LIFE Project Number

# LIFE16 ENV/IT/000345

# Final Technical Report

(extract from the Final Report)

## Covering the project activities from 01/07/2017[1] to 31/03/2021

Reporting Date[2]

## 30/06/2021

LIFE PROJECT NAME or Acronym

# LIFE DeNTreat

Project Data

| | |
|---|---|
| **Project location:** | Lombardia (Italy), Bruxelles (Belgium), Norte (Portugal) |
| **Project start date:** | 01/07/2017 |
| **Project end date:** | 30/06/2020 **Extension date:** 31/03/2021 |
| **Total budget:** | € 1'391'893.00 |
| **EU contribution:** | € 835'133,00 |
| **(%) of eligible costs:** | 60 |

Data Beneficiary



| | |
|---|---|
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[1] Project start date
[2] Include the reporting date as foreseen in part C2 of Annex II of the Grant Agreement

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**The deliverables mentioned in this report can be requested by sending an email to the addresses listed on the front page. The request must be suitably motivated and the purpose must be described.**

# 1. List of keywords and abbreviations

| | |
|---|---|
| ANAMMOX | ANaerobic AMMonium Oxidation |
| ATO | Ambito territoriale ottimale, it is a territory on which integrated public services are organized, for example wastewater or waste |
| BREF-BAT | Best Available Techniques Reference documents |
| C/N ratio | carbon-to-nitrogen ratio, is a ratio of the mass of carbon to the mass of nitrogen in a substance |
| C2M | Close to the Market team affiliated to EASME |
| CAS | Conventional Activated Sludge system |
| CITEVE | Centro tecnologico das industrias textil e do vestuario de Portugal (Associated Beneficiary) |
| COD | Chemical Oxygen Demand. It is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution |
| DTP | Digital Textile Printing |
| EASME | Executive Agency for SMEs - European Commission |
| EURATEX | European Apparel and Textile Confederation (Associated Beneficiary) |
| GHG | GreenHouse Gases |
| GWP | Global Warming Potential |
| HDK | Hardware Development Kit |
| IPCC | Intergovernmental Panel on Climate Change |
| LARIANA | Lariana Depur (Coordinating Beneficiary) |
| LCA | LifeCycle Assessment |
| N | Nitrogen |
| $NH_4$ | Ammonia |
| $NH_4^+$ | Ammonium ion |
| NLR | nitrogen loading rate |
| PAQUES | Nederland-based Leading company in biological wastewater and gas treatment. They own the patent for Anammox process |
| pH | logarithmic scale used to specify the acidity or basicity of an aqueous solution |
| PIDACS | Process Identification And Data Collection Sheet |
| PN | Partial Nitritation |
| POLIMI | Politecnico di Milano (Associated Beneficiary) |
| SCR | Stamperia di Cassina Rizzardi (Associated Beneficiary) |
| TKN | Total Kjeldahl Nitrogen. It is a method for the quantitative determination of nitrogen contained in organic substances plus the nitrogen contained in the inorganic compounds ammonia and ammonium ($NH_3$/$NH_4$+) |
| TSS | Total suspended solids (TSS) is the dry-weight of suspended particles, that are not dissolved, in a sample of water that can be trapped by a filter that is analysed using a filtration apparatus |
| WP | Workpackage |
| WWTP | WasteWater Treatment Plant |

## 2. Executive Summary

This report describes activities carried out and results achieved in the LIFE DeNTreat project execution.

As reported in the project proposal, LIFE DeNTreat aims at demonstrating an **on-site** wastewater treatment module meant to **sustainably abate** nitrogen pollutants from selected points of discharge to reduce nitrogen content of overall urban wastewater. This module, adopting the Anammox anaerobic microbial process, is expected to be used complementing traditional wastewater treatment plants (WWTP) to perform a local pre-treatment of N-rich wastewater streams from industrial sources before their conveying in the sewage.

Project goals remained unchanged with respect to what initially stated in the proposal.

A pre-industrial wastewater treatment Demonstration plant based on an Anammox bioreactor, demonstrated in a representative operational environment (Figure 1 in Stamperia di Cassina Rizzardi premises), and processing 40 $m^3$/day of wastewater is the central output of the project.

Figure 1: the LIFE DeNTreat demonstrator

General design data

- Design flow rate: 40 $m^3$/d
- Operating flow rate: 10-40 $m^3$/d
- Influent concentration: 130-260 mgNtot/l; avg±st. dev.: 176±44
- Target effluent concentration: < 50 mgNtot/l (5%-ile=100 mgN/l); < 0,6 mgN-$NO_2$/l.

In Figure 1 the on-site demonstrator that has been installed to perform the planned tests is shown.

According to initial plans, detailed studies and analyses to assess the environmental, social, economic and financial impacts and performances connected to the adoption of the DeNTreat technology have been also carried out enabling aware decision making from future adopters:

- for **environmental impacts assessment**, an LCA-based approach was adopted, with a clear definition of the functional unit (kg of removed Nitrogen) and of the boundaries of the analysis. The main data sources are the field tests carried out at the demonstrator, and field data gathered from existing plants treating both urban and textile wastewaters in the Como district. Two kinds of data were collected and analysed, resulting in a twofold (still consistent) output. In fact, both inventory and impact assessments are included in the analysis to combine a high-level comprehensive view on the impacts associated with the new technology (LCA impacts) with specific environmental measurements that are relevant for the implementation scenario focussing on given environmental aspects such as Nitrogen removal capability, GHG emissions, sludge produced. The latter focuses, overall, on the actual reduction of N-related contaminants in the wastewater collected by industrial collection systems, in the water leaving the WWTP, emitted in the air by the secondary wastewater treatment process; the reduced sludge production, disposal and transportation; also including the environmental benefits related to the reduced energy consumption;

- moving to **social and socio-(macro)economic impacts**, a study was performed dealing with socio-economic impacts assessment. It starts with an overview of Digital Textile Printing (DTP) spread and market, based on global reports and on specific data in the Como district (the most important in Italy as for the diffusion of DTP technology in the textile industry) and in Portugal. Water policy implications of the discharged wastewater originated by the DTP processes are considered and analysed in the framework of the European, Italian, and local regulation on wastewater discharges. Risks and opportunities that DTP poses in the local territory where DTP processes are so widely diffused have been also investigated. These data and thoughts are expected to be inspiring for future textile districts adopting the DeNTreat solutions. The impact of pandemics was also included in the analysis. Framework conditions were also explored considering the new wastewater tariff that was adopted in several industrial districts (including the Como textile district) to increase the costs paid by companies discharging wastewater with a high nitrogen contaminant content (and its impact on the DeNTreat technology widest adoption);
- a **market analysis** was carried out considering all relevant elements for the drafting of a business plan for a future company adopting and commercializing the DeNTreat technologies (a "NewCo" strongly participated by Lariana Depur). The NewCO has the business key to enter the market in the know-how developed during the project for the application of the anammox process to wastewater (mainly) from textile sources. The possible competitors were classified and investigated reaching the conclusion that no research or even commercial initiative is currently a possible solution to the target of LIFE DeNTreat (N-rich wastewater): neither those trying to remove urea from textile processing nor those processing wastewaters. Potential customers were carefully qualified and characterized with an initial focus on Italian textile districts. Identified companies have been divided into three groups according to the volumes of wastewater produced. The range below 50,000 cubic meters of annual production could become interesting after an initial learning/development phase on large plants. As emerged from the study, the crisis of 2007-2012 and the pandemics we are facing affected the financial profiles especially of small companies that fail in offering the financial sustainability to cope with the investments required by the proposed technology (they are often poorly profitable, weak in equity and with a low self-financing capacity).

The project activities have been fully completed and all planned deliverables were issued. The project formulated two extension requests: a first delay of 6 months was requested at the end of the year 2019 to allow the partners to absorb some delays incurred in the installation of the Demonstrator and its operations (due to difficulties in finding some components to be custom-made, and in problems in purchasing good quality anammox bacteria). A further three-months extension was subsequently requested to deal with shutdowns and delays caused by COVID-19.

# 3. Introduction

Environmental problem/issue addressed

Digital (or inkjet) textile printing (DTP) is gradually replacing traditional serigraph printing. Although its present market share is above 5% of the world textile printing business, inkjet printing is growing at a fast rate and, based on the last data registered (even if partially affected by the COVID pandemics), it covers about 75% of all printing factories in the textile district of Como and, in the medium-to-long term, it is also expected to spread all over the other European textile districts (thus increasing also the 5% share mentioned above to some 10%, according to estimations performed by textile experts).

DTP initially emerged as a prototyping tool and a vehicle for printing small batches of fabric for niche market products, but it rapidly evolved. In highly demanding markets (such as apparel, fashion, and haute-couture), requests for customization, short product lifecycles and reduced time-to-market have brought DTP to great diffusion in those contexts.

Apart from its extreme flexibility and scalability, DTP is also potentially interesting from an environmental point of view, as testified by various authors[3]. In fact, DTP allows to lower water, energy, and materials consumption with respect to traditional (screen/serigraph) printing: thermal energy usage reduced up to 80%, wastewater up to 60%, electricity consumption by 30%, abatement of wasted dyes.

This notwithstanding, as reported by many authors[4], for other aspects of the processing (in particular: preparation for print) DTP is extremely worse than traditional printing, thus reducing the environmental benefit for the textile printing phase and inhibiting its usage in larger lots of production. In fact, in addition to traditional preparation treatments, such as soda treatments, scouring, bleaching, drying, milling, etc., DTP requires other treatments because of the different physical characteristics of the inks used compared to traditional printing pastes. DTP systems use low-viscous inks to attain high jetting frequency from small nozzles. This implies that some ingredients of the printing pastes must be put over the fabric before printing. DTP is thus a `two-phases' printing as opposed to the `all-in' approach of conventional printing: in the latter case, all the dyes, chemicals and thickeners required are included in the printing paste, whereas in the former some ingredients are applied in a new (if compared to screen printing) pre-treatment process.

The pre-treatment process for DTP is usually carried out in continuous production lines with the following procedure:

- impregnation of fabrics with special compounds in aqueous solution, in full bath;
- mechanical drying through pressing cylinders (foulard), intended to regulate the amount of ink and to remove any excess product applied;
- thermal drying in oven or stenter.

With this application system, fabrics are totally immersed in aqueous solutions and, on average, undergo an increase in weight up to 70-100% (after the cylinders). This results in a large consumption of water, chemicals, and energy because the textiles must then be dried before being printed. Moreover, while in the screen-printing process, the printing compounds are applied just where the ink is needed, in DTP the whole fabric surface needs to be treated.

More significantly, form an environmental point of view, DTP and, more specifically, the fabric preparation step, produces effluents with high concentration of organic and ammoniacal nitrogen, which can hamper the capability of centralized wastewater treatment plants to cope with the respect of nitrogen limits in the final effluent to be discharge into the recipient water body.

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[3] See, for example, results obtained in the LIFE project "TIEPRINT" (LIFE 99 ENV/IT/000122) involving a Como-based printing mall

[4] Digital Printing of Textiles. Edited by: Ujiie, H. © 2006 Woodhead Publishing

Outline the hypothesis to be demonstrated / verified by the project

Aim of this project is to demonstrate the full-scale feasibility of applying autotrophic N removal processes (partial nitritation + Anammox) to treat wastewater from digital printing factories to respect discharge limits to public sewers.

Description of the technical / methodological solution

The process is carried out in a Demonstration plant with a treatment capacity of up to 40 $m^3$/d of ink-jet printing wastewater that implements a purely biological autotrophic nitrogen removal process installed in SCR (Stamperia Cassina Rizzardi) premises and supervised by LARIANA (Lariana Depur). Feasibility, efficiency, and efficacy of the process have been tested in the internal laboratories of LARIANA and in the Laboratory of Environmental Engineering at POLIMI (Politecnico di Milano), also including different textile effluents coming from CITEVE (the Portuguese partner), to check the replicability of the process on other wastewater typologies. Achieved results ensure replication of project outcome to other geographical areas and to other industrial sectors and the definition of a proper business strategy to be adopted to assure project exploitation after conclusion. An environmental analysis, based on an LCA-based approach, as well as social and economic impacts assessment have been carried out. Performance indicators were monitored and reported all along the project duration. The main indicators are focused on environment and include greenhouse gases emission, energy consumption and volumes of sludge produced.

Expected results and environmental benefits

The initial goals of the project remained unchanged with respect to what stated in the proposal. Results obtained using the lab-scale pilot (almost throughout the entire project) look constantly promising with a significant capability to reduce N load. The demonstrator pilot experienced a huge variance in results. Technical and methodological modifications implemented on the demonstrator during 2020 only partially resulted in a significant effect on plant performances stabilization. Initially expected removal rates higher than 50% have been registered only at a lab-scale (up to 70-75%), where initially expected environmental impacts (70% less energy consumption, up to 80% less sludge production and less $N_2O$ emissions if compared to conventional processes) are currently confirmed only at a lab scale, while the variability of performances experienced in the pilot undermined overall results robustness.

## *Expected longer term results*

Whether implemented in industrial contexts, the project results are expected to contribute to:

- accomplish Directive 91/271/EEC art.5 requirements asking to ensure that the minimum percentage of reduction of the overall load entering all urban WWTP in a given area is at least 75% for total nitrogen produced and the respect of residual nitrogen concentration in WWTP discharges, to be maintained below 10 mg/l;
- achieve a reduction of the GHG emissions during biological wastewater treatment for N removal to less than 67% of the currently adopted technologies;
- an abatement of the sludge produced as a result of the nitrogen abatement process to less than 25% of the currently adopted technologies;
- reduce the GHG emissions, though allowing the development of this industrial sector, which is beneficial to maintain European-based industry and know-how.

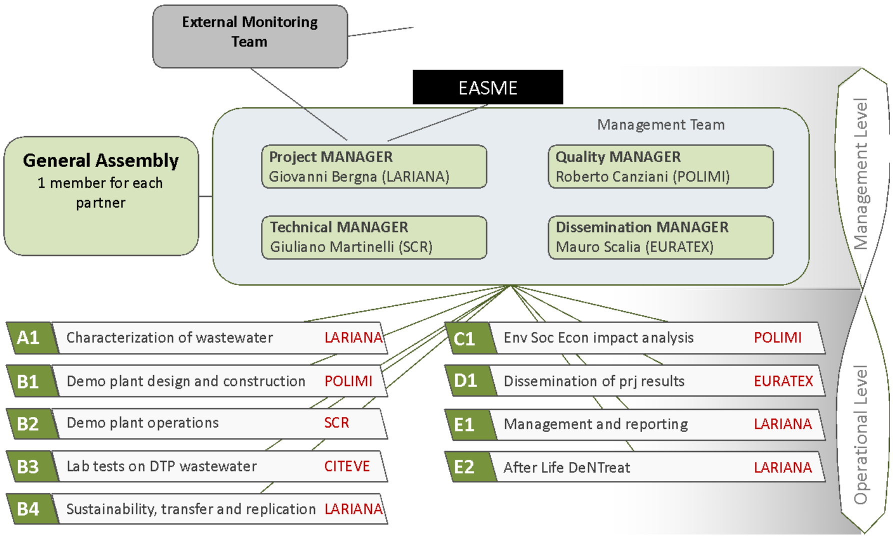
These goals will be achieved thanks to the dissemination effort and an effective After-LIFE exploitation plan.

# 4. Administrative part

Project management process, working methods, partners and problems

Figure 2 reports the overall governance structure partners agreed upon to drive the project. As depicted, an Operational level has been identified where all the workpackages of the project are reported and responsible partners properly identified in compliance with the initial proposal (no variations with respect to the initial plan need to be reported).

Figure 2: Life DeNTreat governance structure




The partner identified as responsible for a specific workpackage was also in charge of the coordination of the other partners involved in the subordinate tasks. Each workpackage leader reported at least monthly to the Management team about the technical advancement of its activities.

The Management team involved the Project Manager (PM, supported by an external administrative consultant), a Quality manager (responsible to validate all the project deliverables from a formal and scientific point of view), a Technical manager in charge of all the technical activities related to the demonstrator and a Dissemination manager. This team interacted at least once every 6 months to monitor project advancements and decide upon discrepancies with the initial plans. For major issues a General Assembly was appointed including one member for each partner.

Each partner has identified two contact points for the project in order to streamline dedicated communication. Technical updates were requested to the partners on a monthly basis for those involved in running tasks, both for internal review and for providing quick updates to the Monitor. On the other side, administrative updates were requested at least on a quarterly basis. They must be reported using the templates provided in a dedicated Google Drive shared folder. This folder is also used to share technical advancements of the projects, project deliverables and schedules. All the interactions within the consortium worked perfectly ok.

Communication with the EASME and Monitoring team, amendments

The Project Manager is the unique contact point between the project and the EASME. He or his delegate (the external consultant mentioned above) directly interacted with the Monitor (Dr. Giandrini) either providing updates on the project status or asking for clarifications on technical and administrative issues. Additional interactions started from the 2019 July's meeting and ended in September 2020 with the C2M team, a group of Business experts endorsed by EASME to support the project team in business-related activities. As mentioned, a first amendment to the Grant Agreement has been issued in December 2019 to ask for a 6-months project extension and a new one, forwarded in November 2020, asked for a further 3-months extension to face the side effects of the pandemics. Technical and financial plans remained unchanged.

# 5. Technical part

## 5.1. Technical progress, per Action

**Task:** **A.1.1 Analysis of the addressed wastewater producing processes**
Responsible: EURATEX
Other contributors: LARIANA, POLIMI, CITEVE
Foreseen start date: 1 July 2017 Actual start date: 1 July 2017
Foreseen end date: 31 October 2017 Actual end date: 14 February 2018

A detailed questionnaire has been developed by EURATEX, LARIANA, POLIMI and CITEVE intended to gather information from textile companies around Europe, with a special focus on ones using Digital Textile Printing.
EURATEX, as the official voice of the European clothing and textile industry, has an extensive network across the EU and is in an appropriate position to investigate the issue of nitrogen pollution among its Member companies, as a part of Task 1.1. Analysis of the addressed wastewater.
EURATEX used a questionnaire to collect feedback on the topic from potential end-users. 12 answers mostly from Italy were. As for the interviews, although the expected number of conducted interviews was 4, EURATEX managed to conduct 2 full interviews (Belgium and Italy) and a preliminary insight into the issue from its German Member.
Preliminary conclusions indicate that: i) urea pre-treatment used for digital printing is only applied on natural and cellulosic fabrics and ii) such practice is applied mostly in few European textile districts, like those researched. One of the explanations stated that synthetic fabrics, such as polyester are printed with a special printing technique called sublimation with no use of urea. Differences occur in digital printing on other fabrics; viscose requires a higher concentration of urea during pre-treatment to “attach” certain colours on the fabric. Regarding geographical differences, the region of Como in Italy may be subject to higher nitrogen release due to the nature of textile and clothing industry which is mostly focused on fashion hence uses more natural and cellulosic fabrics that require urea pre-treatment.
The task encountered certain limitations. Additional effort was put to receive more answers to the questionnaires and to conduct additional interviews. In October 2017, EURATEX introduced the project and invited its Members to collect feedback to the questionnaire during an internal meeting with its Members. In addition, the questionnaire was spread via EURATEX official communication channels. By the Monitoring meeting held over 7-8 March 2018, EURATEX managed to collect 8 completed questionnaires and conduct 3 interviews. Later, EURATEX updated the deliverable with additional 3 questionnaires from Italy and 1 from Portugal.
Finally, these limitations can be explained by several reasons, mainly: companies’ little or no concern on the specific issue, other priorities, reluctance towards surveys, lack of staff and time.

**Reference deliverable**: A1.1.1 Nitrogen pollution in textile districts - rev.00 14/02/2018
A1.1.1 Nitrogen pollution in textile districts - rev.01 07/03/2018
A1.1.1 Nitrogen pollution in textile district - rev.02 07/10/2018

**Task:** **A.1.2 Company audits for N-rich effluents characterization (for demonstration plant)**
Responsible: LARIANA
Other contributors: SCR, POLIMI
Foreseen start date: 1 August 2017 Actual start date: 1 August 2017
Foreseen end date: 31 December 2017 Actual end date: 28 February 2018

A.1.2 was meant to pursue two complementary objectives: acquire detailed pictures on Stamperia di Cassina Rizzardi (SCR) wastewater, flows, requirements in order to effectively support the project elaboration; develop a coherent classification of production processes with reference to the quality and quantity of the effluents produced in order to identify the potential application of the LIFE DeNTreat technology.

Data collection has been carried out through properly organized audits in SCR covering: printing textile production, fibres typologies and quantities, working periods, type and age of used equipment and environmental impacts (water and pollutants).
During the project, LARIANA has revised the "Process Identification And Data Collection Sheet" (PIDACS, included in the Deliverable A1.2.1) developed and validated within previous projects and used it to gather information from SCR premises and used it for gathering data with SCR collaboration. Recorded data range from general company data concerning the organization, utilities consumption, inbound and outbound flows (again concerning utilities but also production), etc. This information has been then used to create a "production model" of the investigated company. Each process belonging to the overall process picture has been also studied in detail and sample collection points identified.
The following step focused on wastewater samples collection: 10 sampling campaigns (for a total of 78 samples) have been carried out and mass balance established.
The collected samples have been then tested internally in LARIANA and by POLIMI, each carrying out specific analyses according to available technologies and competences. More specifically, LARIANA has completed all the tests intended for effluents characterization (reported in the deliverable A1.2.2) while POLIMI has carried out tests on ureolysis of urea-rich effluents (described in the deliverable A1.2.3). Tests for determining the biodegradable fraction of the organic substance in the wastewater and on the nitrification activity have been completed in January 2018 with a minor delay with respect to the plan included in the proposal.
In the period from May to June 2018, further sampling campaigns (118 samples) were carried out to optimize the SCR mass balance.

**Reference deliverables:** A1.2.1 Analytical protocol for wastewater collection and testing and Manual for audit execution in textile companies - rev.00 29/09/2017
A1.2.1 Analytical protocol for wastewater collection and testing and Manual for audit execution in textile companies - rev.01 27/10/2017
A1.2.2 Report on SCR wastewater characterisation - rev.00 28/02/2018
A1.2.2 Report on SCR wastewater characterisation - rev.01 01/08/2018
A1.2.3 Preliminary Ureolysis tests and biomass activity - rev.00 05/03/2018

**Task: A.1.3 Company audits for N-rich effluents characterization (for laboratory pilot plant)**

Responsible: CITEVE
Other contributors: POLIMI
Foreseen start date: 1 August 2017 Actual start date: 1 August 2017
Foreseen end date: 31 December 2017 Actual end date: 30 April 2018

This task was coordinated by CITEVE. The main goal was to collect valuable high-level data on Portuguese digital textile printing companies, in order to characterize the wastewater properties of the washing process of the digital textile printing materials and evaluate the potential of its treatment using Anammox technology. The conclusions obtained in this task were important for following project activities, namely Action B.3.
In order to fully characterize the digital textile printing companies regarding their wastewater characteristics, two Portuguese companies with DTP processes were selected by CITEVE to be audited:

- Company 1 – Satinskin, S.A.
- Company 2 – Estamparia Têxtil Adalberto Pinto da Silva, S.A.

Company 1 is 100% DTP and the Company 2 combines traditional and DTP processes, with high tradition and experience in the printing field.
In each company, an audit was carried out to identify the production process, the water and nitrogen flows, aiming to select the streams with interest for further analysis.
Besides the characterization of the wastewater streams of the selected companies, characterizations of wastewaters from traditional printing textile companies were also performed. This analysis has

allowed the comparison of results between different companies and the prediction of the evolution of wastewater characteristics in the textile.
Concerning all the analyses, as it was previewed in the project proposal, the physicochemical characterization of more than 30 streams has been performed.

The performed analysis showed that the final wastewater from Company 1, which only has DTP process, presents higher concentration of TKN and $N\text{-}NH_4$.
Regarding physicochemical parameters of the viscose process, the wastewater characteristics from the two companies are also quite different in the majority of parameters. This fact may be related to the different digital textile printing pre-treatment recipes used by each company and to the intensity of printing colour of the design that was being processed (it is known that lighter colours require less amount of urea than darker ones). However, these results confirm the potential of wastewaters from the viscose process for being treated with the Anammox technology, due to the high TKN content.

**Traditional textile printing companies' characterization**

In order to compare the characteristics of wastewaters from traditional textile printing companies with companies that also have DTP process, the final wastewaters of different companies were also characterized showing that a wider range of values was obtained for each parameter. This issue may be related to differences between the two studied companies, for instances, different raw materials, printing pastes recipes and printing processes.

**Conclusions**

Considering the information gathered during audit to Company 1 and Company 2, namely the results from wastewater characterisations, it is possible to conclude that wastewaters from DTP have a high nitrogen content. Considering Company 1 results, which only has DTP process, the high values of TKN concentration obtained indicate that wastewaters from this company seem very promising to be treated by Anammox technology and can give us an insight of how wastewaters will be in the future, due to the increase observed in DTP technology implementation.
The characterization of final wastewaters from different traditional textile companies has revealed that these wastewaters are quite variable. Although they present a buffer tank, it is well known that, depending on the material that is being processed, sometimes it is not possible to maintain constant wastewater characteristics. The wastewater treatment technology to be applied must be able to suit each company reality.
Considering the overall results obtained in this task, final wastewaters and wastewaters from the washing of viscose process (from both companies) were selected to be treated with the Anammox technology within task B.3.2 to give the partnership an idea of how this technology could react to these wastewaters. Although it was only possible to collect from Company 1, wastewaters from washing the cotton and terry processes also seem very promising to be treated with this technology.

**Reference deliverable:** A1.3.1 Report on digital textile printing companies characterisation - rev.00 30/04/2018 (internal report: not mentioned in the original Description of Activities)

**Task:** **A.1.4 Demonstration scenario definition**
Responsible: LARIANA
Other contributors: n/a
Foreseen start date: 1 August 2017 Actual start date: 1 August 2017
Foreseen end date: 31 December 2017 Actual end date: 28 February 2018

A1.4 was intended to define the demonstration scenario using data collected before project start-up and information directly audited in SCR during A1.2. The goal is to define different scenarios with a combination of different sets of discharge streams to be treated and typology of effluents. As to date, all the required data have been collected within task A.1.2 and the virtual model created. Simulations have been carried out to identify the best combination of inputs and outputs and a detailed area where to place the Demo identified accordingly.
The four scenarios calculation results are summarized in Figure 3.

| | Scenario 0 | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|
| Direct SCR discharge into the sewer | | | | | |
| Volume m³/y | 324.888 | 0 | 103.702 | 291.844 | 314.858 |
| COD kg/y | 335.327 | 0 | 73.010 | 271.239 | 301.679 |
| COD mg/l | 1.302 | 0 | 704 | 929 | 958 |
| **N kg/y** | **52.488** | **0** | **2.631** | **11.684** | **23.808** |
| **N mg/l** | **162** | **0** | **25** | **40** | **76** |
| N-NH4 kg/y | 1.506 | 0 | 237 | 1.045 | 1.335 |
| N-NH4 mg/l | 5 | 0 | 2 | 4 | 4 |
| | | | | | |
| SCR discharge to the on-site treatment | | | | | |
| Volume m³/y | 0 | 324.888 | 221.185 | 33.043 | 10.030 |
| Volume m³/d | 0 | 985 | 670 | 100 | 30 |
| **% on total SCR discharge volume** | **0** | **100,00** | **68.08** | **10,17** | **3,09** |
| COD kg/y | 0 | 335.327 | 262.317 | 64.087 | 33.647 |
| COD kg/d | 0 | 1016 | 795 | 194 | 102 |
| COD mg/l | 0 | 1.032 | 1.186 | 1.940 | 3.355 |
| % on total SCR discharge COD load | 0 | 100,00 | 78,23 | 19,11 | 10,03 |
| **N kg/y** | **0** | **52.488** | **49.856** | **40.804** | **28.680** |
| N kg/d | 0 | 159 | 151 | 124 | 87 |
| N mg/l | 0 | 157 | 190 | 637 | 852 |
| **% on total SCR discharge N load** | **0** | **100,00** | **94,99** | **77,74** | **54,64** |
| N-NH4 kg/y | 0 | 1.506 | 1.270 | 461 | 171 |
| N-NH4 kg/d | 0 | 5 | 4 | 1 | 1 |
| N-NH4 mg/l | 0 | 29 | 25 | 11 | 6 |
| % on total SCR discharge N-NH4 load | 0 | 100,00 | 84,29 | 30,62 | 11,37 |
| | | | | | |
| Final SCR discharge into the sewer | | | | | |
| Volume m³/y | 324.888 | 324.888 | 324.888 | 324.888 | 324.888 |
| COD kg/y | 335.327 | 184.430 | 217.284 | 306.487 | 320.185 |
| COD mg/l | 1.032 | 568 | 669 | 943 | 986 |
| **N kg/y** | **52.488** | **21.070** | **22.637** | **28.029** | **35.288** |
| **N mg/l** | **162** | **65** | **70** | **86** | **109** |
| N-NH4 kg/y | 1.506 | 7.948 | 7.779 | 7.189 | 5.646 |
| N-NH4 mg/l | 5 | 24 | 24 | 232 | 17 |

**Figure 3: Scenarios main results**

**<u>Reference deliverables</u>:** A1.4.1 Report on demonstration scenarios definition - rev.00 06/02/2018
A1.4.1 Report on demonstration scenarios definition - rev.01 02/08/2018

**Task: B.1.1 Preliminary design and plant layout**
<u>Responsible</u>: POLIMI
<u>Other contributors</u>: LARIANA, SCR
<u>Foreseen start date</u>: 1 August 2017 <u>Actual start date</u>: 1 August 2017
<u>Foreseen end date</u>: 30 November 2017 <u>Actual end date</u>: 15 December 2017

The preliminary project was completed with the support of an external engineering consultant, and validated by POLIMI, LARIANA and SCR. The related document is available for consultation in attachment. The design was carried out in compliance with the initial expectations and the finally delivered preliminary design was released with a minor delay of 2 weeks due to a more careful revision of the plant elements.

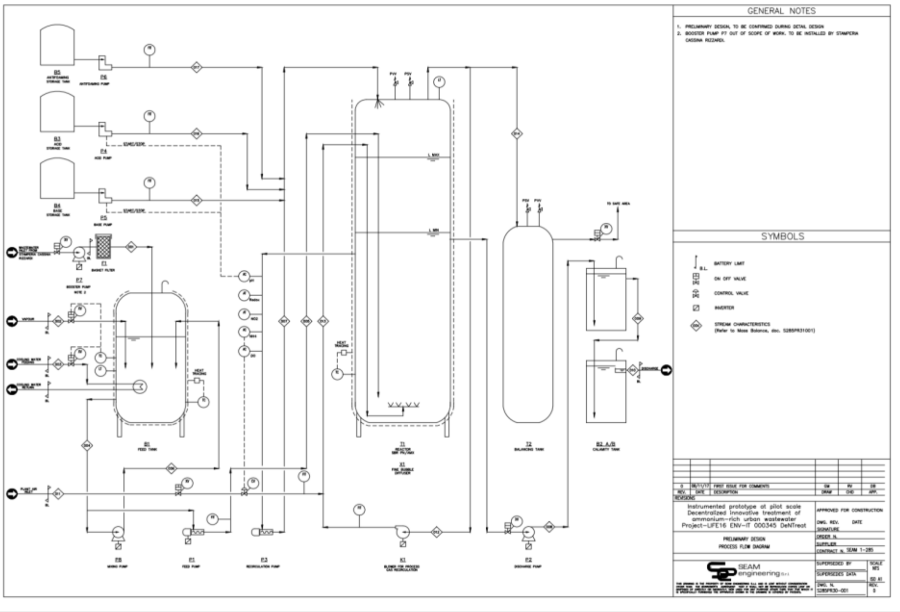



Figure 4: Preliminary overall design of the Demo plant extracted from B.1.1.1 deliverable

**<u>Reference deliverable</u>:** B1.1.1_00_Preliminary design and plant layout - First draft of the equipment datasheet - rev.00 01/12/2017

**Task:** **B.1.2 Final design**
<u>Responsible</u>: POLIMI
<u>Other contributors</u>: LARIANA, SCR
<u>Foreseen start date</u>: 1 November 2017 <u>Actual start date</u>: 15 November 2017
<u>Foreseen end date</u>: 31 January 2018 <u>Actual end date</u>: 15 March 2018

Basis of design and document list have been defined, as well as a 3D-rendering of the demonstration plant. The list of specification, the operation manual and the final tables (P&Is and building details) have been released (an extract in Figure 5) with 1 month of additional delay with respect to the schedule. This delay was due to some revision steps performed in order to assure the compliance of the designed equipment with the space available in SCR.

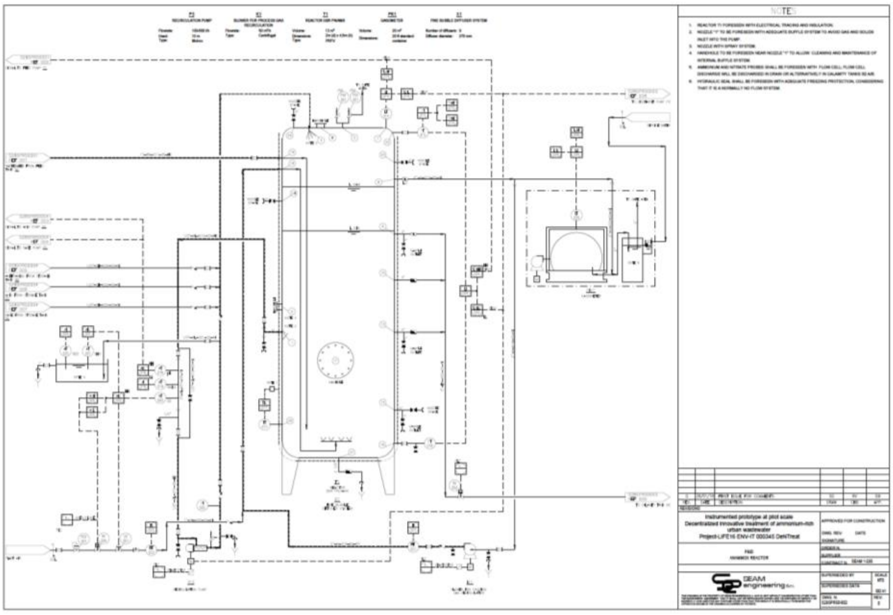


Figure 5: Final design of the Demo plant extracted from the B.1.2.1 deliverable (PeID Reactor)

**Reference deliverables:** B1.2.1 Final design of the demo plant - rev.00 01/03/2018
B1.2.2 Preliminary start-up manual and operative handbook for the demo plant - rev.00 01/03/2018

**Task:** **B.1.3 Demonstration plant construction**
Responsible: LARIANA
Other contributors: POLIMI
Foreseen start date: 1 January 2018 Actual start date: 26 March 2018
Foreseen end date: 31 March 2018 Actual end date: 31 August 2018

B1.3 objective was the construction of the Demonstration wastewater treatment plant according to the final design.
All the equipment, piping, auxiliary and security devices, monitoring instruments and automation software, electrical and mechanical assembling have been purchased and supplied according to the final design and to the (carefully assessed and compared) bids.
Some delays occurred on components provision. In particular, the tanks needed for the demonstrator were not commercially available in the sizes designed, thus we had to wait for 4 weeks for them to be manufactured. During August few hours were spent to complete the work during SCR summer holydays.
To avoid further delays, it was decided to assembly and install the plant directly on SCR premises. Further changes to the layout of the system were necessary depending on the size of the components.
Further changes to the layout of the system were necessary depending on the size of the components.
In the following Figure 6 the plant lay out is reported as built.

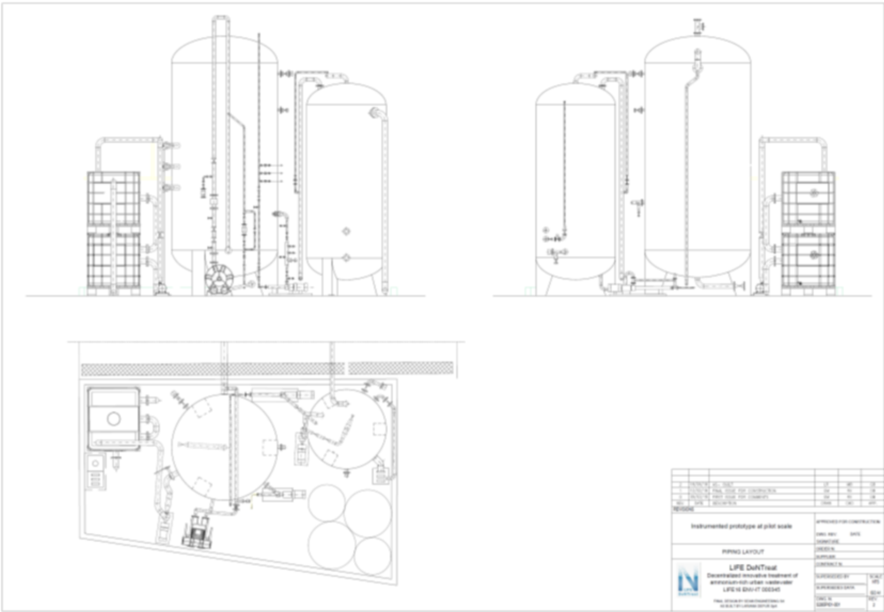


Figure 6: Demo plant lay out (as built)

For the control of the demo plant, a remote-controllable software has been developed that allows to remotely check the current status of the system and to set the parameters.
An Operation and maintenance Manual has been delivered together with the pilot.
**Reference deliverable:** B1.3.2 Start-up manual and operative handbook - rev.00 14/09/2018

**Task:** **B.2.1 Demonstration plant installation and start-up at SCR**
Responsible: SCR
Other contributors: LARIANA
Foreseen start date: 1 March 2018 Actual start date: 26 March 2018
Foreseen end date: 30 April 2018 Actual end date: 14 September 2018

To achieve the objective of the action, the feasibility of installing the system at SCR was verified in accordance with the scenario identified as optimal.
The foundation pit, the electric power, compressed air and wastewater lines have been set up to connect the demo plant to existing SCR processes and to allow demo plant operation. As reported in action B.1.3, the demo plant was built and installed directly on SCR premises. This work concluded at the end of July 2018 while the start-up tests were performed during August and the first two weeks of September.

Figure 7: Start of construction (26 March 2018)

Figure 8: Demo plant completed in SCR premises (end of July 2018)

Operative simulations to check the functionality of the plant parts were carried out, including simulation of machines dysfunction and alarm signals. The overall plant functionality was tested verifying the integration of all the parts.

**Task: B.2.2 Operation of the demonstration plant at SCR**

Responsible: SCR
Other contributors: LARIANA, POLIMI
Foreseen start date: 1 April 2018 Actual start date: 15 September 2018
Foreseen end date: 31 March 2021 Actual end date: 31 March 2021

The Demo plant has been kept running until the end of the project (and it is running also after the project conclusion). 3 major modifications have been implemented since its initial installation: the steam heating line of the feeding tank has been changed adding a pressure reducer and a steam mixer; a demister has been added to the gas recirculation line to de-humidify the recirculated gas; a filter has been installed before the secondary line used to measure ammonium and nitrate in order to avoid biomass loss.
The start-up manual and operative handbook (B2.1.1) was delivered in two versions during the Task. The first tests on the demonstrator have been carried out in September 2018, being "blank" tests to verify the hydraulic parts and automation. In October 2018 further tests have been carried out using wastewater directly taken from SCR production line. Some problems arose related to the steam inlet and the breaking of the blower. After solving these problems, in November and in December 2018 the reactor started working with bacteria delivered in August.
In January 2019 the bacteria tank was emptied and filled up with new bacteria just delivered. Some problems arose, including a loss of biomass, that floated instead of settling. After these "anomalous" granules have been lost, the problem became less and less intense and, as of end of February, the reactor was operating with bacteria treating 4 to 8 $m^3$ of wastewater per day.
Focussing on the first results obtained, almost all the indicators moved as expected:

- TKN IN: 188 mg/l
- TKN OUT: 39.7 mg/l
- TKN: = - 78,9%; Total Nitrogen (including effluent nitrite and nitrate): - 55.7%

Only total phosphorus increased unexpectedly from 2.0 to 8.2 mg/l. One possible explanation is a problem with the analysis kit. Additional analyses were performed in order to understand if there's a problem with the analysis kit or something else. Moreover, Nitrate should decrease to lower concentration values. By the way, these values are typical of the start-up transient period, and it is better to wait until stabilized operating conditions have been established before drawing definitive conclusions.

From March to the middle of April 2019 the plant worked to increase the biomass and to increase the load treated obtaining the following results:

- TKN IN: 174 mg/l
- TKN OUT: 59 mg/l
- Total Nitrogen: - 54%

The concentration of nitrites and nitrates always remained below 5 $mgNNO_3/l$ and 20 $mgNNO_2/l$, with the exception of two nitrite peaks equal to 55 mg/l and 49.7 mg/l. The phosphorus remained under control with an average input of 2.08 mg/l and an average output of 2.19 mg/l.
On 12 April an electrical fault occurred at the probes signal converter which caused an excessive dosage of soda, causing an increase in pH and inhibition of biomass. Following the observation of a bacterial long-suffering, after a few days from the event, a new supply of biomass was requested to the supplying company (PAQUES).

In the meantime, the bacterial mass inside the reactors has been revived and re-acclimated, reducing the loading capacity from 8 to 4 $m^3$ per day and with a slow recovery the results obtained in this period are:

- TKN IN: 195 mg/l
- TKN OUT: 89 mg/l
- Total Nitrogen: - 35%

In July 2019 the new biomass was loaded into the reactor and some good results were registered on the pilot plant with -23% of N charge. The lab-scale pilot also gave good results with about 50% of N content reduction providing evidence on the good quality of the latest purchase of Anammox granules.
During August all activities stopped, and some problems arose at the beginning of September. After few weeks the granules re-started to perform as before summer both in the pilot and in the lab-scale. Something changed in October 2019: a rapid downgrade of performances occurred both on the

Demonstrator and on the lab-scale pilot. Both the plants were processing (almost) the same input wastewater coming from SCR. Even the addition of fresh biomass (9th October) didn't improve the efficiency of the PN/Anammox process.
From September to 9 October the results were:

- TKN IN: 217 mg/l
- TKN OUT: 110 mg/l
- Total Nitrogen: -21%

The nitrates were high (an average of 50 mg/l).
Possible explanations were investigated addressing wrong ranges of the set points for pH and DO and additives in colouring dyes used by SCR. A set of meetings were carried out involving Lariana, POLIMI, SCR and Centro Tessile di Como (a textile lab working with the local textile companies and with a huge expertise in textile product analyses). The goal was to explore all the possible hypotheses justifying the poor behaviour of the biomass and to plan countermeasures.

In January 2020 the reactor was emptied, and new biomass was loaded. As usual, during the first few days the biomass released phosphorus but after that the values return to the usual levels. This biomass didn't give satisfactory results:

- TKN IN: 155 mg/l
- TKN OUT: 49 mg/l
- Total Nitrogen: -18%

Initially the nitrates were very high, an average of 74 mg/l, with a low concentration of nitrites (1 mg/l), then we managed to lower the concentration of nitrates, but the nitrite concentration increased (~ 65 mg/l). This probably due to the high set of OD (1.5-2 mg/l) which caused an high growth of the AOB layer outside the granule. This overgrowth caused part of the biomass to detach from the granule and remain in the bulk as flake. This biomass reduced the spread of ammonia within the granule, where anammox are concentrated, resulting in an accumulation of nitrites.

In March 2020 the reactor was emptied, and the new biomass was loaded. Initially the nitrates immediately increased but lowering the OD setting and lowering the sedimentation times the values dropped

- TKN IN: 169 mg/l
- TKN OUT: 68 mg/l
- Total Nitrogen: -34%

From the end of March to the half of April 2020 we had COVID issues, so the reactor was managed remotely. During this period the biomass suffered, and its concentration decreased, so we decided to buy a new biomass tank to add. Despite the new load, removal rates remained low:

- TKN IN: 146 mg/l
- TKN OUT: 105 mg/l
- Total Nitrogen: -13%

After the lockdown, SCR resumed its activity at a very slow pace, which led to an alternation of periods without significant ammonia loads but with high COD values which in turn caused biomass suffering.
During August all activities stopped.

In September 2020 a new supply of biomass was loaded in the Demonstrator, and it was restarted adopting the novel protocol developed in the last months together with the external consultant. For the start-up it was chosen to have a low concentration of biomass, equal to about 4 grams per liter: half of that foreseen for full operation. This is in order to allow a starting condition without limitations of nitrogen load and concentration, and for a growth of the biomass already acclimatized to the feeding conditions.

From the end of September to the end of October 2020 the plant had the following results:

- TKN IN: 188 mg/l

● TKN OUT: 99 mg/l
● Total Nitrogen: - 38%

The concentration of nitrites and nitrates had an average of 1,3 $mgNNO_3/l$ and 9,8 $mgNNO_2/l$. The Nitrogen Removal Rate (NRR) detected in the period is about 0,18 kgN m-3 d-1. Considering that in the fully operational plant the biomass present will have a concentration about twice the current one, a NRR of 0.36 kgN m-3 d-1 is assumed.
This removal rate is more than half of that assumed for the design (0.6 kgN m-3 d-1).

From the end of October to until mid-December 2020 the plant registered the following results:

● TKN IN: 198 mg/l
● TKN OUT: 125 mg/l
● Total Nitrogen: - 21%

This decrease is probably due to an initial increase in the flow rate that was subsequently reduced, but the removal rate did not increase. In this period, the concentration of nitrates and nitrites had an average of 0.98 $mgNNO_3/l$ and 20.8 $mgNNO_2/l$ and the Nitrogen Removal Rate (NRR) detected in the period is about 0.13 kgN m-3 d-1.
On 12 November a sample of process gas was taken to analyze the amount of $N_2O$.

From mid-December 2020 to January 2021 the plant registered the following results:

● TKN IN: 182 mg/l
● TKN OUT: 93 mg/l
● Total Nitrogen: - 33%

The concentration of nitrates and nitrites had an average of 0.74 $mgNNO_3/l$ and 25.8 $mgNNO_2/l$ and the Nitrogen Removal Rate (NRR) detected in the period is about 0.10 kgN m-3 d-1. It seems that total nitrogen removal efficiency has increased but the NRR is decreased. From December 24 to January 6 there was the company closure for Christmas holidays. On December 29 for the buffering of the pH we replaced the sodium carbonate with caustic soda to give an extra contribution of carbonates to the biomass. On 4 January the carbonate line clogged causing an important lowering of the pH; the line was cleaned when the company reopened.

On January 9, 2021, about half of the biomass was lost due to PLC problems that caused an inappropriate opening of the drain valve. This caused a decrease of the performances:

● TKN IN: 192 mg/l
● TKN OUT: 190 mg/l
● Total Nitrogen: - 2.4%

The concentration of nitrates and nitrites has an average of 0.50 $mgNNO_3/l$ and 10.6 $mgNNO_2/l$. On 14 January the dosage of the iron solution without EDTA began.

From the middle to the end of January the plant had the following results:

● TKN IN: 148 mg/l
● TKN OUT: 122 mg/l
● Total Nitrogen: - 8.2%

The concentration of nitrates and nitrites had an average of 0.51 $mgNNO_3/l$ and 12.5 $mgNNO_2/l$. On 16 January the pressure gauges PT015 of the reactor was dirty causing a stop of the discharge cycles. At the same time, the carbonate line was clogged again. Both issues contributed to a lowering of the pH to 6.4. On 18 January the sodium carbonate was replaced with caustic soda.

On February 2 2021, 400 litres of fresh biomass were loaded into the rector to increase the Anammox activity.
From February to until mid-March 2021 the plant has the following results:

● TKN IN: 150 mg/l
● TKN OUT: 101 mg/l
● Total Nitrogen: - 15%

The concentration of nitrates and nitrites had an average of 3.42 $mgNNO_3/l$ and 13 $mgNNO_2/l$. The oxygen set was varied to maintain a certain nitrite accumulation and to achieve an ammonia removal target. On February 25 the temperature ranges were changed in order to keep 28-33°C in the reactor.

In March we started with the inorganic carbon dosage in order to try to increase the autotrophic activity. The dosage is 25 kg/d, about 70 mg/l of carbon. In this period the plant has the following results:

- TKN IN: 124 mg/l
- TKN OUT: 73 mg/l
- Total Nitrogen: - 14.3%

On March 24 another 580 litres of fresh biomass stored in the warehouse were loaded and from March 25 control of the oxygen dosage based on ammonia values has begun thanks to the activation of a dedicated logic.

**Conclusions**

On the basis of the data of the entire experimental period, the process is feasible but with some precautions and attention to the plant engineering and the balance of the biomasses involved. The problems encountered as they were resolved are explained in detail in the report on plant operation. The performances achieved in the period are of the order of 200 mgNtot/gVSS/d with a total nitrogen input load on average equal to 108 mgN/gVSS/d, with peaks of 400 mgN/gVSS/d, trends visible in Figure 9. Higher yields can potentially be achieved with the right plant engineering and management precautions. At the plant level it is necessary to keep the biomass in the reactor, keep the granular shape intact avoiding shear stresses and equalize the wastewater both from the point of view of the polluting load and view of the chemical-physical conditions, avoiding as much as possible high variations in temperature and pH. It is important to have real-time data of the most important parameters such as dissolved oxygen, pH, RedOx, ammonia nitrogen, nitric nitrogen and nitrous nitrogen, keeping the probes efficient and clean in order to allow optimal and instant automatic control of the variations that occur inside the reactor. Initially it's important to acclimate the biomass with a equalized wastewater to create a stable balance between the biomasses and allow the formation of a sufficient layer of AOB biomass around the grain that produces the nitrites necessary for the Anammox activity and protects the inner layers from the penetration of dissolved oxygen, inhibiting the Anammox component. It is necessary to keep the NOB biomass under control to avoid a competitive consumption of nitrites and the accumulation of nitrates, compromising the total nitrogen removal yield. Further attention is to be paid to possibly inhibiting substances that can be used in the company's production process and that can compromise the activity, growth and balance between biomasses. For the future it would be important to focus on the search for inhibiting substances used in the company's production cycle.

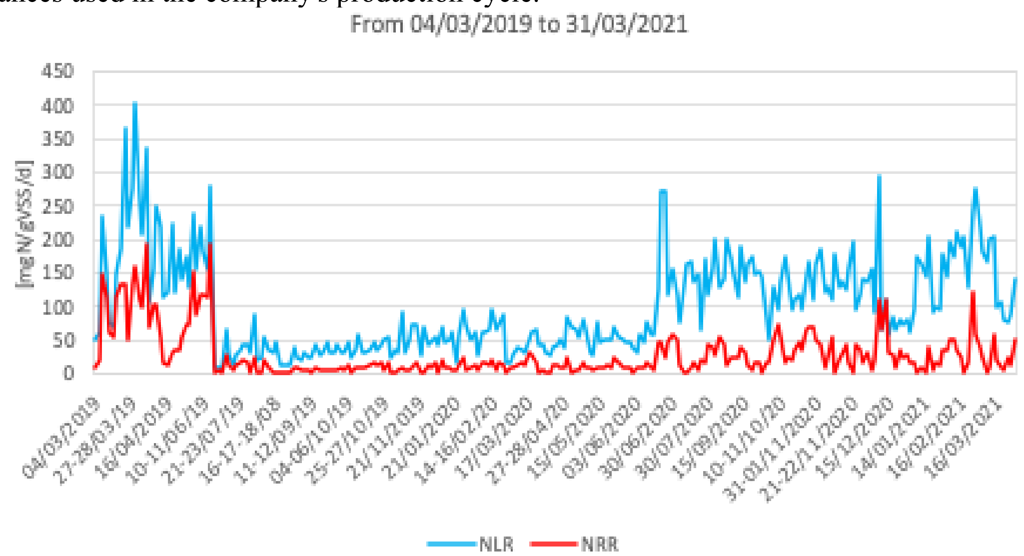



Figure 9: Trends of nitrogen loading rate and nitrogen removal rate of the experimentation period

**Reference deliverables**: B2.2.1 Report on plant operation at SCR – first release - rev.00 31/05/2019
B2.2.2 Report on plant operation at SCR – second release - rev.00 30/03/2020
B2.2.3 Report on plant operation at SCR – third release - rev.00 31/03/2021
B2.2.4 Final report on plant operation - rev.00 31/03/2021

**Task:** **B.2.3 Monitoring, data processing and simulation for tuning process control procedures through dedicated software**
Responsible: POLIMI
Other contributors: n/a
Foreseen start date: 1 May 2018 Actual start date: 15 September 2018
Foreseen end date: 28 February 2021 Actual end date: 28 February 2021

The task was carried out by POLIMI and aimed at monitoring, analyse and perform simulations in order to tune the process control procedures through dedicated software.
The deliverable was issued in two versions: one at the end of April 2019 and one at the end of the task. The most relevant findings are mentioned below.
*Simulation*
Simulation software: BioWin. A complex model has been designed and implemented with the goal to mimic the behaviour of the real plant. This modelling activity gathered data from literature, from preliminary lab-scale investigations performed before LIFE DeNTreat and from real data collected on the demonstrator. Main evidence from model execution is as follows:

- kinetic parameters didn't need modifications as compared to previous modelling work on demonstration pilot;
- influent characterization is crucial for a good model since the quality of the wastewater has a really strong influence on both the real plant and on it "digital twin". BioWin is not intended to simulate the behaviour of the model varying the mixture of "pollutants" (and other ingredients) included in the wastewater, thus real data can be gathered and used in order to understand which simulated parameters (e.g.: temperature, COD, BOD, …) are affected by the effects of those additional contaminants;
- $N_2O$ emissions are like those produced by conventional biological nitrogen removal processes (about 2% of the nitrogen load). The low dissolved oxygen concentration (< 0.5 mg/L) may cause the formation of this gas by ammonium oxidising bacteria, as confirmed in the most recent scientific literature (e.g.: Vasilaki et al., 2019)[5]. However, higher dissolved oxygen concentration may favour nitrite oxidising bacteria and cause a lower anammox activity, which would upset the whole nitrogen removal process.

The developed model can predict reliably the process behaviour in almost stabilized and robust situations. Final fine tuning focused on the evaluation of process conditions and operational parameters on $N_2O$ emissions.
The simulation work also allowed to detail a set of recommendations for scale-up design:

- the Equalization tank must be big enough to ensure constant feed and avoid discontinuities, though managing the trade-off between size of the reactor; industrial effluent variations; size of the equalization tank (and occupied area). We can select either a separate feed and discharge OR a constant volume displacement feed;
- concerning Aeration, direct feeding ambient air in the headspace is recommended; moreover, finding the right "size" of oxygen bubbles could strongly improve the plant performances favouring gas recirculation and mixing;
- sensors must be placed directly in the bulk from top of the reactor also including an O2 sensor in the headspace to perform a mass balance of oxygen.

[5] Vasilaki V., Massara T.M., Stanchev P., Fatone F., Katsou E. (2019) A decade of nitrous oxide ($N_2O$) monitoring in full-scale wastewater treatment processes: A critical review. Water Research 161, 392-412, doi: 10.1016/j.watres.2019.04.022.

Considering both wastewater volumes and N overall content of wastewater coming from textile companies in the Como district, 2 module sizes were identified: 125 and 15 m$^3$. Combining one or more of these two modules, all the identified potential adopters reach the required treatment capacity. High-level design (i.e.: design criteria, methodology, recommendations) have been delivered by POLIMI at the end of June 2020 considering all the above suggestions and elements.

**Reference deliverables:** B2.3.1 Simulation model of the biological process - rev.00 30/04/2019
B2.3.1 Simulation model of the biological process - rev.01 30/03/2021
B2.3.2 Scale-up designs - rev.00 30/04/2020
B2.3.2 Scale-up designs - rev.01 30/03/2021

**Task: B.3.1 Laboratory tests of biological activity**
Responsible: CITEVE
Other contributors: POLIMI
Foreseen start date: 1 January 2018 Actual start date: 1 March 2018
Foreseen end date: 31 March 2018 Actual end date: 31 March 2019

This task aimed to present the main results obtained in laboratory tests on DTP Company wastewater from Portugal, assessed to provide valuable inputs to future exploitation of the DeNTreat project outputs in heterogeneous manufacturing contexts.
The sub-action B 3.1 had the goal to further evaluate Anammox effectiveness by varying wastewater characteristics and the main goal of sub-action consists in the recommendations for future adoption of the DeNTreat technology. Considering the results obtained in task A.1.3, CITEVE selected two manufactures with N-rich wastewater and performed the physicochemical characterization of different sampling selected streams. The biological activity tests have been performed by POLIMI.
Companies selected by CITEVE were the same as those audited in A.1.3: Company 1 – Satinskin S.A.; Company 2 – Estamparia Têxtil Adalberto Pinto da Silva, S.A.
Wastewaters selected for characterization and biological activity tests were the following:

- Final wastewaters from Company 1 and Company 2;
- Wastewaters from washing the viscose process from Company 1 and Company 2;
- Wastewaters from washing the cotton process from Company 1 and Company 2;
- Wastewaters from washing the terry towel cotton process from Company 1;

For physicochemical characterization, the following parameters were determined: pH, conductivity, COD, TKN, NH4-N and SST. This characterization was performed for more than 10 different wastewater streams. For biological activity tests, POLIMI fine-tuned the testing procedure and evaluated the functionality of the lab-scale plant. The results from physicochemical characterizations of the selected wastewaters are presented in Table 1.

| Physicochemical parameters | Company 1 | | | | Company 2 | | |
|---|---|---|---|---|---|---|---|
| | Final wastewater | Viscose process | Cotton process | Terry towel (cotton) process | Final wastewater | Viscose process | Cotton process |
| pH | 10.2±0.3 | 10.0±0.1 | 10,0 | 9,9 | 11.0 | 9.8 | 9.5 |
| Conductivity (µS/cm) | 1112±309 | 451±93 | 338 | 1730 | 1900 | 412 | 816 |
| COD (mg/l) | 1215±361 | 625±233 | 620 | 2350 | 1070 | 440 | 252 |
| TSS (mg/l) | 12±4 | 11 | <5 | 9 | 170 | 6 | 20 |
| TKN (mg/l N) | 743±392 | 369±91 | 311 | 2680 | 65 | 271 | 271 |
| N-$NH_4$ (mg/l N) | <6.0* | <6.0* | <6.0* | 43.3 | 68.0 | <6.0* | 26.6 |
| N-$NH_4$/TKN | - | - | - | 0.016 | 1.0 | - | 0.1 |
| COD/TKN | 1.8±0.4 | 1.7±0.2 | 2 | 0.9 | 16.5 | 1.6 | 0.9 |

* Quantification limit

**Table 1. Physicochemical characterization of the selected wastewater streams**

Although wastewater characteristics are quite variable, in general, the results presented in Table 1 are in accordance with those obtained in A.1.3. The selected effluents present high TKN concentrations, confirming their suitability to be treated using the Anammox technology. From all selected effluents, the one which presents higher TKN concentration is the terry towel cotton

process. However, this is the one with lower representativeness in the printing process (particular case).
The results of COD/TKN ratio also evidence the potential of these wastewaters for being treated with this technology.
As it is possible to see in Table 1, COD/TKN ratios obtained are low (16.5 mg $O_2$/mg TKN for the final wastewater of Company 2 and approximately 1 mg $O_2$/mg TKN the other wastewaters). According to the literature, low COD/TKN ratios result in better treatment performances of high-strength nitrogenous wastewaters. Although COD/TKN ratio obtained for final wastewater in Company 2 was slightly higher (probably due to the conventional printing processes also performed in this company), it is thought that this wastewater can also be effectively treated using the Anammox technology.
Physicochemical characterization of the selected wastewater streams (from both Portuguese companies) has confirmed the high TKN content of these wastewaters, indicating their potential for being treated using the Anammox technology.
Results are included in B3.2.1 deliverables.

**Task:** **B.3.2 Laboratory pilot plant tests**
Responsible: POLIMI
Other contributors: CITEVE
Foreseen start date: 1 April 2018 Actual start date: 1 March 2019
Foreseen end date: 30 September 2018 Actual end date: 30 October 2019

CITEVE performed all the activities of sampling and chemical characterisation of the samples in parallel to B3.1 and as described in B3.1. The laboratory pilot plant tests were carried out on POLIMI premises starting from the beginning of September 2018. Main conclusions from this task are as follows:

- Sample from Company1 was successfully treated with more than 64% N-removal efficiency if diluted 1:1 and only 27.5% if treated with 6-h cycles
- Undiluted sample wastewater from Company2 was successfully treated, with a N-removal efficiency of 60-70% (respectively for 6-h cycles and 8-h cycles)
- Both the Company1 and Company2 effluents can be successfully treated with the PN/Anammox process in a gas-lift SBR reactor
- A 7 or 8-h cycle duration should be required to allow the conversion of organic nitrogen to ammonium, which looks like the kinetically limiting step of the process, not to limit the activity of NOB and exploit the anammox activity at its best.

This work-package has had a big delay compared with the initial schedule. Since it is not on the Critical Path of the project, it did not affect the overall duration of the project.
**Reference deliverables:** B3.2.1 Report on wastewater candidates for DeNTreat adoption - rev.00 24/07/2019 (internal deliverable)
B3.2.1 Report on wastewater candidates for DeNTreat adoption - rev.01 15/10/2019 (internal deliverable)

**Task:** **B.4.1 Transferability and replication of project results**
Responsible: LARIANA
Other contributors: EURATEX, CITEVE, SCR
Foreseen start date: 1 July 2019 Actual start date: 1 July 2019
Foreseen end date: 31 March 2021 Actual end date: 31 March 2021

This action was meant to ensure replication of project results to other geographical areas and to other industrial sectors.
Activities carried out are summarized in the following list (with reference to commitments):

- identified potential targets are textile or water technological institutes or centres; industrial association; public bodies; WWT companies; engineering or construction companies in the wastewater sector. Partners established promising contacts with selected counterparts both in Italy and in Portugal as mentioned in the relevant deliverable;

- a market analysis was carried out identifying how many companies could be interested in the technology (size, discharge volumes, N concentration, location, ...); elements that can influence the choice (increase in concentrations, discharge limits, costs), and recommended financial status;
- competitors were explored. It turned out that no direct competitors are emerging in the market for the DeNTreat technology, while some initiatives are experimenting urea substitute chemicals to prevent nitrogen production. This notwithstanding, none of these initiatives has any commercial relevance;
- dissemination material was produced to facilitate project results communication (please refer to D activities);
- demo days addressing textile and non-textile actors were organized in SCR involving Confindustria (industrial association) and Comodepur (WWTP management company);
- the "Replicability and transferability plan" document was issued;
- a final "Close to market" roadmap has been edited by LARIANA and shared with the C2M consultants endorsed by EASME;
- within the Textile BREF Working Group, EURATEX mentioned DeNTreat as a "candidate" technology. Since evidence on its efficacy at industrial scale levels still lacks, it is not allowed to include DeNTreat as a BAT but only as an emerging technology.

**Reference deliverables:** B4.1.1 Report on Market Analysis - rev.00 06/03/2020 (internal deliverable)
B4.1.1 Report on Market Analysis - rev.00 16/07/2020 (internal deliverable)
B4.1.2 Replicability and Transferability plan - rev.00 31/03/2021
B4.1.3 DeNTreat technology description in accordance to the standard structure for describing BAT candidate techniques - rev.00 28/02/2021

**Task: B.4.2 Sustainability of project outcomes**
Responsible: LARIANA
Foreseen start date: 1 July 2019 Actual start date: 1 July 2019
Foreseen end date: 30 June 2020 Actual end date: 30 June 2020

This task aimed at defining the business strategy adopted to assure project outcome exploitation after project conclusion. Lariana was in charge of identifying and describing the needs and requirements of potential target markets, starting from other textile companies operating in the Como district, moving to textile companies around Europe (identified with the support of CITEVE and EURATEX) and exploring other sectors (Action B4.1 provided inputs for this goal).
LARIANA appointed an external consultant with expertise in Business Planning. A first version of the document was issued in February 2020 and the final version was positively reviewed by C2M team in September 2020.
**Reference deliverables:** B4.2.2 Business plan - rev.00 20/03/2020
B4.2.2 Business plan - rev.01 21/09/2020
C2M.00 Close to Market Roadmap - rev.00 30/09/2019
C2M.00 Close to Market Roadmap - rev.01 31/03/2021
C2M.01 Report on preliminary information for business plan - rev.00 31/07/2020

**Task: C1.1 Environmental impacts assessment**
Responsible: POLIMI
Other contributors: all but CITEVE
Foreseen start date: 1 December 2017 Actual start date: 1 December 2017
Foreseen end date: 28 February 2021 Actual end date: 28 February 2021

A literature search was carried out at the beginning of the task on the environmental impact assessment and on the comparison between traditional and Anammox-based solutions.
Real data to work on has been available after the Demonstrator started running to speed (in 2019).
Expected environmental benefits deriving from the adoption of the LIFE DeNTreat technology can be summarized as follows:

- sludge production: -25%
- energy savings: -14.8%
- external carbon consumption: -100% (about 70'000€ due to the avoided glycerol consumption for heterotrophic denitrification of nitrogen load discharged by SCR)

Concerning $N_2O$ emissions, a field measurement of $N_2O$ emissions has been performed both at "Alto Seveso" WWTP (Lariana) and in the Gas-lift SBR at SCR. Registered results:

- conventional WWTP average Emission Factor 0.55% (±0.21)
- lab-scale reactor average Emission Factor: 2.03% (±0.44)
- Despite the increase in nitrous oxide production during the wastewater treatment process, the overall impact can still be reduced in terms of chemical usage, energy requirements, and sludge disposal.

An updated version of the "Report on progress on performance indicators" was issued by POLIMI in June 2020. Data collected in the last months of the project were included in a final version of the deliverable including results of the gas $N_2O$ measures and the latest data from the demonstration and pilot plants.

**Reference deliverables:** please refer to C1.2 deliverables

**Task: C1.2 Socio-economic impacts assessment**
Responsible: POLIMI
Other contributors: all (also CITEVE contributing even if not included in the initial plan)
Foreseen start date: 1 December 2017 Actual start date: 1 December 2017
Foreseen end date: 30 November 2020 Actual end date:

As for the social-economic impacts assessment, POLIMI analysed data collected by project partners through direct questionnaires answered by selected stakeholders throughout project duration. Furthermore, meetings have been organized with Italian industrial associations supporting in the provision and quantification of the socio-economic impacts deriving from the DeNTreat initiative. Those interactions were assisted by LARIANA and involved ARERA (Regulatory Authority for Energy, Networks and Environment) and ATO (Ambito Territoriale Ottimale) of the county of Como with a focus on the recent approval of the new tariff formula for the treatment of industrial wastewater, which has been applied starting from 2019 to the customers of all the local treatment plants (including LARIANA's). The new pricing, in fact, includes a quota that considers the pollution from nitrogen derivatives, making the DeNTreat solution even more interesting for textile companies.
Considering other social impacts, indicators have been identified, and further data collected from literature and sector studies.
Latest data collected address:

- existing voluntary commitments of textile sector;
- socio-economic impacts for the Como Textile District, including risks, opportunities, consequences and output;
- perceived citizens and market needs, also considering new priorities stated by the COVID-19 pandemics.

**Reference deliverable:** C1.2.1 Report on LCA and socio-economic impact assessment – first release - rev.00 03/06/2019
C1.2.2 Report on LCA and socio-economic impact assessment – second (final) release - rev.00 31/03/2021

**Task:** **C1.3 Performance indicators monitoring and reporting**
Responsible: POLIMI
Other contributors: all but CITEVE
Foreseen start date: 1 December 2017 Actual start date: 1 December 2017
Foreseen end date: 31 March 2021 Actual end date: 31 March 2021

C1.3 was intended to monitor and measure the results achieved within the project with reference to indicators identified in the table on Performance Indicators submitted in attachment to the project proposal.
The first deliverable was issued in November 2018; the second release was released by end of June 2020 and the final version at the end of the project.

**Reference deliverables:** C1.3.1 Performance indicators monitoring and reporting - rev.00 28/11/2018
C1.3.2 Performance indicators monitoring and reporting – 2nd release - rev.00 31/12/2019
C1.3.3 Performance indicators monitoring and reporting – third (final) release - rev.00 31/03/2021
(deliverables include the internal report: Assessments on GHG emissions: state of the art - literature review)

**Task:** **D.1.1 Creation and maintenance of dissemination material and of the project website**
Responsible: LARIANA
Other contributors: all
Foreseen start date: 1 July 2017 Actual start date: 1 July 2017
Foreseen end date: 31 March 2021 Actual end date: 31 March 2021

Activities carried out for Dissemination are in line with the initial plans, including: preparation of 4 versions of the Dissemination Plan; creation and update of the project website and of links on the social channels; production of dissemination material.
The project website has been designed and developed (www.life-dentreat.eu) with the support of an external consultant, also including a project LOGO. It has been also updated in June and December 2018, June 2019, June 2020, and January 2021 including advancements of the project, news, and dissemination material.

The Dissemination deliverables were released involving LARIANA, the external consultant and EURATEX to provide a unique strategy and operative plan of the dissemination activities. In compliance with the initial plan and with inputs included in the Dissemination plan, the following dissemination actions have been carried out:

- Editing of three different "SMALL BOARDs"
- Editing of three different "BIG BOARDs"
- Presence on social media: Instagram, Youtube, LinkedIN, Twitter and Facebook
- Roll-up exposed by CITEVE at ModTissimo in Porto
- Roll-up exposed by SCR during info days
- Preparation of three scientific newsletters that have been sent to selected mailing lists (each partner sent it to its mailing list, in compliance to GDPR regulation). >2000 contacts identified
- Editing of a brochure used by partners in the selected events.

**Reference deliverables:** D1.1.1 Dissemination plan – version 1 - rev.00 31/01/2018
D1.1.2 Dissemination plan – version 2 - rev.00 15/05/2019
D1.1.3 Dissemination plan – version 3 - rev.00 11/02/2020
D1.1.4 Dissemination plan – version 4 - rev.00 31/03/2021

**Task:** **D.1.2 International Events, Conferences, fairs, Workshops and Papers**
Responsible: LARIANA
Other contributors: all
Foreseen start date: 1 July 2017 Actual start date: 1 July 2017
Foreseen end date: 31 March 2021 Actual end date: 31 March 2021

CITEVE presented DeNTreat:
- in the International Conference in Textile and Clothing at the ITechStyle Summit 2018
- at the Final Conference of the PT Capacity Building project (LIFE14 CAP/PT/000004)

EURATEX disseminated the DeNTreat leaflet at the following events:
- Premiere Vision Paris international trade fair for fashion, 19 – 21 September 2019
- TechTextil international trade fair for technical textiles and nonwovens, Frankfurt, 14 May – 17 May 2019

EURATEX also promoted the leaflet at the ITMA fair, international trade fair on textile machinery, Barcelona, 20 – 26 June 2019.
EURATEX updated its Members on the progress of the project during the internal Sustainable Businesses meeting. The meeting organised bi-annually gathers national delegates from the EURATEX membership discussing environmental topics. Recent meetings were held over 16-17 October 2018 (Brussels) and 1-2 April 2019 (Milano).
The Mod'tissimo info-day has been organized in September 2020.
EURATEX planned to organise info-days intended for textile companies. As a consequence of COVID-19 pandemics, those meetings have been merged and converted into a remote event on 14 December 2020.
A synopsis of the last and dissemination actions towards scientific stakeholders is provided in the Final dissemination deliverable.

**Reference deliverables:** 1 kick-off event (25/09/2017, LARIANA)
Project website (month 3, LARIANA)
Project website updated (month 12, LARIANA)
Project website updated (month 24, LARIANA)
Project website updated (month 36, LARIANA)
Project website final update (month 45, LARIANA)
1 scientific international conference (month 44, 24/02/2021, POLIMI)
4 scientific newsletters + 4 notice boards (24/02/2021; 15/07/2018; 14/06/2019; 04/05/2020; 15/03/2021)
3 scientific articles published (by month 45, POLIMI)
D1.4.1 Layman report - rev.00 31/03/2021
Info-days organized (SCR info-day - 07/03/2019; CITEVE info-day - 15/10/2020; EURATEX info-day - 14/12/2020)

**Task:** **D.1.3 Links with other research projects**
Responsible: POLIMI
Other contributors: all
Foreseen start date: 1 July 2017 Actual start date: 1 July 2017
Foreseen end date: 31 December 2020 Actual end date: 31 December 2020

POLIMI and LARIANA interacted with the following LIFE projects:
1) LIFE14 ENV/ES/000633 - LIFE SAVING-E – Two-Stage Autotrophic N-remoVal for maINstream sewaGe trEatment
2) LIFE16 ENV/IT/000486 - LIFE LESSWATT – Cutting the carbon footprint of industrial wastewater treatment

Information have been exchanged also with the following projects:
3) TANATEX Chemicals B.V.: aims at producing alternative products to be used in place of urea in DTP.

4) DIGITAL FOAM project: aims at developing an innovative process for preparing and finishing textile substrates, based on the use of the foaming technology. This process guarantees higher production efficiencies and lower environmental impacts: lower use of water (-70%), reduced quantity of chemicals (40-50%), lower energy consumption (from 0.2 kWh to less than 0.05 kWh per m2 of treated fabric) and lower nitrogenous substances in the wastewater (from about 1000 mg/L to 100 mg/L).
5) TRETile project: aims to exploit the biodegradation capacities of three micro-organisms (anammox, algae and fungi), in order to develop innovative purification processes that make the textile industry more sustainable.
6) PerFORM WATER 2030 project: application of innovative biological treatments on the mainstream of a municipal wastewater treatment plant to reduce energy consumption for nitrogen removal through a cold Anammox process.

Those activities are reported in D1.3.1. An updated version of the report was issued in December 2020.

**Reference deliverables**: D1.3.1 Report on networking activities - rev.00 15/06/2019
D1.3.2 Report on networking activities - second release - rev.00 05/03/2021

**Task:** **E.1 Management and reporting to the EC**
Responsible: LARIANA
Other contributors: all
Foreseen start date: 1 July 2017 Actual start date: 1 July 2017
Foreseen end date: 31 March 2021 Actual end date: 31 March 2021

All the activities planned are consistent with the initial schedule and adapted to variations occurred due to the delays. The activity is coordinated by LARIANA and managed with the support of an external consultant. Most relevant activities that have been carried out include:

- Organization of six plenary sessions project meetings:
  - one in POLIMI on 25-26/09/2017 (Kick-off)
  - one in LARIANA on 7-8/03/2018 (Monitoring meeting, together with the Monitor)
  - one in ModTissimo+CITEVE on 27-28/09/2018 (Mid-term meeting)
  - one at beginning of March 2019 in SCR
  - one in SCR+LARIANA involving the funding authorities on 4-5 July 2019
  - one in EURATEX (Bruxelles) on 21/11/2019
  - one remotely on 26/05/2020
  - one remotely on 27/11/2020
  - one remotely on 11/03/2021 involving Mr. Giandrini

+ Editing of meeting minutes

- Preparation and management of a Google Drive shared folder
- Editing of updates forwarded to the Monitor explaining major changes occurred in the project
- Collection and analysis of financial updates from the partners on a bi-monthly basis
- Editing of meeting minutes
- Overall analysis of the state of play of the project and editing of periodic management reports
- Delivery of two requests for project extension
- Interaction with the C2M consultants for business-related activities
- Submission of the Mid-Term report and attached deliverables
- Preparation of the Final Report (this document)

**Reference deliverables**: E1.1.1 Internal progress report - rev.00 31/01/2018
E1.1.2 Internal progress report - rev.00 31/10/2018
E1.1.3 Internal progress report - rev.00 05/04/2019
E1.1.4 Internal progress report - rev.00 17/06/2019
E1.1.5 Internal progress report - rev.00 10/02/2020
E1.1.6 Internal progress report - rev.00 04/11/2020
E1.1.7 Internal progress report - rev.00 02/03/2021

**Task:** **E.2 After-LIFE DeNTreat**
Responsible: LARIANA
Other contributors: POLIMI
Foreseen start date: 1 July 2018 Actual start date: 1 July 2018
Foreseen end date: 31 March 2021 Actual end date: 31 March 2021

In the first stages of the task, two activities have been carried out addressing the "Quick clinic" task:
- identification of non-textile companies providing wastewater samples useful to ponder the transferability potential of the DeNTreat technology
- preliminary discussion on the available exploitation options for project results.

The E2.1 "Quick Clinic" is a sub-action intended to pave the way towards an easier exploitation of project results. To achieve this goal, the idea was to test wastewater samples coming also from non-textile company and ponder their possible treatment with the DeNTreat demonstrator. To that end, 2 wastewater samples have been collected (the digestate of a thermophilic sludge digester of WWTP treating industrial wastewater and liquid industrial waste, located in the textile district of Como) and processed using the lab-scale pilot. Collected recommendations include that industrial wastewater must comply with the following constraints: (1) biodegradable COD to Nitrogen ratio < 3; (2) ammonium to total Kjeldahl nitrogen (TKN) > 0.3; (3) temperature > 25°C; (4) total suspended solids < 500 mg/L; (5) TKN > 150 mg/L.
Customized quotations were elaborated considering different discharged volumes and different ratios of nitrogen contaminants. A simulation was also carried out to ponder the impact of the LIFE DeNTreat technology on a textile district considering different scenarios. The developed estimations are useful for future potential adopters.
An "Hardware Development Kit" document was delivered with a unique reference to all the project documents useful for a future adopter interested in implementing the LIFE DeNTreat technology in a new district or in a new company.
A report on BAT-BREF activities was issued by EURATEX presenting all the actions carried out to promote the LIFE DeNTreat technology in this context.
An "After life plan" was finally issued including plans for disseminating and exploiting project results after its conclusion.

**Reference deliverables:**
E2.1.1 Laboratory test performing and report - DTP companies - rev.00 31/03/2020
E2.1.2 Laboratory test performing and report - No textile company - rev.00 31/03/2020
E2.1.3 Customized quotations - rev.00 31/07/2020
E2.1.4 Preliminary feasibility assessments - rev.00 31/12/2020
E2.2.1 Report on Hardware Development Kit - rev.00 15/05/2020
E2.2.2 Report on BAT/BREF activities - rev.00 08/03/2021
E2.3.1 Simulation of district impacts: wastewater discharges scenarios in the case study of the Como district - rev.00 31/03/2021
E2.2.3 After-LIFE Plan - rev.00 31/03/2021

## 5.2. Main deviations, problems and corrective actions implemented

Although the overall project objective is kept unchanged, two deviations occurred and resulted in as many requests for project extension. First deviations occurred in the first half of the project mainly due to problems in the installation and start-up phases of the Demo plant and on its initial operations (the activity got off to a late start due to problems in finding the anammox bacteria. A second deviation, occurred due to CoVID-19 pandemics, resulted in a 3-months delay on selected actions. All those deviations have been presented and discussed in the relevant documentation sent to EASME when requesting project extension.

## 5.3. Evaluation of Project Implementation

Project management required a constant work to assure easy communication between the partners and adherence to the initial objectives of the project. Even if the partnership is quite small, partners have really different background and styles of work and are located in three different countries. Actions established and carried out to assure a good interaction towards project goals achievements are:

- Organization and management of Coordination meetings
- Organization and management of Monitoring meetings
- Setting-up and management of a shared Google Drive folder for sharing project technical and financial documents and information
- Organisation of several physical or remote meetings among the partners involved in the design, development and construction of the Demonstrator
- Organization of phone calls with external consultants and with project partners in order to plan and monitor the project technical activities
- Management of the financial aspects of the project
- Editing and provision of updating reports to the Monitor
- Editing of requests for project extension

In short: all the initially planned deliverables and milestones have been accomplished with neither technical nor content-wise deviations to be reported, thus keeping project goals completely unchanged. The only deviations apply to the schedule of the delivery of some documents and prototypes as discussed in §6.2.

**The industrial ww treatment tariff and the implication of textile sector competitiveness.**

During the implementation of the project there was an important change in the tariff calculation methodology in Italy. The previous tariff applied until 2017, is substantially proportional to the volume and to the concentration of COD, while for nitrogen it is considered a fixed coefficient independent of the concentration of nitrogen in the wastewater discharged. In the Como Textile Districts, for industrial ww discharged into the sewer with N concentration over the limit, the user has to pay a fee per limit derogation (over 100 mgN/l) = 0.75 €/kgN.

For example, the tariff for an industrial ww with 200 mgN/l, 1000 mg COD/l, 100 mgSST/l is 1.66€/m3.

The fee for nitrogen is 0.54 €/kgN

The new tariff formula is composed of three components: the variable component is proportional to the concentrations of COD, SST, P and also of N. As a consequence, for the same example proposed above, there is an increase in the tariff of 28% (2.12 €/m3) with a fee for nitrogen 8.5 times the previous tariff (4.64 €/m3).

In order to comply with the sewer discharge limit and avoid derogations, it is important for Digital Textile Printing sector to have an economically feasible solution.

## 5.4. Analysis of benefits

Environmental benefits

*a. Direct / quantitative environmental benefits*

Preliminary investigations performed especially in Activity C.1 allowed to better describe the impacts and to identify where and how to collect data, but the initially stated goals remained unvaried. More precisely, the DeNTreat technology allows to:

- obtain a residual N content below 100 mg/l in the wastewater released in the collection system;
- easily accomplish Directive 91/271/EEC art.5 requirements asking to ensure that the minimum percentage of reduction of the overall load entering all urban WWTP in a given area is at least 75% for total nitrogen produced;
- assure the respect of residual nitrogen concentration in WWTP discharges, to be maintained below10 mg/l;
- reduce the Green-House-Gases emissions during biological wastewater treatment to less than 70% of the currently adopted technologies, mainly linked to reduced energy and reagent consumption;
- reduce the amount of sludge produced as a result of the nitrogen abatement process to less than 25% of the currently adopted technologies.

For impacts expressed in percentage, the wider the number of adopters, the higher the achievable impact.

Considering actual performances of the demonstrator and comparing them with one of the two centralized plants controlled by LARINA (the one called “Livescia”, that is the treatment plant processing SCR wastewater), achieved impacts are detailed below.

<u>At project closure</u> (i.e.: considering the volumes processed by the Demonstrator):

- reduced $CO_2$ emissions: - 0.4%

  Looking to the general picture and considering the entire chain, thus also including the effects of external carbon source (rbCOD) production, transport and side treatments such as sludge dewatering and incineration, the LCA (Deliverable C1.2.2) evidenced a GHG emission of 15 kg$CO_2$eq/ kg N removed for centralised urban wastewater treatment plant (Livescia WWTP) and 9.93 kg$CO_2$eq/ kg N removed for the treatment of SCR wastewater by means of the PN/Anammox process.

  The reference data is the $CO_2$ produced at Livescia WWTP with reference to the N removed: 80300 kgN removed/year = 1205 t$CO_2$/year
- reduced $N_2O$ emissions: - 0.07%

  The results obtained in the project show that the reduction in $N_2O$ production in the Anammox based process is slightly lower (-6%) than that measured on the conventional plant. This unlike what is reported in the literature: Anammox based processes can reduce $N_2O$ emissions from 1.2% of conventional biological processes to less than 0.1% of the total nitrogen removed (Wyffels, S. et al., Water Sci. Technol. 49, 5/6, 2004, 57–64; Kampschreur, M.J. et al., Water Research, 2008, 812-826).

  $N_2O$ emitted is reduced from 0,012 to 0,01128 kg$N_2O$/ kg N removed.

  The reduction would be at least 0,672 kg$N_2O$/y equivalent to 0,672 * 298 kg$CO_2$/kg$N_2O$ = about 200 kg$CO_2$/year.

  The reference data is the $N_2O$ produced at Livescia WWTP with reference to the N removed: 80300 kgN removed/year = 964 kg$N_2O$/year
- Waste Reduction: -1.0%

  Conventional biological nitrogen removal processes produce about 1,8 kg TSS/kgN removed of sludge while pure autotrophic processes produce less than 0.2 kg TSS/kgN removed. To remove about 933 kg N /year we produce about 187 instead of 1679 kg TSS/year, with a reduction of 89%.

  The reference data is the sludge produced at Livescia WWTP with reference to the N removed: 80300 kgN removed/year = 144540 kg TSS/year

- Improved industrial effluent Quality: the Demo plant treats 40 $m^3$/d of wastewater from digital textile industry = around 14600 m3/year; 34% less nitrogen (from yearly average 188 to about 124 mg/L = 933 kg Nremoved/ y).
- Improved Water Quality - kgN/year: -1%
  The yearly average concentration of nitrogen discharged to the river Livescia improve from 13.3 mg/L (27930 kgN/y) to 13,2 mg/L (27659 kgN/y).
  The reference data is the total wastewater and the total N discharged by Livescia WWTP.
- Reduced resource consumption (excluding energy): -1.1%
  Conventional heterotrophic biological denitrification processes require a minimum catabolic stoichiometric amount of 4,5 kg COD/kgN removed, accounted as readily biodegradable COD (rbCOD). This is a minimum value, as biological uptake of carbon for synthesis is not accounted for. The amount taken up for synthesis can be negligible in long sludge-age processes. At Livescia WWTP an external source of rbCOD is used. Pure autotrophic processes don't require any addition of external COD. As 933 kgN/year will no longer be discharged to the Livescia WWTP, the amount of external COD avoided is about 3 tCOD/year from external source, with a reduction of 7,5% (about 277 instead of 280 tCOD/y that are presently consumed which is the reference data).
- Energy savings: - 0,71%
  Conventional biological nitrogen removal processes require about 2,3 kWh/kgN, while pure autotrophic processes require 0.9 kWh/kgN removed (Mulder, 2003; Water Science and Technology Vol 48 No 1 pp 67–75). To remove about 933 kg/year we need only 840 instead of 2146 kWh/year, with a reduction of 61%.
  The reference data is the energy consumption for total N removed at Livescia WWTP: 80300 kgN removed/year = 184690 kWh/year

<u>5 years after project conclusion</u> (i.e.: installing 6 industrial-scale plants performing as expected by the Demonstrator):

- reduced $CO_2$ emissions: - 14.8%
  Looking to the general picture and considering the entire chain, thus also including the effects of external carbon source (rbCOD) production, transport and side treatments such as sludge dewatering and incineration, the LCA (Deliverable C1.2.2) evidenced a GHG emission of 15 kgCO2eq/ kg N removed for centralised urban wastewater treatment plants and 9.93 kgCO2eq/ kg N removed for the treatment of DTP companies wastewaters by means of the PN/Anammox process.
  The reference data is the CO2 produced at WWTPs with reference to the N removed of industrial origin: 360,400 kgN removed/year = 5,406 $tCO_2$/year
- reduced $N_2O$ emissions: - 43.7%
  The results obtained in the project show that the reduction in $N_2O$ production in the Anammox based process is slightly lower (-6%) than that measured on the conventional plant. This unlike what is reported in the literature: Anammox based processes can reduce $N_2O$ emissions from 1.2% of conventional biological processes to less than 0.1% of the total nitrogen removed (Wyffels, S. et al., Water Sci. Technol. 49, 5/6, 2004, 57–64; Kampschreur, M.J. et al., Water Research, 2008, 812-826).
  $N_2O$ emitted is reduced from 0,012 to 0,01128 kgN2O/ kg N removed.
  The reduction would be at least 113,4 kgN2O/y equivalent to 113,4 * 298 $kgCO_2/kgN_2O$ = about 33.8 $tCO_2$/year.
  The reference data is the $CO_2$ produced at WWTPs with reference to the N removed of industrial origin: 360,400 kgN removed/year = 259.5 $kgN_2O$/year
- Waste Reduction: -15.9%

Conventional biological nitrogen removal processes produce about 1.8 kg TSS/kgN removed of sludge while pure autotrophic processes produce less than 0.2 kg TSS/kgN removed. To remove 157,500 kg N /year we produce about 31.5 instead of 284 t TSS/year, with a reduction of 89%.
The reference data is the sludge produced at WWTP with reference to the total N removed: 880,000 kgN removed/year = 1,584 t TSS/year

- Improved industrial effluent Quality: -29.7% tonsN/year
  On-site treatment plants treat 950,000 m3/y of wastewater from the 6 DTP companies; 75% less nitrogen (from yearly average 221 to about 55 mg/L = 157,500 kg Nremoved/ y).
- Reduced resource consumption (excluding energy): -72%
  Conventional heterotrophic biological denitrification processes require a minimum catabolic stoichiometric amount of 4,5 kg COD/kgN removed, accounted as readily biodegradable COD (rbCOD). This is a minimum value, as biological uptake of carbon for synthesis is not accounted for. The amount taken up for synthesis can be negligible in long sludge-age processes. Pure autotrophic processes don't require external source of COD. By not removing 330 tons N/year in the WWTP of the Como textile district, and assuming that only this quota of N removed needs an external source of COD, 709 tons COD/year from external source are avoided, with a reduction of 72% (compared with the present consumption of 990 tons COD/y which is the reference data assuming that only the 25% of N removed in the 4 WWTPs needs an external source of COD).
- Energy savings: - 10,9%
  Conventional biological nitrogen removal processes require about 2.3 kWh/kgN, while pure autotrophic processes require 0.9 kWh/kgN removed (Mulder, 2003; Water Science and Technology Vol 48 No 1 pp 67–75). To remove about 157,5 tons/year we need about 142 MWh/year instead of 362 MWh/year, with a reduction of 61%.
  The reference data is the energy consumption for total N removed at the 4 WWT Plants: 880 tons N removed/year = 2,024 MWh/year.

*b. Qualitative environmental benefits*

Possible consequences of the diffusion of this technical/methodological approach on policy and governance are the development and enhancement of a long-term sustainable technology, which will lower the environmental impact of textile ink-jet processes, by lowering the nitrogen load discharged to centralized urban wastewater treatment plants and, hence, to the environment. Tested locally and exploited globally, DeNTreat technology could be adopted in several other European districts dealing with textile printing as soon as DTP will reach also high-volume undifferentiated productions of low-cost fabrics. Thanks to tests performed in D.2 action, also application to other sectors have been investigated.

Economic benefits

Also for economic benefits, estimations are still based on hypotheses performed on the basis of feedback collected from potentially interested companies contacted during business plan editing. The wide application of this technology is expected to produce long-term cost savings in terms of lower energy consumption and lower sludge disposal costs. Business opportunities can be created by servicing ink-jet textile printing factories that might be forced to stop their activity due to excessive costs for the nitrogen removal from their effluents. Interestingly, in some European countries and, in particular, in Italy, where the DTP technology is mostly popular, new regulations emerged limiting the amount of sludge that can be disposed in agriculture. A recent regulation in Italy (ruling of the Lombardy Regional Administrative Court, dated end of July 2018) set to zero the amount of sludge that can be disposed in agriculture; this regulation has been recently revised by the Decree Law 28 September 2018, n. 109 establishing a higher (but still small) amount of sludge coming from WWTP that can be disposed in agriculture. This means that WWTPs have to treat the sludge through incineration. Incineration roughly doubles the disposal cost, this making the DeNTreat solution even more interesting from an economic point of view. Moreover, several authorities have started revising the way the Tariff for wastewater treatment is calculated: the new version includes nitrogen content. This evolution makes DeNTreat technology even mor urgent.

Social benefits

The wide application of this technology will increase the potential for the environmental-friendly application of ink-jet printing, which is an essential requirement to client-oriented policy in the textile sector. The lack of fulfilment of this requirement may cause loss of revenue in this sector and, thus, loss of jobs. In fact, should the environmental regulations remain as they are now (most probably they are going to be even narrowed), with no improvements in the wastewater treatment technologies, entrepreneurs should be forced to move their productions outside Europe, especially ones with the worst environmental profile. Investigations performed by POLIMI and LARIANA through a direct interaction with local representatives of textile manufacturers show how this is a real and actual danger, at least in Italy. Increasing attention is also paid in Portugal, as it emerged through direct discussion with local companies.

Replicability, transferability, cooperation

Replicability and transferability investigations we performed both in B.4, C.1 and in D.2 actions are based on hypotheses on the evolution of the market after the pandemics. Extending and formalizing the initially identified exploitation approaches, partners adopted an adaptive business model for the new industrial entity taking care of project results after LIFE conclusion.

Best Practice lessons

Main lessons learnt concern the demonstration plant and its management:

- It is useless to move the plant too much. It is better to identify where it has to be located and install it directly in that place. This saves time and allows to directly face the actual (functional and non-functional) problems of the hosting premises;
- Components and sub-assemblies required for the plan can have non-standard sizes. If this happens, the delivery lead time can considerably increase;
- Bacteria coming from different sources can have different performances. It is recommended to pre-test their performance in small batches;
- Bacteria are living organisms that (strongly) change their behaviour varying the wastewater quality. They can also die. It is fundamental to foresee a quite long "adaptation" time and it is recommendable to monitor several physical and chemical parameters to robustly foresee the equipment behaviour.

Some lessons come also from dissemination/exploitation investigation we performed:

- Outside Italy, DTP is still combined with traditional textile printing technologies. This strongly affects the quality of the produced wastewater. It is advisable to refer to the set of indications included in the HDK on the characteristics of the wastewater that best answer to Anammox bacteria requirements in order to guide the new adopters in splitting up N-rich wastewater sources from the whole plant;
- Data acquired on the Demonstrator have been analysed and aggregated in order to clearly show the benefit of the new technology for prospective adopters in a suitable shape. For future dissemination it is advisable to identify relevant scenarios for the prospective adopter and to show the performances for each of them.

Policy implications

The revision of BREF-BAT for textile started in August 2017 with the reactivation of the Technical Working Group (TWG). EURATEX as a member of the TWG is actively contributing to the process as the voice of the European textile and clothing industry. Life DeNTreat was mentioned in the preparatory documents for the Kickoff meeting in June 2018 as a possible example of an emerging technology with a positive environmental impact, however, due to the pre-mature nature of the project and lack of results, there was no concrete discussion on this. Focussing on European regulation on N pollutants, in all the analysed countries of the European Community, the applied environmental discharge limits refer to Directive 91/271/EEC, while the sewage discharge limits are sometimes different for each WWTP basin or water management area. These limits are defined according to the treatment capacity of the WWTP.

In compliance with the discharge limits in the environment, it is not necessary to regulate the sewer discharge limits in a univocal manner at EU level in order to facilitate the optimization of the wastewater treatment cost and to meet the different needs of industrial districts.

However, the DeNTreat technology makes it easier to comply with the water directive and reduce treatment costs, and it also allows to improve the environmental sustainability of the digital textile printing technology and to satisfy the demands of the textile market. In recent years, the operational references drawn up by voluntary guidelines promoted by both brands and institutions of various kinds (ZDHC - Zero Discharge of Hazardous Chemicals - www.roadmaptozero.com, Detox my fashion - www.greenpeace.org/international/act/detox/ etc.), are becoming increasingly important. These guidelines often impose more stringent limits than those of the legislation also on traditional pollutants such as nitrogen, and they are now essential references, in addition to compliance with national laws and European directives, to maintain market positions in relation to global competition.

# 6. Key Project-level Indicators

In the following table, performances reached with reference of the most important KPIs are discussed comparing initial estimations included in the proposal and final estimations based on evidence from practices.

| | | | 5 YEARS AFTER THE PROJECT (FINAL ESTIMATION) | | 5 YEARS AFTER THE PROJECT (PROPOSAL ESTIMATION) | | comments |
|---|---|---|---|---|---|---|---|
| Improved Environmental and Climate Performance (including resilience to climate change) | Reduction of greenhouse gas emissions (GHG) | CO2 | -799 tons / year | -14.8% | not estimated | | The LCA evidenced a GHG emission of 15 kgCO2eq/kgN removed for traditional wwtp and 9.93 kgCO2eq/kgN removed using the PN/Anammox process. |
| | | N2O | -113.4 kg $N_2O$ / year | -3% | -3.63 tons $N_2O$ / year | -21.6% | The impact is lower than what stated in literature |
| | Waste management | Waste Reduction | -252.5 t TSS / year | -15.9% | -528 tons sludge / year | -21% | In the Final Estimation, the % is calculated considering the sludge produced only to remove N from ww |
| | Water | Improved industrial effluent Quality | 0.950 Mm3/year | 12.2% | 1,96 Mm3/year | 19.6% | In the Final Estimation, we only focused on the DTP companies that we foresee to adopt the DeNTreat technology |
| | | | -157.5 tons N/year | -29.7% | -330 tons N/year | -50.7% | |
| | | Improved Water Quality | 37 Mm3/year | 100% | 80 Mm3/year | 100% | In the Final Estimation, we only focused on the DTP companies that we foresee to adopt the DeNTreat technology |
| | | | -157.5 tons N/year | -37.5% | -330 tons N/year | -37.5% | |
| Better use of natural resources | Reduced resource consumption (excluding energy) | Raw materials | -709 tons COD /year | -72% | -371 tons COD /year | -23.3% | Pure autotrophic processes don't require external source of COD, thus we save about 72% of this. Reference denominator has been updated based on 2020 data |
| | Energy | Reduced energy consumption | - 220 MWh / year | -10.9% | - 462 MWh / year | -14.3% | Energy saving is almost as expected but the % is lower than what stated in the proposal because we had to change the denominator (energy consumed in the year) |
| Economic Performance, Market Uptake, Replication | Employment | Jobs created | 9 FTE | 0,1% | 60 FTE | 0,4% | In the Final Estimation we only consider direct FTE hired to manage the plant while in the Proposal Estimation we also considered jobs not lost by DTP companies |
| | Replication / Transfer | N . of replication / Transfer | 10 replications | | 20 replications | | In the Final Estimation we considered numbers from the Business plan |
| | Market uptake | market size in nr. of customers | 46 customers | | 20 customers | | |
| | Reduction of cost per unit or process | | +0,34 euro/kgNremoved | +6.9% | -0,8 euro/kgNremoved | -28% | Based on data from the Demonstrator, the cost is currently higher than expected and than in the traditional wwtp |
| | Payback Time | capital invested / net income | 8 - 32 years | na | 4 years | na | For the reason above, the payback time is also longer |
| Communication, dissemination, awareness rising | Awareness raising | Nr. of entities / individuals reached/ made aware | 15000 | na | 80.000 | na | Pandemics slightly limited the chance to disseminate project results, but still we reached a significant number of stakeholders |