environmental impact and potential nutrient recovery from wastewater separating systems. This investigation done by a combination of calculation based on literature values and field growth studies conducted in Finland.

The study involved the comparison of various separation, collection, and storage methods for urine and human feces in rural areas (Figure 21). The report shows the calculated environmental impacts of the different scenarios, including factors such as carbon footprint and eutrophication potential. The reference system in the study was the treatment of wastewater utilizing a three-chamber septic tank and sand filter where excess sludge was transported to a wastewater treatment plant for further handling.

The study primarily centered on rural areas, making its findings relevant to the NURSECOAST-II project, which aims to address the treatment of tourist areas lacking larger wastewater treatment plants in close proximity or at least at areas where it has been decided to do the wastewater treatment locally.

Human urine was found to be an environment friendly fertilizer and captured urine was found at least as effective as commercial fertilizers. While traces of drugs, hormones and other substances could be detected in the aged urine, none were found in the soil or in barley fertilized with such urine. Due to need for more equipment, the carbon footprint of the dry toilet method is greater than that of the current method. However, when the increased usability of wastewater products as fertilizers in dry toilets is considered, the difference between the two methods is no longer significant. Applying source-separation systems in rural areas, four times more phosphorus and over thirty times more nitrogen could be recovered compared to the current wastewater treatment system. The research project also emphasizes that sustainable and efficient nutrient recycling necessitates effective management across the entire chain, encompassing collection, transportation, storage, processing, and eventual utilization. To ensure cost-effectiveness and the acceptability of end products, it is crucial to establish a market for them; otherwise, the potential benefits of nutrient recovery may be lost (Malila *et al.* 2019[30]).

[30] Malila, R., Lehtoranta, S., Viskari, E.-L. (2019). The role of source separation in nutrient recovery – Comparison of alternative wastewater treatment systems. Journal of Cleaner Production, Vol 219:350-358.

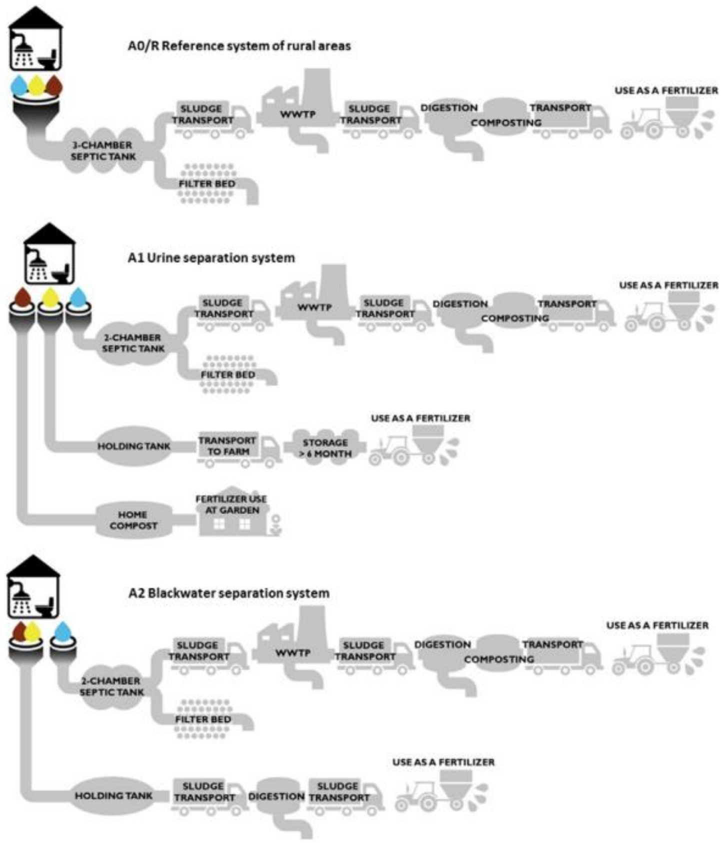

Figure 21. Reference system and two alternative solutions with source separation used for LCA analysis (Malila et al.2019).

Currently, human urea and composted faeces cannot be used as fertilizers in Finland. Due to positive environmental impact, reduction of total costs, and efficacy and safety as a fertilizer, the study group suggests that separately collected, aged urine should be accepted as nitrogen enricher in edible crops cultivation.

Source separation, concentrate and transport urine

The Mobile Nutrient Recovery Under Field Conditions (MORTTI[31]) project sought innovative solutions for capturing and utilizing nutrients in urine and faeces. A novel system was tested in field conditions, employing a new alkaline urine dehydration technology developed by the Swedish University of Agricultural Sciences (SLU). The technology reduces the volume of urine to less than one-tenth of the original volume, resulting in significant savings in transport costs particularly from sites outside sewer networks. In this method urine was adsorbed to a mixture of ash and lime and excess liquid evaporating. The final powder product contains ash with a high cadmium content (4-7 mg/kg

[31] MORTTI (2023). Nutrients in urine: waste them or use them? https://www.sitra.fi/en/projects/nutrients-urine-waste-use/

dry matter) and is suitable as a forest fertilizer. Furthermore, by adjusting the volume of ash in the carrier composition, the final product can be tailored for use as a soil improver in fields, offering versatile applications.

The method was piloted at the Finnish Defence Forces training area of Camp Mauri in Säkylä, as camp conditions provided a natural place for testing methods developed for source separation, and the conscripts produce high-quality raw material suited for the purpose. The Finnish Defence Forces also do waste management and sanitation in the camp, but the biodegradable waste landfill ban that was implemented in 2016 and the high cost of transporting liquid toilet waste by vacuum truck for processing in waste-water treatment plants have created a need to develop sanitation to enhance nutrient recovery and to lower transport costs (MORTTI 2023).

Mini wastewater treatment plant for vacation homes in tourist area

The Danish Environmental Protection Agency in Denmark has provided support to BioKube due to the significant need for a technology that can effectively treat wastewater in tourist areas with vacation homes. This need extends to holiday resorts and similar establishments with periodically varying loads throughout the year. There has been limited implementation of enhanced wastewater treatment for the many vacation homes. There are likely over 200,000 vacation homes in Denmark that are not connected to a sewer system and, in the coming years, need to establish a treatment solution capable of functioning under the unique conditions prevalent in vacation homes (Taarnhøj *et al.* 2018[32]).

Wastewater treatment in vacation homes demands a specialized technology tailored to handle fluctuating loads in the incoming wastewater to the treatment facility. Biological treatment is an often-used method for wastewater purification, relying on the breakdown of contaminants by microorganisms within the treatment facility. However, the challenge lies in the fact that these microorganisms require a continuous supply of nutrients for the system to remain operational. BioKube has developed and patented a technology that ensures a consistent nutrient supply even during periods when the property is unoccupied. The core of this technology involves a continuous backwash to the sedimentation tank, introducing dissolved nutrients that are circulated back into the treatment system, thereby sustaining the microorganisms. Every quarter treated wastewater from the last clarification chamber is circulated back to the sedimentation tank through a backwash process. This ensures a continuous supply of nutrients to sustain the biological processes, keeping the microbial community alive. Despite being active, the biology is essentially 'hungry,' resulting in even lower effluent discharge from a vacation home after the winter period compared to normal operation in a year-round residence (Figure 22).

[32] Taarnhøj, P., Heinicke, G., Pedersen, B.M. (2018). Minirenseanlæg til Sommerhuse, MUDP rapport.

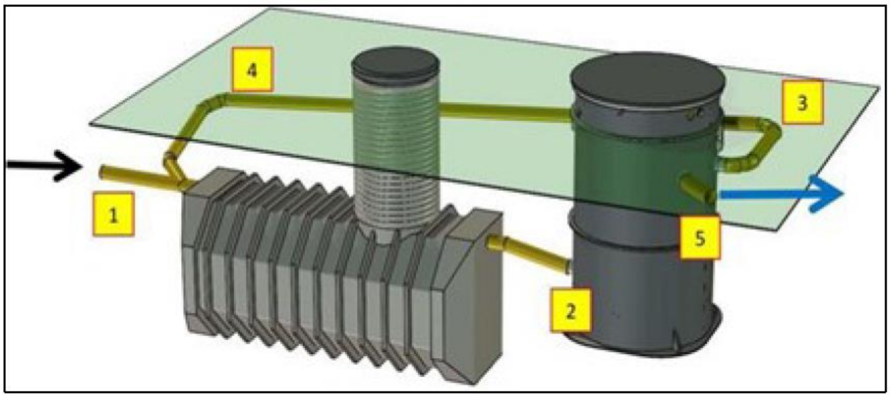

Figure 22: Principal of the mini wastewater treatment system (Taarnhøj et al. 2018).

Through verification, it has been demonstrated that the mini wastewater treatment system fulfil the discharge requirements even when not receiving wastewater throughout the winter period from October to April, a common scenario for vacation homes. Furthermore, it has been confirmed that the mini wastewater treatment system meets discharge requirements from the very first day of use after the winter period (Taarnhøj *et al.* 2018).

Vertical Flow Labyrinth Treatment system

The Vertical Flow Labyrinth VFL® technology is a continuous-flow activated sludge process for biological nitrogen and phosphorus removal. This system integrates mechanical pre-treatment, excess sludge collection, biological treatment, and solid-liquid separation within a single tank. The design allows for the establishment of anoxic, anaerobic, and aerobic zones, enhancing the removal of nitrogen and phosphorus (Figure 23).

The technology demonstrates high efficiency in biological nitrogen removal, achieving denitrification rates exceeding 90% and nitrification rates surpassing 80%. Additionally, the technology facilitates biological phosphorus removal with an efficiency exceeding 80%. The system allows for the integration of phosphorus removal by dosing directly into the wastewater treatment plant tank. This versatile approach accommodates various discharge options, including release into sensitive water bodies, groundwater, and bathing water. The treated water from these wastewater treatment plants can be considered for reuse e.g. irrigation.

The system is designed for decentralized and semi-centralized wastewater treatment solutions, with operational capacities ranging from 8 to 18 PE for the smallest units and 30 to 300 PE for the largest units.

The biological reactors are designed to be transported in a ready-for-use state using oversize transportation trucks (VFL 2023[33]).

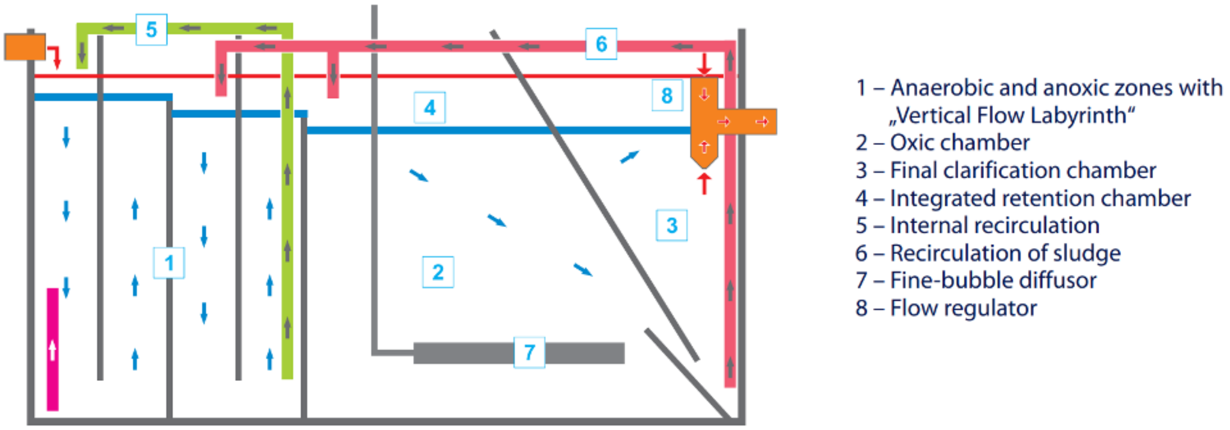

Figure 23: Sketch of Vertical Flow Labyrinth Treatment system (VFL 2023).

Aerated treated wetland

Another solution is the use of constructed wetland. Tackling the treatment of highly loaded wastewater (e.g., industrial wastewater) poses challenges in conventional treatment wetlands due to increased area demands for effective pollutant removal. The emergence of new intensified Treatment Wetland (TW) systems, such as aerated systems, has introduced innovative possibilities in Wetland Technology. These systems demonstrate the capacity to efficiently treat various types of wastewater (WW), while simultaneously reducing the required area and mitigating some operational limitations inherent observed in conventional wetlands (Arias *et al.* 2015[34]).

To enhance P removal, media with a high P binding capacity is utilized as filling material. The technology is also useful in tourist areas, offering the advantage of reducing the required space and implementing aeration during periods of high load during the tourist season.

Non-biological treatment of wastewater

A collaborative project on direct filtration has been undertaken by researchers and wastewater treatment plants in Sweden and Denmark. The setup, as illustrated in Figure 24, has been employed for treating wastewater using forward osmosis. Forward osmosis utilizes a tight membrane where primarily water

[33] VFL (2023). http://www.vflholding.com/files/files/vflholding-wastewater-treatment-technology.pdf

[34] Arias, C. A. Oirschot, D. V., Kilian, R., Pascual, A., Carvalhoa, Lv T., Zhang, Y., Brix, H. and Alvarez, J.A. (2015). Design and performance evaluation of a highly loaded aerated treatment wetland managing effluents from a food processing industry in Denmark Water Practice & Technology 10, 4, 644-651.

passes through, and a salt gradient is applied to drive water through the membrane, in this instance, using seawater. Consequently, the technology is most applicable to wastewater treatment plants situated in proximity to the sea. The system treats wastewater mechanically, but in comparison to other systems, it utilizes a tight membrane, resulting in the attainment of high-quality treated wastewater. The system has been constructed by combining raw water and pre-treated wastewater prior to forward osmosis, incorporating microsieves (MS) or microsieves and microfiltration (MF) in combinations (Hey *et al.* 2017).

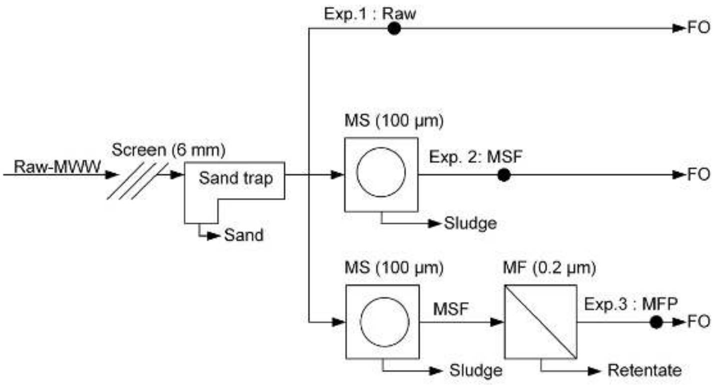

Figure 24. Pilot plant for mechanical treatment of wastewater (Hey et al.2017).

Forward osmosis technology was able to remove over 96% of BOD and phosphorus. While the nitrogen removal rate was not explicitly shown in this study, it was mentioned that other studies have reported a removal rate of approximately 50%. An observed decline in the membrane flux was attributed to fouling, and it appears that the various pre-treatment methods do not effectively prevent this issue (Hey *et al.* 2017). The treated wastewater (permeate) is discharged into the sea; therefore, it would be advantageous if a larger fraction of nitrogen could be removed.

Conclusion

There exists an opportunity to reduce nitrogen and phosphorus in the effluent discharge, preventing local pollution in tourist areas, especially during the peak tourist season. When compared to technologies used at larger wastewater treatment plants, the discharge can be reduced by a factor of 6-7. The most effective results are attained through the utilization of biological wastewater treatment. One challenge may be the viability of microorganisms during the low-flow season. However, methods exist to recirculate water and by doing that ensure substrate for the microorganisms during the whole year. Constructed wetlands present an alternative solution, and it has been shown that by implementing aeration, the capacity of the wetland can be enhanced, which is particularly beneficial during the tourist season.

Excess sludge is commonly transported to larger wastewater treatment plants for subsequent management, offering the potential for reclaiming nitrogen and phosphorus removed from the treated wastewater for reuse. Pilot-scale studies have investigated both source separation of wastewater and direct filtration. The treated wastewater has high nutrient levels and the quality is suitable for irrigation, whereby potassium, nitrogen and phosphorus can be reused. To achieve this, wastewater production must align with the fertilization requirements throughout the year. Alternative technologies have been tested to recover nitrogen and phosphorus on-site as solid products, or to concentrate nitrogen and phosphorus before transportation. Public opinion and legislation may be a serious barriers to the reuse of nitrogen and phosphorus from wastewater.

5. Final <2000 PE WWTP wastewater seasonality examination in the partnering countries for given touristic locations and pilots - Survey studies

Authors: Josefin Flink, Tiia Pedusaar, Anda Zake

Estonia, Latvia and Sweden have carried out surveys regarding small wastewater treatment plants in their respective countries. Each country has a target group to whom the questionnaires were sent out, and a summary of the results of the various surveys is presented here in this report (Table 15). The surveys have been financed and carried out within the framework of the NURSECOAST-II project.

Table 15. Shows the countries that performed a survey, and the target group response rate to show the number of replies.

No.	Country	Target group of the questionnaire	Response rate of the questionnaire	Total population of the study area	% of population rely on on-site solutions
1	Estonia	Tourism enterprises	34 (23.3 %)	32 000	43%
2	Latvia	Touristic point owners/managers	36 The survey was publicly available	12 254	40%
		Tourists	95 The survey was publicly available		
3	Sweden	Private property owners and association (joint property unit)	353 (31.7%)	25 000	16%

Estonia

Objective and study area

Survey on decentralised wastewater systems on Moonsund Archipelago in Estonia was conducted to get first insight into small wastewater treatment systems (less than 2000 PE) connected to tourism on Moonsund Archipelago. The archipelago is composed of the islands Saaremaa, Hiiumaa, Muhu, Vormsi and about 900 other smaller islands. UNESCO established the Moonsund Archipelago Biosphere Reserve

This report is written in the project NURSECOAST-II which is funded by the Interreg Baltic Sea Region 2021-2027 programme and co-funded by the European Union.

in 1990 under the Man and the Biosphere Programme. This survey concentrated on the territory of Saaremaa Municipality including the biggest island Saaremaa with the surrounding small islands.

Background

The countries bordering the Baltic Sea have invested heavily in large wastewater treatment plants (>2000 ie). Wastewater generated in rural areas, especially on islands and coastal areas relies mainly on onsite wastewater systems and has received less attention. At the same time, the tourism pressure is growing in islands and coastal areas because of people seeking authenticity and untouched nature. These small tourist spots along the seacoast have a high seasonal character and cause variable wastewater loading, impacting water quality of the coastal sea.

Saaremaa Municipality has a population of about 32 000 people, of whom about 57% use the public water supply and sewerage service. The rest have on-site wastewater systems.

Methodology and sample

The questionnaire was developed based on recommendations of the Ministry of Climate (https://kliimaministeerium.ee/merendus-veekeskkond/vesi/reovesi-ja-reoveekogumisalad), but altered to take into account the needs of NURSECOAST-II project. Further feedback was collected from Saaremaa Municipality. As the target group for the questionnaire was tourism enterprises in Saaremaa Municipality, their information and contact data were collected from Visit Saaremaa website in May and June 2023. Small ports (marinas) information was obtained from State Port Register in August 2023 (https://www.sadamaregister.ee/). The poll started in September 2023 and ended at the beginning of November 2023. Altogether 146 tourism enterprises received the questionnaire, and the response rate was 23,3% (34 answers).

Most of the respondents were active in accommodation sector, but in many cases, this is combined with other services (harbour or catering). Most of the tourism facilities are rather small: 71% of the respondents can accommodate up to 20 visitors at a time. As expected, tourism is very seasonal and only 1/3 of the tourism facilities operate all-year-around in Saaremaa.

Conclusions

The questionnaire results showed that we hit the target group well – the island's tourism service providers, who have an on-site wastewater system and do not have the opportunity to join the public water or sewerage system. The questionnaire results demonstrated a high seasonality - the main tourism period starts in April-May and ends in October.

The survey showed that the majority of tourism service providers (73%) rely on-site systems like storage tank or septic tank and leachfield. There are a few other solutions in use like septic tank together sand filter or wastewater treatment based on activated sludge or biofilm treatment. 79% of tourism enterprises reported that wastewater systems have been built not earlier than 2001. About 24% of the sample claimed that they empty the WWS at least once per month and altogether 56% of them claim to do it at least once in half-a-year. In most cases (67%), the waste (the sludge) is taken to regional sewage plant.

The questionnaire results will be shared to the Saaremaa Municipality and will help analyse the needs and technological options of the island in the long-term run.

Latvia

Objective and study area

In Latvia, the study mainly took place in Kurzeme region – Northwest part of Latvia. Including the practical sample testing in small rivers close at the coastline (Figure 25). The aim for the activity was to identify the pollution changes in water quality based on intensity of tourism season in places where the centralized wastewater collection is not acceptable.

• Analyzed data on the existing wastewater treatment facilities, where wastewater is treated in territories with CE <2000, located in a zone of up to 100 km along the Baltic Sea coast;

• Triple sampling was carried out in 14 separate water bodies in Kurzeme (the project's territory in Latvia). The water bodies were chosen close to the Baltic Sea coast. Each time, one sample was taken in the Gulf of Riga.

• Sampling and obtained results are digitally mapped;

Parallelly two surveys among tourism point owners/managers and tourists were done from August till beginning of December 2023.

Figure 25.The study mainly took place in Kurzeme region – North West part of Latvia.

Background

The Baltic Sea coast in the west of Latvia was the heavily guarded western border of the USSR during the Soviet occupation. Today, the Kurzeme seafront has preserved the charm of nature in many places, untouched by civilization.

The coast of the Gulf of Riga in Kurzeme has a special charm. The ancient coastal fishing villages - Bigauņciems, Lapmežciems, Ragaciems - tempt with a white, sandy beach, guest houses and cottages in the dunes, taverns and freshly smoked fish.

Methodology and sample

Sampling

Concentrations of organic matter, total nitrogen and phosphorus are good indicators to assess the condition of water bodies. These substances are the main plant nutrients (biogenic substances) occurrence of which in surface waters causes their eutrophication and ecosystem degradation. The main source of these substances is wastewater from cities and settlements, which, after treatment in wastewater treatment plants, is discharged into surface water bodies.

In order to assess the condition of 14 water bodies, sampling was organized on June 14, July 31 and November 8, 2023. Chemical consumption, total nitrogen and total phosphorus were selected as indicator parameters. COD levels reflect organic pollution in water that is consumed as needed for biochemical oxidation, based on the concentration of all nitrogen and phosphorus, assessing the amount of nutrients and the potential risks of eutrophication of surface objects.

The results showed that chemical oxygen consumption in sources of water bodies varied from 27.9 to 124.3 mg/l, total phosphorus concentration - from 0.020 to 0.196 mg/l and total nitrogen - from 0.59 to 6.16 mg/l (Figure 26–Figure 28).

According to the Latvian Environmental Agency's project "Determination of Background Level Monitoring Stations and Benchmark Status of Latvian Rivers and Lakes" report from 2003, biogenic content in reference rivers of Latvia, in the basin of which there is no or little anthropogenic influence. Referring to the data published in the report, the concentration of total phosphorus in Latvian rivers varied from 0.01 to 0.12 mg/l, and that of total nitrogen - from 0.02 to 2.6 mg/l. In summer, rivers are characterized by moderately high concentrations of organic substances and biogenic substances (average around BOD5 2.6 mg/l, P_{tot} – 0.068 mg/l, N_{tot} – 1.46 mg/l).

Survey

Questionnaires were conducted in two categories:

- tourism service clients

  and

- tourism points owners.

which will be analyzed in more detail in the form of graphs.

Conclusions

Sampling

Taking into account the obtained results, it can be considered that all water sources can be characterized as rivers with a high load of organic substances and a moderately high load of biogenic substances (i.e. nitrogen and phosphorus concentrations comparable to the reference biogenic concentration above). It should be noted that the organic load was calculated from BOD as a result, assuming that generally BOD5 accounts for only about 65% of the total oxygen consumption determined by the carbon in the municipal wastewater. Sources no. 2, 3, 4, and 14 are also described as sources with a high phosphorus load (phosphorus load 2 times higher than the phosphorus concentration of biogenic concentrations of reference rivers), but in river no. 11. increased concentrations of organic substances, phosphorus and nitrogen were found compared to reference sources.

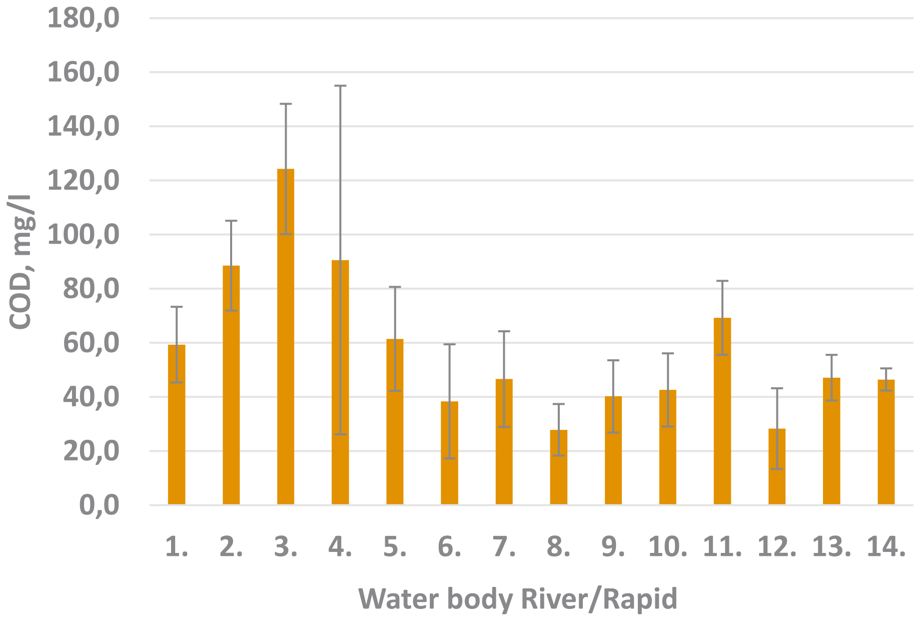

Figure 26. Average concentrations of chemical oxygen consumption in samples.

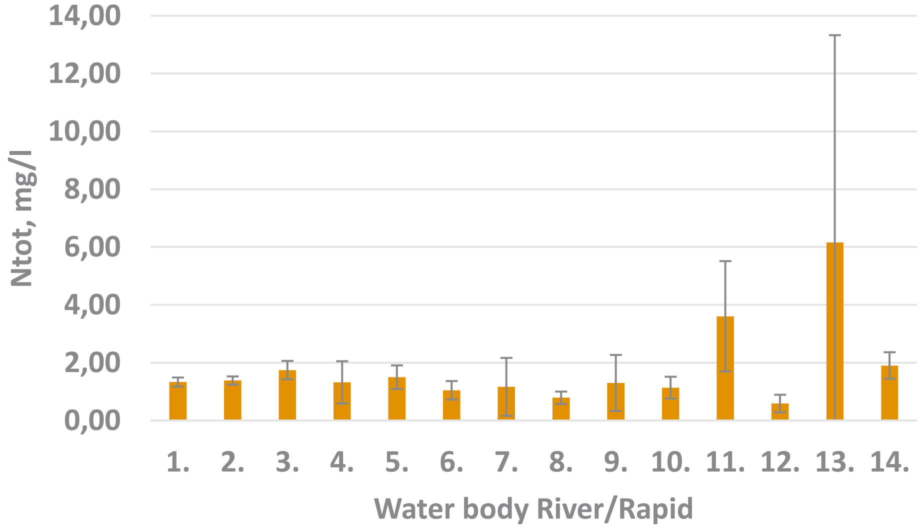

Figure 27. Average total nitrogen concentrations in the samples.

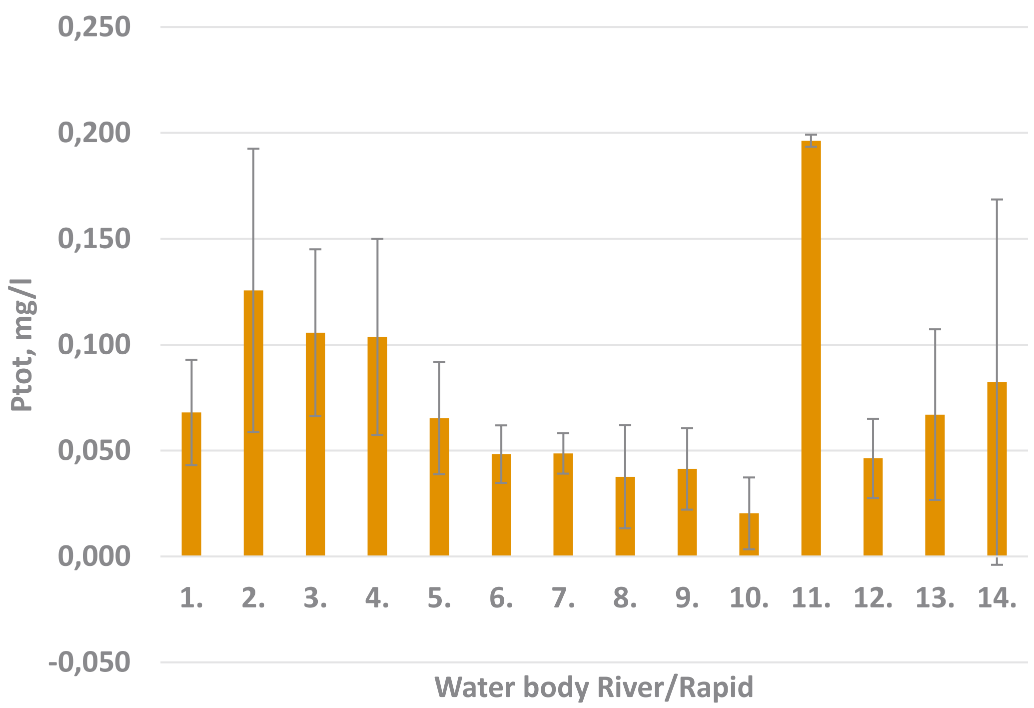

Figure 28. Average total phosphorus concentration(mg/l) in the samples.

Also, according to the test results, during the monitoring, the indicator parameter values exceed the requirements for wastewater emitted from agglomeration treatment plants in terms of total phosphorus, total nitrogen and chemical oxygen consumption.

Survey

The response rate shows the willingness and responsibility to discuss these items. The survey among tourists showed, that wastewater treatment quality issue is important. The lack of information could be one of the reasons for almost equal (~30% each) answers, that support from local municipality is (is not) enough and can't answer (Figure 29).

Looking only to few graphs from survey we can admit that 38% of respondents to tourism companies did not want to answer or did not have an opinion about municipal support. 24% of the surveyed companies believe that the support is enough, while 35% would like to receive greater involvement of the municipality in solving wastewater problems (Figure 30Figure 30).

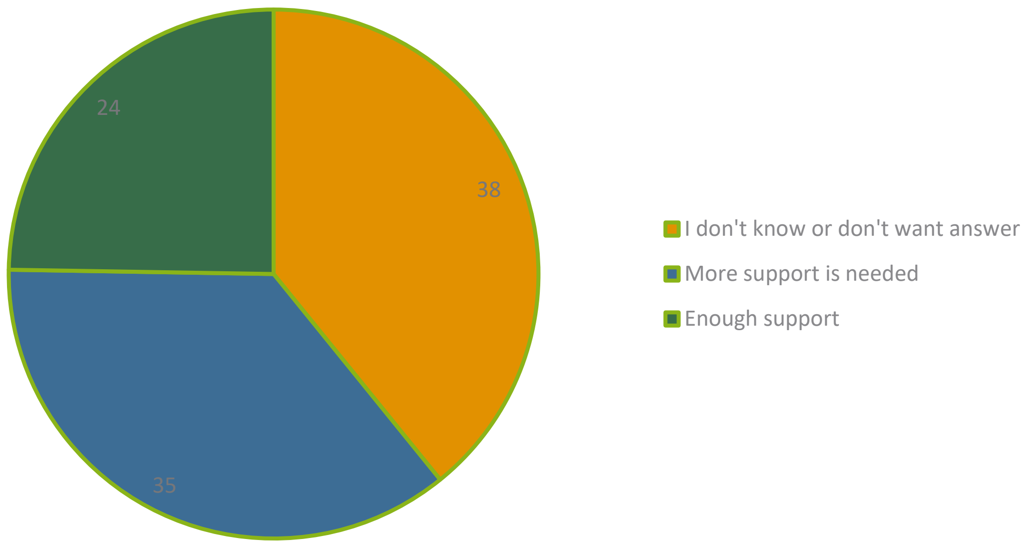

Figure 29. How my municipality supports me in the area of wastewater?

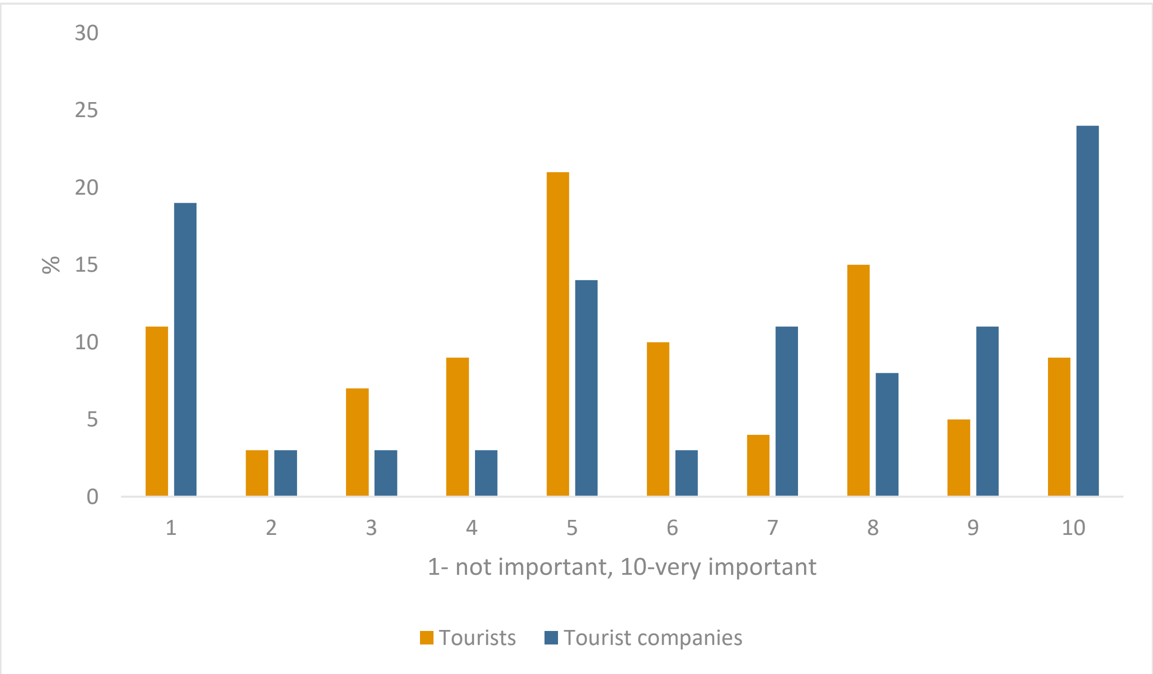

Figure 30. How important is it to you how a tourism company manages its wastewater? How do you think how important is it to your customers? 1- not important 10 - very important.

As we can see from the results, tourism companies overestimate their customers at both ends of the spectrum. Too many companies think it doesn't matter to customers, and just as many think customers value quality wastewater management more than they really do (Figure 31).

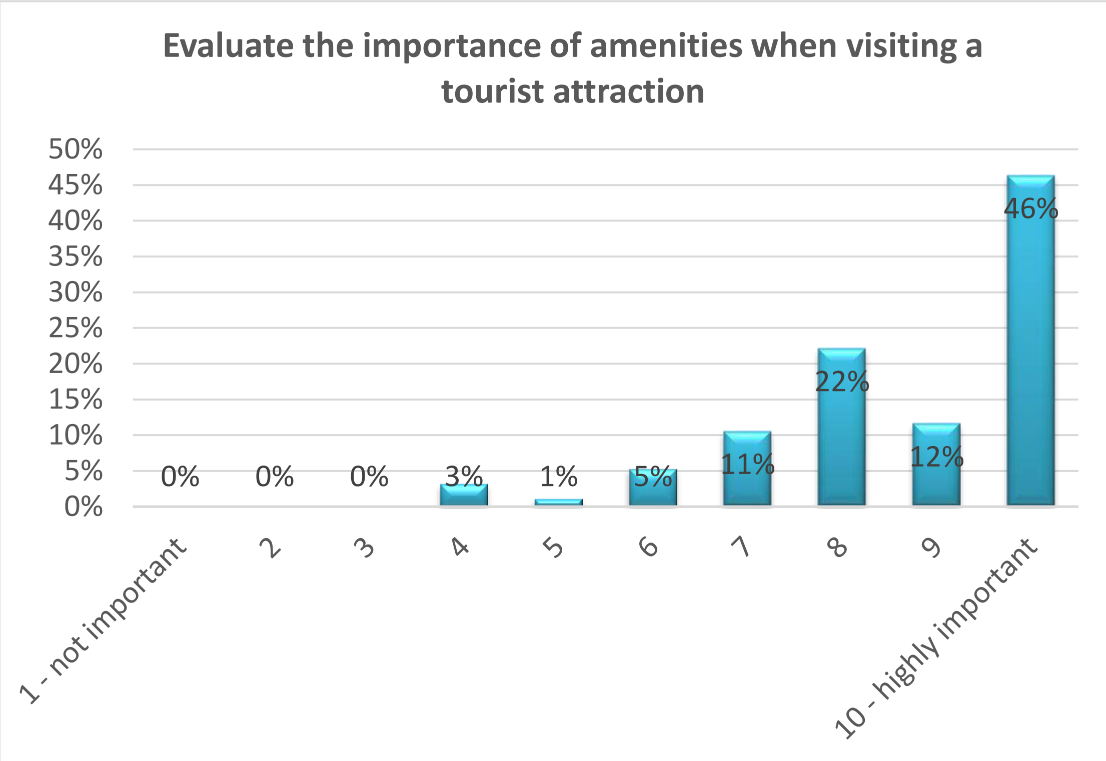

Figure 31. The importance of amenities when visiting a tourist attraction.

These results seem very interesting and reveal directions in which to work in future.

Sweden

The Swedish survey investigates individual sewage systems in Söderhamn, a mid-sized coastal town in Gävleborg, Sweden. The study focuses on non-public wastewater treatment facilities in Soderhamn municipality, catering to residents without access to the public water supply and sewerage service. With a population of 22 000, 4000 individuals rely on on-site water and sewerage systems. The survey, aligning with legislative changes from January 1, 2023, explores residents' needs, contributing insights for local planning and the Nursecoast II project. Compliance with health and environmental standards is crucial.

The survey, part of the municipality's water services plan, achieved a 31.7% response rate from 353 participants.

Objective

The primary aim is to understand the needs and experiences of property owners with individual sewage systems. Data collected will inform the Water Services Plan for Söderhamn Municipality and contribute to the Nursecoast II project.

Background

Motivated by municipal needs and Nursecoast II project participation, the survey explores challenges faced by small wastewater treatment plants along the Baltic Sea, especially during tourism seasons.

Legislative changes in Sweden permit municipalities greater flexibility in water service planning. Property owners' ability to arrange solutions independently under specific conditions is emphasized. This survey aids in identifying areas requiring private or municipal water and sewage solutions.

Methodology and sample

Conducted alongside the Water Services Plan establishment and small wastewater treatment plant survey, the questionnaire utilized Geosecma, esMaker, and IDATA. Estonian Project partners and Söderhamn Nära contributed expertise. Demarcation excluded areas with municipal connections and residents abroad, focusing on those without municipal water and sewage.

The survey spanned from October 3rd to November 5th, 2023, with a response rate of 31.66%. In the designated areas, 353 property owners responded to the survey, providing a comprehensive dataset for analysis.

Results and conclusion

According to the results from the questionnaire, most of the respondents in the coastline areas are summer residents who are in favor of getting access to municipal water and sewerage. The survey results indicate that 24.9% of the respondents have an on-site sewage treatment plant that was built before 1980, which is the largest proportion. 70.4% (263 respondents) of the respondents claim to have a three-chamber septic tank, and 70.61% have an infiltration bed as the last purification step (Table 16). Out of 309 respondents, 20 stated that they have an on-site "mini sewage treatment plant", of which 48% claim to be using "biological treatment".

Table 16. Some characteristics of non-public wastewater treatment facilities in Soderhamn municipality (Sweden).

Type of system	Respond rate	Main characteristics of the system
Septic tank (three chambers)	58,4% (206/353)	Material: plastic (35%), fiberglass plastic (15%), concrete (25,2%)
	17, 9% (63/353)	Average volume of the tank: 3 m^3
	90,7% (320/353)	Half of the respondents empty it at once a year
Infiltration bed	93,5% (330/353)	Have an infiltration bed: Yes (70.6%) No (13.6%) Do not know (15.8%)
	37,7% (133/353)	Size of the bed: less than 15 m^2 (14%), 15-20 m^2 (27,8%), 30-60 m^2 (35,3%)

The survey results, accessible at the municipality of Söderhamn, offer insights into the situation of residents without municipal water and sewage. These findings, important for future planning and actions, maintain participant anonymity but with geographical locations accessible.

Survey questionnaire synergies

Listed here are survey questions that are similar in Sweden and Estonia.

1. Year of construction of the property's sewage system:
2. The year of renovation of the property's sewage system?
3. Are you planning to renovate your sewage treatment plant?
4. Amount of wastewater generated (m^3/month)?
5. How is wastewater treated on the property?
6. If there is a closed tank, what is the capacity of the tank (m3)?
7. What material does the tank consist of?
8. Is there an infiltration plant?
9. If yes, what is the capacity of the infiltration bed (m3)?
10. If yes, what type of infiltration bed?
11. Is there a mini sewage treatment plant?
12. If there is a mini sewage treatment plant, what type?
13. Capacity on the mini sewage treatment plant?
14. Capacity of septic tank (m^3)?
15. Size of the sand filter?
16. Emptying the sewage system?
17. Source of drinking water on the property?

Listed here are survey that are similar in all three regions:

1. What services does the company provide?
   1.1 Catering and accommodation
   1.2 Accommodation
   1.3 Catering
2. What is the approximate number of guests per season?
3. Which month has the highest number of visitors?
4. What is the approximate number of guests during the busiest month?
5. Have you thought about improving the existing domestic sewage system (planned, ready to invest)?
6. Your opinion on municipal support for wastewater management:
   6.1 No opinion
   6.2 Need for more municipal support
   6.3 Municipal support is sufficient
7. Which wastewater management solution have you chosen?
   7.1 Centralized canalization
   7.2 Storage tank
   7.3 Septic tank
   7.4 Local WWT
   7.5 Other
8. How is the sewage removed and how is the sewage systems maintained at your property:
   8.1 Regularly on a contractual basis
   8.2 As required
   8.3 Own/different management

Surveys in each of the regions and responsiveness to the provision of data show a lack of information in different details in wastewater treatment and responsibility field.

Joint conclusion of the survey studies

The results highlight a successful targeting of the desired group, primarily those relying on systems such as storage tanks, septic tanks, leach fields, septic tanks with sand filters, or advanced treatments like activated sludge or biofilm treatment.

The Estonian survey emphasizes the high seasonality of tourism on the island, with the main period extending from April to October. Notably, a majority of tourism enterprises reported the installation of wastewater systems after 2001, and a significant portion (56%) practices emptying at least once every half-year, with the majority (67%) disposing of waste at regional sewage plants. The collected data can be used to contribute to long-term planning by providing insights into the island's needs and technological options.

Similarly, the Swedish survey focused on respondents in coastal areas, revealing a preference among summer residents for accessing municipal water and sewerage in the NURSECOAST-II study areas. The majority of respondents reported having a three-chamber septic tank (70.4%) and utilizing an infiltration bed as the final purification step (70.6%). Notably, 24.9% of respondents possess on-site sewage treatment plants built before 1980.

In conclusion, the findings from these studies underscore the intricate landscape of wastewater management practices in both regions, emphasizing the critical importance of comprehending and addressing local contexts. The amassed information proves invaluable for illuminating the distinctive requirements and technological inclinations in these areas, thus providing essential insights for guiding long-term planning endeavors aimed at achieving sustainable and efficient wastewater management. While both Estonia and Sweden rely on conventional treatment measures, such as septic tanks and infiltration beds, the identified need for solutions extends beyond larger systems to encompass on-site wastewater management. This highlights the need of ongoing research to develop innovative and sustainable solutions.

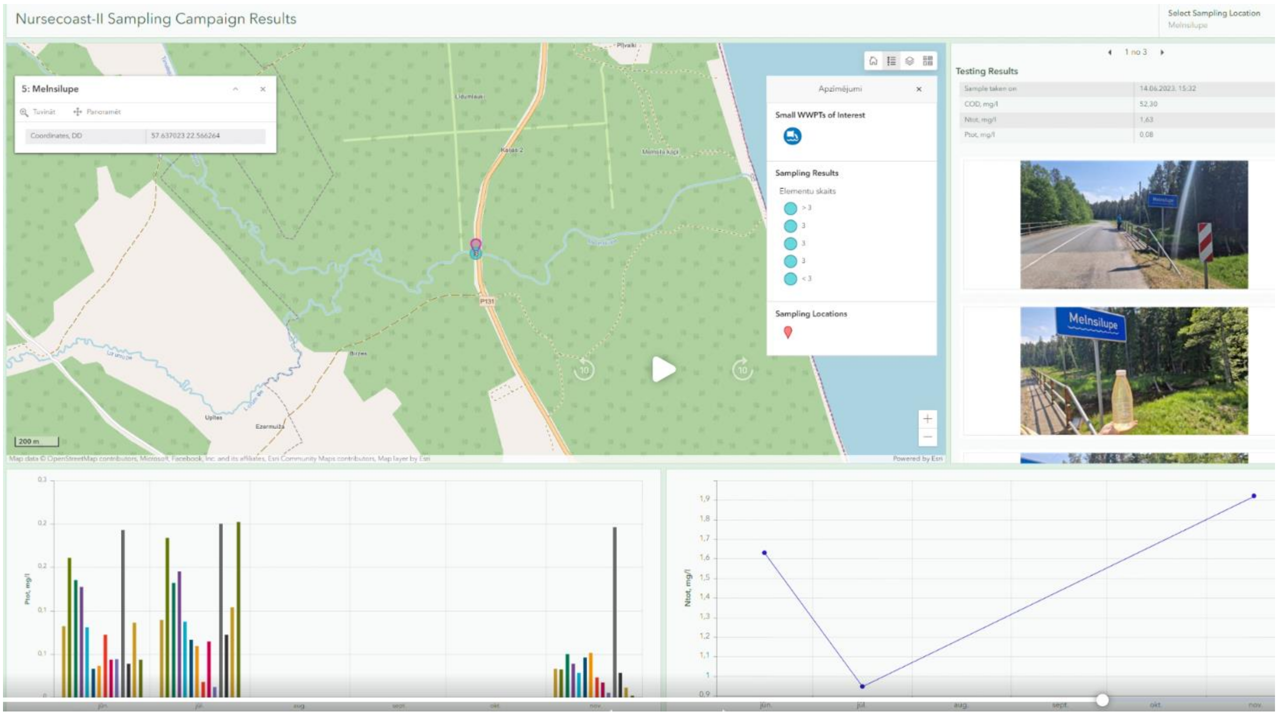

Figure 32. Screenshot of the platform

A geographic system platform has been created on Latvian research data (Figure 32). It is possible to map samples taken, insert photos from the object and develop comparable schedules. It is planned to supplement the results from other project member states to develop and extent the system in the next project periods.

6. Conclusions

Based on seasonality mapping and analyses the relevant conclusions are following:

- There is neither no treatment data available of WWTPs <2000 PE in all project's countries nor data about the number of small WWTPs.
- Due to the lack of data, it is not possible to estimate the real impact of small WWTPs on the environment. It is even more challenging to study seasonal changes in the efficiency of WWTPs, because of lack of monthly or quarterly data.
- Legislation varies in different project countries because EU legislation does not cover WWTPs <2000 PE. Treatment requirements vary country by country regarding WWTPs <2000 PE.
- There is no sufficient information about the environmental load of the small WWTPs -> small WWTS may contribute significantly to the nutrient load to the Baltic Sea, especially locally.
- The Council Directive of 21 May 1991 concerning urban wastewater treatment (91/271/EWG) regulates the rules regarding treatment of wastewater and monitoring of WWTPs above 2,000 PE. The introduction of the Directive was a step in the right direction, but it requires stricter regulations.
- The most beneficial solution from an environmental perspective would be to include all WWTPs. However, considering the costs of implementing those regulations, this approach that's spreads costs over time should be considered reasonable. The proposal has not yet been adopted.
- The rules for carrying out measurements and collecting data should be uniform in all European Union countries. It would also be beneficial to maintain a common database, which would significantly facilitate conducting scientific research. This database should be intended for both specialists and citizens to enable easy access to public information.
- The spatial, analytical and legal analysis of WWTPs across BSR countries uncovered many discrepancies in data accessibility and collection, spatial distribution of the WWTPs, effluent standards and technological solutions. This could be a good starting point for the local authorities to improve these aspects for the safer management of excess nutrients in the near-coast touristic regions.
- The criteria for technology selection depends on the legislation (requirements for treatment efficiency).
- Nanobubble technology may have great potential in the future either to increase the capacity of small WWTPs without a necessity to extend its size, or to improve the efficiency of the outdated plants that require modernization to meet the standards.

- Constructed wetlands are good nature-based solutions, and their utilization should be encouraged. It has been shown that by implementing aeration, the capacity of the wetland can be enhanced, which is particularly beneficial during the tourist season.
- Package plants are also good treatment facilities if they are well established and maintained. One challenge may be the viability of microorganisms during the low-flow season. However, methods exist to recirculate water and by doing that ensure substrate for the microorganisms during the whole year.
- In all wastewater treatment technologies, the most important thing is correct use and regular maintenance. Combining technologies can offer the best solution, and different methods of improving wastewater treatment should be utilized even more.
- There are solutions for nutrient recycling but many of them are still not cost effective. The treated wastewater has high nutrient levels and the quality is suitable for irrigation, whereby potassium, nitrogen and phosphorus can be reused. Public opinion and legislation may be a serious barrier to the reuse of nitrogen and phosphorus from wastewater.
- Based on the surveys, conventional treatment measures are being used, such as septic tanks and infiltration beds, and there is need for solutions extends beyond larger systems to encompass on-site wastewater management. This highlights the need of ongoing research to develop innovative and sustainable solutions.
- To tackle the seasonality, it requires sustainable solutions e.g. technology to safeguard sufficient treatment efficiency in a cost-efficient way, commitment and cooperation between actors (e.g. authorities, entrepreneurs, local people), education and awareness raising about sustainable water management is needed.
- Holistic approach (taking into consideration local context and different dimensions env, social, economic) is needed when selecting the most suitable solutions.
- The reduce, recycle, reuse, restore, recover (5R) approach should be highlighted to promote sustainable water management and the whole value chain approach should be integrated especially regarding the tourism sector.

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