LIFE ENRICH FINAL REPORT

Action E1

Date: February 2022

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Final Report

Covering the project activities from:
Technical part: 01/09/2017 to 30/11/2021
Financial part: 01/09/2017 to 30/11/2021

Reporting Date
28/02/2022

LIFE ENRICH

Data Project

Project location:	Spain	
Project start date:	01/09/2017	
Project end date:	28/02/2021	**Extension date:** 30/11/2021
Total budget:	€ 2,734,130.30	
EU contribution:	€ 1,640,478.18	
(%) of eligible costs:	60	

Data Beneficiary

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1.Table of Contents

2. List of Abbreviations, Tables and Figures

2.1. List of Abbreviations

AB Advisory Board

BNRM Biological Nutrient Removal Model

CAPEX Capital expenditures

EB Executive Board

ENRICH Enhanced Nitrogen and Phosphorus Recovery from wastewater and Integration in the value CHain

EU European Commission

JRC Join Research Center

KPI Life Key Performance Indicators

N Nitrogen

OPEX Operational expenditures

P Phosphorus

PLC Programmable Logic Controller

P&ID Piping and instrumentation diagram

WWTP Wastewater Treatment plant

2.2. List of Tables

2.3. List of Figures

3. Executive summary

The overall objective of LIFE ENRICH is to implement the circular economy concept through the demonstration of the whole value chain for nutrient recovery in urban wastewater treatment plants and its further reuse for fertilizing products valorization.

The current situation of the wastewater treatment sector and the agricultural sector (fertilizers production) is that they are independent one to another: while WWTPs are discharging nutrients to the environment (rivers, dewatered sludge, and atmosphere); fertilizer industry consumes large amounts of nutrients from natural reserves or from complex manufacturing processes. This context should change, and LIFE ENRICH has demonstrated that it is possible: the industry, the environment and the society can benefit through the exploitation of existent synergies between both sectors.

The project targets several environmental problems, related to the steps of the process from the recovery of raw materials (upstream) to the creation of a final product and its use for agricultural activities (downstream). The most relevant environmental problems targeted in the project are:

- C-footprint of the N removal process in the WWTP related to the high energy demand
- Huge amount of sewage sludge production and disposal impacts
- Risk of eutrophication by the nutrients present in the effluent discharged
- C-footprint of production and use of chemical fertilizers
- Depletion of phosphate rock reserves

Life ENRICH deals with the whole value chain: the recovery of nutrients in the WWTP, the characterization and optimal mixing of them to obtain added-value fertilizers and the validation of its performance in a real case study (end-user). The N and P recovered were transformed in alternative fertilizers struvite (P, N) and ammonium nitrate (N) that were used as well as sewage sludge in crop trials. Murcia Este WWTP was the facility selected to operate the technological prototypes and horticultural and extensive crops were tested in Cabrils, Agramunt, and Castelldans soils, all within Spanish territory.

Thus, LIFE ENRICH project has defined and achieve several secondary objectives to ultimately guarantee the real implementation of the value chain. First, there have been assessed the feasibility of a) an innovative process to recovery simultaneously P and N in WWTPs through the integration of different cutting-edge technologies and b) the agronomic properties of alternative fertilizes (produced with recovered N and P) and the sewage sludge. 3 prototypes were operated in Murcia Este WWTP: an elutriation process at full scale, a crystallization reactor for struvite production at pilot scale, and a N recovery train for ammonium nitrate production based on adsorption with zeolites and ammonium salt precipitation with membrane contactors. The operational conditions were optimized, showing reduction in uncontrolled P precipitation problems and improvement in sludge dewaterability due to the elutriation process full-scale, as well as high P and N recovery efficiencies in the pilot plants (>85%). The fertilizers produced as well as the sludge were analyzed, showing good quality properties, and tested in horticultural (tomato, broccoli, cauliflower, and lettuce) and extensive (oats, beans, barley) crops in greenhouse and open-air conditions, showing similar properties compared to conventional fertilizers.

ENRICH process was scaled up for Murcia Este WWTP, showing a high potential nutrient recovery of 42% of total P and 11% of total N of the WWTP influent, which is an annual production of 1,100 ton of struvite and 1,937 ton of ammonium nitrate (139 ton/year of P and 297 ton/year of N recovered), which could fertilize up to 30 ha of horticultural cropland. Life Cycle Analysis (LCA) applied through the whole value chain (WWTP and field) have shown that ENRICH solution allows a reduction CO_2 equivalent emissions (20%) and mineral resource scarcity (58%), mainly from avoiding intensive energy consumption in conventional N fertilizers, sludge transport emissions (due to sludge production reduction), and the depletion of phosphoric rock (critical raw material) used in conventional P fertilizers; moreover, N_2O emissions, stratospheric ozone depletion, terrestrial acidification and marine and freshwater eutrophication would also be reduced. Life Cost Cycle (LCC) have shown that WWTP could reduce the total OPEX of the facility considering the selling of the fertilizers and also the savings, that come from reduction in antiscaling consumption and external cleanings for avoiding uncontrolled P precipitation problems, and reduction in sludge production, polymer and energy consumption in sludge dewatering, and also aeration energy consumption related to N load to biological reactors (it is reduced with N recovery). The CAPEX required to maximize nutrient recovery would be of 6.15 M€, which is a major inversion for WWTPs operators.

The replicability of ENRICH solution was assessed through three different replicability cases in WWTPs which have demonstrated that ENRICH process is robust and flexible to adapt to different process configurations. Also, crop selection is important to maximize the environmental benefits of ENRICH solution. General guidelines for replicability of ENRICH process were defined, regarding site selection and process configuration, as well as operation, thus, they can be used for selecting the optimal strategy in a case-by-case basis.

Two business models were defined, one for fertilizers commercialization and one for technology commercialization. Based on them, the Spanish business plan was planned and the adaptation of the business models to other three European countries apart from Spain was performed. The market analysis for fertilizers selling and the technology competitors study showed that ENRICH products can be competitive not only in Spain, but they also pointed out that there is a common ground and similar needs at European level. The analysis of legal framework highlighted the same conclusion: it is demanded and needed a global common marketplace for alternative fertilizers selling, and it must be supported legally from both wastewater and agricultural sectors. The identification of key players and their feedback at Spanish and European level were key to fully understand the high willingness of these actors to shift towards a sustainable management of wastewater, sewage sludge, fertilizers production and agricultural practices, as well as to identify that legal and economic barriers, as well as safety issues were the main obstacles to fully engage these key players and implement circular economy strategies in nutrient recycling such as the ENRICH solution.

The recent incorporation of struvite in the European Fertilizers Product Regulation (FPR) 2019/1009 is expected to be a catalyst to open European market as well as to achieve fully fertilizer status for struvite and ammonium salts as well. ENRICH project has contributed to minimize safety issues and legal barriers by demonstrated high quality struvite production in compliance with FPR, showing that ENRICH fertilizers and sewage sludge have similar properties as conventional fertilizers, and providing technical experience in ammonium salts (ammonium nitrate) production participating in ESPP initiatives where there is exchange of information and opinions with EU (European Commission) workgroups regarding policy making.

Business models development also identified that public administration is needed to economically promote the implementation of processes and the use of fertilizers, balancing capital investments for ENRICH process and similar, as well as ensuring competitive prices for fertilizers under a changing market regarding new agricultural policies and fertilizer production policies.

Multi-party business models through key agreements with WWTPs operators and alternative fertilizers end-users (either fertilizer industry using them as secondary raw materials, or farmers for direct application) will ensure the success of the ENRICH value chain.

The European countries selected for the adaptation of the business models were Denmark, Italy and Netherlands. They were selected considering different general criteria and specific national context (high use of conventional fertilizers, climate conditions and cropland, nutrient recovery potential, soil requirements, regulatory framework regarding fertilizers and nutrient discharge, sludge management system, the existent commitment from different key players). The replicability and transferability assessment showed that ENRICH value chain implementation in different European territories is possible, with existing market for alternative fertilizers, primarily from fertilizer industry in the short term.

Networking and dissemination activities and materials have had great impact on key players (including Advisory Board and stakeholders' entities), who also shared their feedback on ENRICH value proposition as well as on society's awareness rising, achieving great ratios on people reached.

Results achieved are reflected through the KPIs (Key Project Indicators) of the LIFE ENRICH project.

Overall, LIFE ENRICH project has achieved its objective: it has been demonstrated that it is possible to implement a new value chain for nutrient recovery and its valorization as fertilizers, by connecting wastewater and agricultural sectors. This is possible through ENRICH process, a technical and economic feasible technological solution to produce alternative fertilizers in WWTPs that can be safely and efficiently used in fertilizer industry and croplands. The business models defined allow to create strong, robust alliances involving all key players through the different European countries and taking advantage of their particular contexts. A sustainable management for nutrient recovery and their valorization as fertilizers is possible, beneficiating the industry, the environment and the whole society.

4. Introduction

The overall objective of LIFE ENRICH is to implement the circular economy concept through the demonstration of the whole value chain for nutrient recovery in urban wastewater treatment plants and its further reuse for fertilizing products valorization.

Figure 1 shows, in a simple and graphical way, the current situation of the wastewater treatment sector and the agricultural sector (fertilizers production). It is evident that nowadays both sectors are independent one to another; while WWTPs are discharging nutrients to the environment (rivers, dewatered sludge, and atmosphere); fertilizer industry consumes large amounts of nutrients from natural reserves or from complex manufacturing processes.

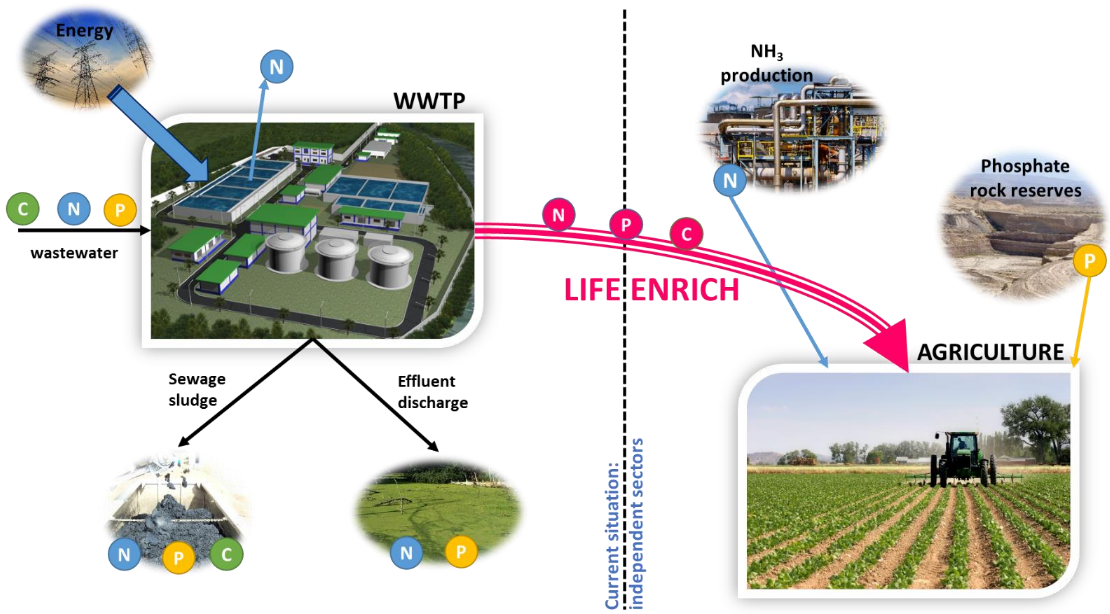

Figure 1. Environmental problems targeted by Life ENRICH project

The project targets several environmental problems, related to the steps of the process from the recovery of raw materials (upstream) to the creation of a final product and its use for agricultural activities (downstream). The most relevant environmental problems targeted in the project are represented in Figure 1 and listed below:

- C-footprint of the N removal process in the WWTP related to the high energy demand
- Huge amount of sewage sludge production and disposal impacts
- Risk of eutrophication by the nutrients present in the effluent discharged
- C-footprint of production and use of chemical fertilizers
- Depletion of phosphate rock reserves

Life ENRICH deals with the whole value chain: the recovery of nutrients in the WWTP, the characterization and optimal mixing of them to obtain added-value fertilizers and the validation of its performance in a real case study (end-user). Moreover, the appropriate business model will be designed in parallel in order to ensure that the proposed solution is ready to be transferred and replicated in other sites/regions.

The recovery of nutrients is achieved by integrating different innovative technologies in Murcia Este WWTP. N-recovery is based on ammonium adsorption into zeolites combined with membrane contactors. Nitrogen is recovered as a salt, expecting to produce up to 40 L/d of a dilution with 10-20% of N. P-recovery is achieved by P elutriation at full-scale followed by a pilot crystallization unit producing around 5 kg/d of struvite, a precipitate composed by magnesium, ammonium and phosphate. The combination of both products is evaluated in two different type of trials: field tests under controlled conditions and small surface and field tests in commercial farms.

The main output of LIFE ENRICH is the business models integrating the different stakeholders involved in the value chain (nutrient producers, fertilizer companies, end-users and administrations) that ensures the replicability of the value chain in other case studies. In addition, the development of a treatment train for nitrogen and phosphorus recovery in existing urban WWTPs is expected to allow a recovery of 42% of P (> 50% as struvite) and a recovery of 11% of N. The environmental benefits of nutrient recovery in the WWTP and its use in agriculture instead of conventional fertilizers are mainly related to a reduction of 0.06 kg CO2/m2 cultivated (19% reduction) and a reduction of phosphate rock consumption of 774 t/year.

Economic aspects are crucial to shift to a circular economy model. To make nutrient recovery a reality, efficacious business models are needed to turn the various values of N and P recovery into commercial success. Accordingly, new multi-stakeholder business models that create synergies between waste management actors and "nutrient customers" (e.g. fertilizer industry) are emerging to harness economic opportunities in value creation from the recovery and reuse of resources that would otherwise be irretrievably lost (and paid for to be disposed).

Disrupted nutrient recycling is a problem for Europe and globally. Envisaging that the project has a high potential of replicability in other geographical markets different from the case study, the project aims at assessing the launch of the proposed business model in 3 different countries (France, Netherlands and Italy) in addition to Spain. Possibilities for replication in EU countries will be assessed not only by considering technical factors related to the water (plant size and configuration, wastewater characterization, etc.) and agriculture (type of crops, fertilization requirements, type o soils, etc.) sectors, but also by taking into account regulation and market trends and players for each country.

5. Technical part

5.1. Technical progress, per Action

ACTION A.1 Recovery of nutrients (upstream): WWTP characterization and selection of prototype location	
Responsible: UPV	**Status:** completed (100%)
Proposed start: September 2017 **Proposed end:** November 2017	**Actual start:** September 2017 **Actual end:** March 2018

Main activities during the reporting period:

Characterization of the different streams of the WWTP

Three intensive analytical campaigns (AC) were carried out in October, November and December 2017, respectively, under normal operating conditions at different points of the water and sludge lines of Murcia Este WWTP. The water line characterization enables to assess the biological phosphorus removal process performance and to evaluate the optimization of the process in order to reduce the loss of P in the WWTP effluent. On the other hand, a proper sludge line characterization is essential to track the nutrients during the waste sludge handling, to assess the possible P precipitation in the different elements along the line. These characterizations with the simulations of different scenarios (Action B1) are the basis for the selection of the proper sludge line configuration aiming to increase the global N and P recovery. 15 sampling points were defined and 27 parameters were analyzed following the Standard Methods for the Examination of Water & Wastewater (APHA, 2005).

The experimental results and the main conclusions obtained from the three analytical performed campaigns are provided in Deliverable *D1_Characterization of Murcia Este WWTP (baseline conditions)*, attached as Annex 2.1.

Site selection

An area already used in previous projects has been identified as the best location for the pilots, because there were some of the auxiliary services (water supply, electricity, air). So, during this period equipment and units were disassembled and the metal platform has been restored to ensure that it could support the weight of the prototypes.

Discrepancies / reasons:

According to the approved proposal, 2 analytical campaigns were forecasted. However, some controversial results obtained in the two initial campaigns made the drawing of conclusions quite complex. Therefore, the technical team decided to do a third campaign. Due to the huge amount of experimental data produced and the subsequent complexity of their interpretation, this Action was completed in March 2018 (4 months later than expected). However, the conclusions obtained are now robust, which is essential for a successful design and operation of the prototype.

As a consequence of the delay of Action A1, the design of the prototype (included in Action A1) was completed later than planned in the proposal. More details are given in the description of Action B1.

Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D1. Characterization of Murcia Este WWTP	100% completed
M3. Complete characterization of Murcia Este WWTP	100% completed
M6. Nutrient mass balances in Murcia Este WWTP	100% completed
M7. Quantification of water, energy and chemicals demand in Murcia Este WWTP	100% completed
M8. Selection of the specific location for the pilot plant in Murcia Este WWTP	100% completed

ACTION A2. Valorization of nutrients (downstream): Definition of field tests: crops selection, methodology and timing

Responsible: ASG	**Status:** completed (100%)
Proposed start: September 2017 **Proposed end:** November 2017	**Actual start:** September 2017 **Actual end:** November 2017

Main activities during the reporting period:

Definition of the baseline situation: available crops, fertilizer requirements

Fruit and vegetables are generally more profitable than cereals and arable crops. Fresh vegetable production accounted for 17% of the EU-27 overall crop output value at producer prices of 2009 but only 2.1% of the total cultivated area (Eurostat 2011; 2012). The annual horticultural production in Spain exceeded the figure of five thousand millions Euros, nearly 1% of the Spanish GDP, during the period 1995-2007 (MARM 2010; INE 2012).

In the EU-15 tomato, lettuce, cauliflower, broccoli, and onions account for nearly 40% of the total area. According to Eurostat (2012), Spain and Italy are the main producers from the EU, with a total vegetable production of about 12 millions of tones each one, additionally France and Greece are also among the major producers

Tomato, lettuce and broccoli are those who have greater surface area of cultivation in Spain in crops of fruit, leaf and flower respectively (Figure 2).

Soft wheat, barley and Oat are those who have greater surface area of cultivation in Spain in grain cereals crops (Figure 2).

Currently, the total greenhouse protected area in the southern European Union member states is about 90,000 ha, with Spain at the top of the list with more than 80,000 ha (Sigrimis et al. 2009). In Spain, protected vegetable production represents 36% of the total vegetable production (MARM 2010, 2014).

From this information, along with the current and future needs of the end user, the representative species for the two different production systems have been selected.

Moreover, for each selected crop, the nutrient requirements have been calculated (Ruano, 2010). The dewatered sewage sludge is spread to the soil (open-field experiments), while the recovered products (struvite and ammonium salts) are used through fertigation (greenhouse and open-air experiments). These calculations are essential in order to quantify the amount of products (Struvite, ammonium salts) that have to be produced by the prototype. More details of the dosis and types of fertilizers applied are described on the D24 Field test results.

*Eurostat 2011, 2012; MARM 2010, 2014, 2020

Sigrimis, N., Cavallini, A., Incrocci, L., Montero, J.L., Perez-Parra, J and Kafka, A. (2009) Data-collection of existing data on protected crop systems (greenhouse and crops grown under cover) in Southern European EU Member States. European Food Safety Authority.

Ruano, S. (2010). Guía práctica de la fertilización racional de los cultivos en España. Ministerio de Medio Ambiente y Medio Rural y Marino.

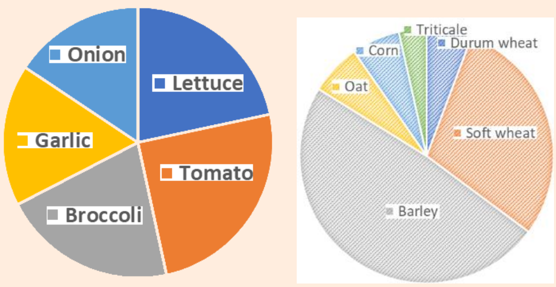

Figure 2. Surface area of cultivation in Spain (Open-air conditions, 2020) for vegetables and grain cereals.

Selection of crops and production system

There are a lot of vegetable species cultivated in EU and in Spain, thus in order to select the crops for the experiments, the following factors were considered: the climate, the surface, the yield and the selling price. Two kind of crops will be considered:

Horticultural crops: The selected crops are **tomato**, **lettuce** and **broccoli**, because they are very relevant and representative horticultural crops in the EU.

Cereals: 301 millions of tonnes of cereals are produced annually in EU, from which **barley** represents almost the 20% because it is well adapted to Mediterranean edaphoclimatic conditions. **Dry beans** are less important in terms of quantity, but this crop was also selected to implement a crop rotation with barley.

Soilless culture use is increasing over the years, being widely used and allowing a better control of fertilizers experiments. Thus, a fertigation system (injection of soluble fertilizers into an irrigation system) is used by dripping systems due to its novelty for struvite use. Both, soil and soilless trial (with perlite) are carried with fertigation systems.

The *field trials* are developed in three locations:

Cabrils (Barcelona): greenhouse and open-air tests with horticultural crops are done by IRTA in small plots under controlled conditions.

Agramunt and Castelldans (Lleida): open air tests with horticultural crops and cereals are done by ASG.

The surface of the different plots, the number of trials and its time planning is described in Deliverable *D3_Protocol for field tests: selected species and test conditions* (Annex 2.2). The analytical plan for each experimental site is also defined in detail.

Discrepancies / reasons:

No discrepancies regarding this Action.

Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D3. Protocol for field tests: selected species and test conditions	100% completed
M4. Definition of the field tests to be done in the commercial plot	100% completed
M2. Selection of the crops to be evaluated in Action B3	100% completed
M5. Definition of the tests to be done in IRTA (greenhouse and open air)	100% completed

ACTION B1. Design and construction of the prototype: elutriation, crystallization, N recovery	
Responsible: Cetaqua	**Status:** completed (100%)
Proposed start: December 2017 **Proposed end:** August 2018	**Actual start:** December 2017 **Actual end:** October 2019

Design of a new sludge line configuration for P separation (full scale)

Based on the data obtained in the three analytical campaigns done in Action A1, the amount of phosphorus that is currently precipitating in the sludge line has been estimated around 554.5 kg P d^{-1}, being the anaerobic digester the main hotspot for the P loss. It is important to quantify the uncontrolled precipitation in the baseline conditions in order to evaluate the reduction of this precipitation once established the new sludge line configuration.

Afterwards, the Biological Nutrient Removal Model No.2 (BNRM2), developed by UPV in 2013, was calibrated with the three analytical characterizations, in order to obtain a model fitted to Murcia-Este WWTP. Finally, this calibrated mathematical model was used to determine the best sludge line configuration that enhances the nutrients recovery and reduces the uncontrolled precipitation. *3 different sludge line configurations* were evaluated. The differences between the three alternatives are based on the procedure to separate the extracted phosphorus from the sludge. The first and the second alternatives are based on the elutriation of the mixed sludge to separate the orthophosphate in the primary thickener supernatant. In the third alternative, the phosphorus is separated from the sludge by centrifuging the mixed sludge between the mixing chamber and the anaerobic digesters. *4 different scenarios* have been proposed to evaluate the different configurations, combining high and low influent phosphorus concentrations with high and low phosphorus removal efficiencies.

The sludge line configuration that maximizes the phosphorus extraction and minimize the uncontrolled precipitation for each scenario, named "Alternative 1" has been selected. In this alternative, the volume of the mixing chamber is increased with the addition of one elutriation tank; the sludge of the mixing chamber is pumped (elutriated) towards the primary thickeners; a fraction of the thickened sludge is pumped directly from the bottom of the thickeners towards the digesters and the other fraction is elutriated again over the thickeners through the mixing chamber.

The main results obtained from these simulations are:

- *Quantification of the phosphorus and nitrogen fate during the wastewater treatment process*.

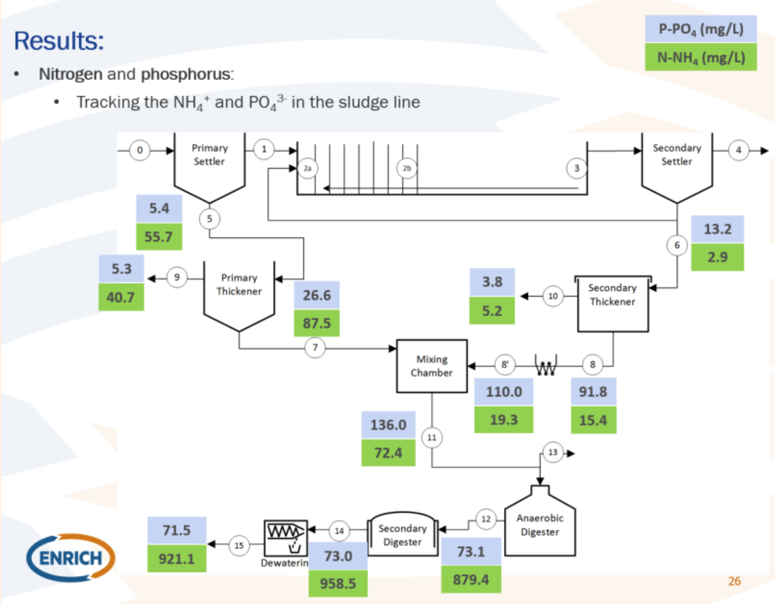

Figure 3. P and N quantification through WWTP in Murcia Este WWTP

- *Quantification of the uncontrolled phosphorus precipitation in the sludge line*. Under the current sludge line operation (baseline scenario), an average of 554.5 kgP d^{-1} precipitate in the sludge line, being the anaerobic digester the main hotspot for the P loss.

- *Quantification of the potential phosphorus and nitrogen recovered for the selected configurations*. In the selected elutriation configuration and considering the most promising scenario, the 50.2% of the influent phosphorus was extracted with a concentration of 91.2 mg P-PO_4^{3-} L^{-1} in the extraction stream. By reducing the primary thickened sludge flowrate to the half, this concentration increases up to 168.0 mg P-PO_4^{3-} L^{-1} and the 43.7% is recovered. These are the options with the lowest phosphorus content in the sludge digestion stream with a 38.0 and 45.6% respectively.

The results of all this Section are detailed in Deliverable *D6_Simulations of different sludge line configurations for P recovery in Murcia Este WWTP*, written by UPV and attached as Annex 2.3. The technical specifications have been defined in detail by Emuasa (Deliverable *D10_Implementation of the optimal sludge line configuration at full-scale in Murcia Este WWTP*, attached as Annex 2.6), based on the indications given by UPV.

Design of the crystallization unit (pilot scale)

A pilot plant for an influent flowrate of 1 m^3/h has been designed. Although it was not initially planned, Aquatec and Suez TI have collaborated with Cetaqua with the design of the crystallization unit.

All the details of the design of the crystallization unit are summarized in Deliverable *D8_Design and technical specifications of the crystallization unit*, written by Cetaqua and Aquatec, and attached as Annex 2.4. A technical description of the different parts that form the overall prototype are defined, including influent storing tanks (to store both the elutriation stream and the centrates from anaerobic digestion), pumps to fed the influent to the reactor, the crystallizer (shape, dimensions, materials, operating parameters, recirculation), air supply pipe, effluent discharge system (deflectors to avoid the wash out of struvite), instrumentation and control and chemicals ($MgCl_2$ and NaOH) dosing systems, tanks to store the chemicals). The document also includes the first approach of the control philosophy of this pilot plant, and also the procedure to follow to start-up and operate the system.

J.HUESA is the company chosen for the construction of the crystallization unit. In order to check, optimize and implement the design, videoconferences and meetings have been held between J.HUESA, EMUASA and Cetaqua. As a result, modifications and adjustments have been applied to the original design and control philosophy. The 3D diagram is attached in Annex 2.8). Main changes are related to:

- internal reactor design. Specific parts were modified in order to achieve a good air distribution through the reactor to assure an adequate bed fluidification.
- struvite harvesting line. It was detected that new harvesting piping layout as well as water supply inlet in the sieve would allow process simplification, complying with pilot plant space limitations and facilitating control and operation.
- selection of element types and final layout. With the aim of minimizing the risk of undesired struvite precipitation, type and placement of valves, pumps, security elements, instrumentation, piping elbows and other elements were checked and modified in some cases
- control flexibility and control adjustment to previous design modifications. Some process control strategies were added in order to have enough process control flexibility to execute experimental plan. Also, changes mentioned above have involve several control modifications

Design of the nitrogen recovery unit (pilot scale)

The nitrogen recovery technology implemented in the project includes two separate units:

1. ***Ammonium adsorption into zeolites***. This unit was be the one that was built for the Life Necovery project (LIFE12 ENV/ES/000332), coordinated by Cetaqua. This unit has a treatment capacity of 1 m3/h and counts with an ultrafiltration unit before the zeolite columns (2 units of 250 L of volume each), that ensures the absence of suspended material.
2. ***Hollow-Fibre Membrane contactors (HFMC)*** to produce ammonium salts from the regeneration stream of the zeolites. UPC has designed the pilot plant for this second step, considering the volume of eluate that would be produced in the adsorption unit. All the details of the design of the membrane contactor unit are summarized in Deliverable *D9_Design and technical specifications of the nutrient recovery unit*, written by UPC, and attached as Annex 2.5. This document is structured into 4 different parts:
   a) Definition of the pilot requirements
   b) General design (P&ID)
   c) Technical description of the equipment: tanks, pumps and valves, sensors

and membrane contactors.

d) Operational protocols: working process, membrane drying, cleaning procedure and membrane contactor integrity test.

J.HUESA is the company chosen for the construction of the nitrogen recovery unit. In order to check, optimize and implement the design, videoconferences and meetings have been held between J.HUESA, EMUASA, UPC and Cetaqua. As a result, modifications and adjustments have been applied to the original design and control philosophy. The modified P&ID is attached in Annex 2.10).
UPC task in action B.1.3 was the design of a nitrogen recovery unit (pilot scale), which was defined in the last report (July 2018). In order to understand better the technology and be able to foreseen possible operational problems, during the construction of the pilot plant, lab experiments were carried out at UPC to determine the optimal operational conditions to treat the ammonium-rich wastewater effluent by zeolites and produce a nitrogen-rich liquid fertilizer by LLMC. The results of those experiments are attached in Annex 2.7.

Construction of the different units and installation of the integrated prototype

1. ***New sludge line configuration for P separation***

Based on the information provided by the UPV, EMUASA worked on the drafting of the construction project to adapt the existing facilities. The following figures show the starting situation and the main modifications carried out.

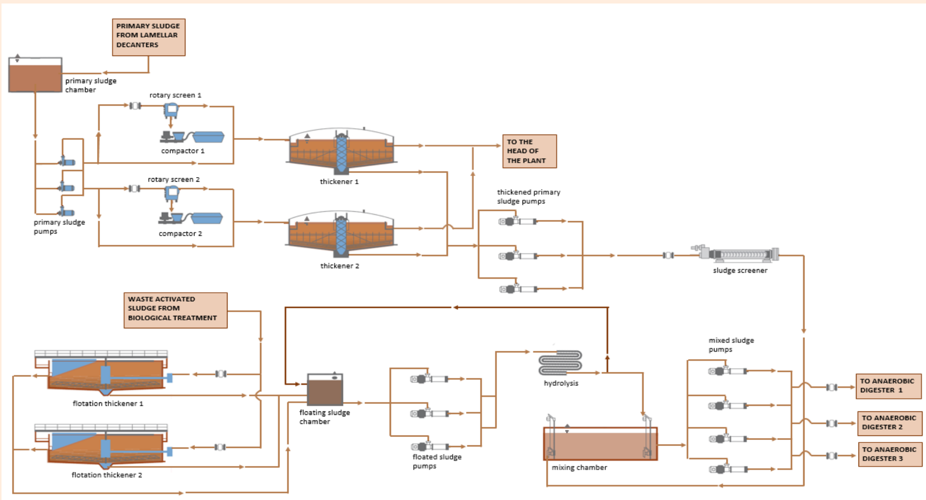

Figure 4. Murcia Este WWTP. Sludge thickening stage. Starting situation

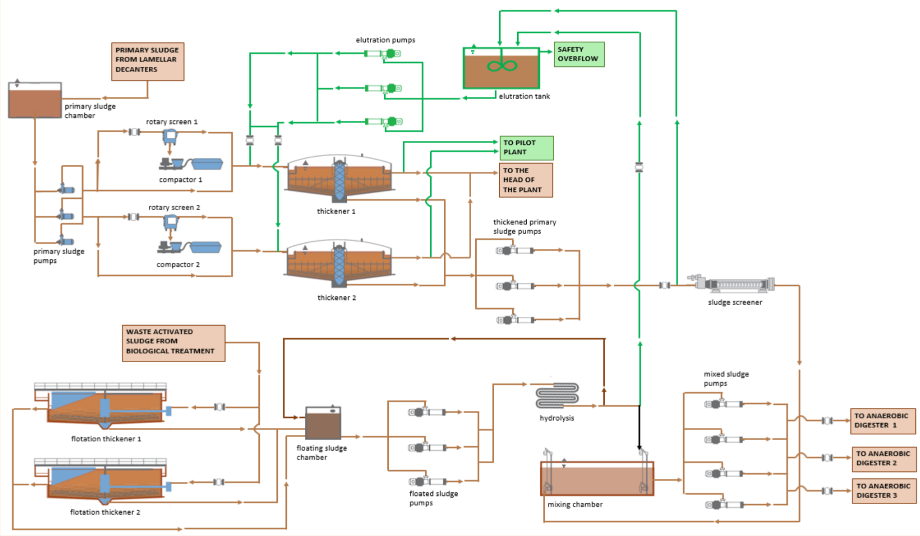

Figure 5. Murcia Este WWTP. Sludge Thickening stage. Elutriation integration

As Emuasa is a public company, the works should be tendered but, in order to have shorter deadlines and lower budget, it was decided to assume the work management, hiring the different services (civil work, electricity, hydraulic installation and programming). One of the requirements was that all modifications should be reversible, so instead of a tank made of concrete, the modification include a tank (elutriation tank, 700 m^3) made of GFRP, modular and removable.

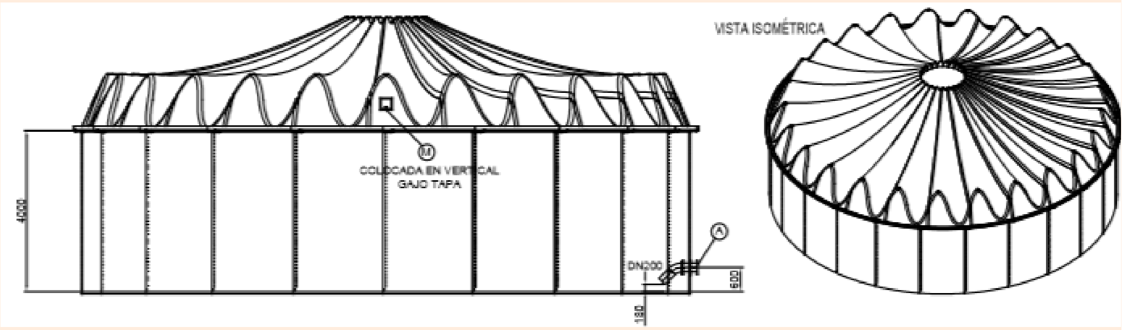

Figure 6. Elutriation tank

As the deposit is located in an area near the river, the composition of the land is filler material. In addition, Murcia is a region that presents a high seismic risk, so the manufacturers did not guarantee the stability of the unit and it has been necessary to brace the place by means foundation piles and slab; which has delayed significantly the initial forecasts.

Figure 7. Views of the works

The tank construction started in May 2019 and finished in June 2019.

Figure 8. Views of the elutriation tank assembly

The elutriation tank was fitted with special mixers in order to avoid blockages or dead zones.

Figure 9. Mixers

Following the indications of the UPV and in anticipation of the expected high concentrations of hydrogen sulfide during the operation of the prototype, in June 2019 the thickeners were emptied, the overflow channels cleaned and protected with a special coating and metal deflector bells replaced by new ones made of FRP (the cost of this intervention was assumed by Emuasa).

In July 2019, the opening of ditches and the installation of pipes and other hydraulic elements started: pumps, flow meters, valves and solenoid valves. The construction ended ended in September 2019.

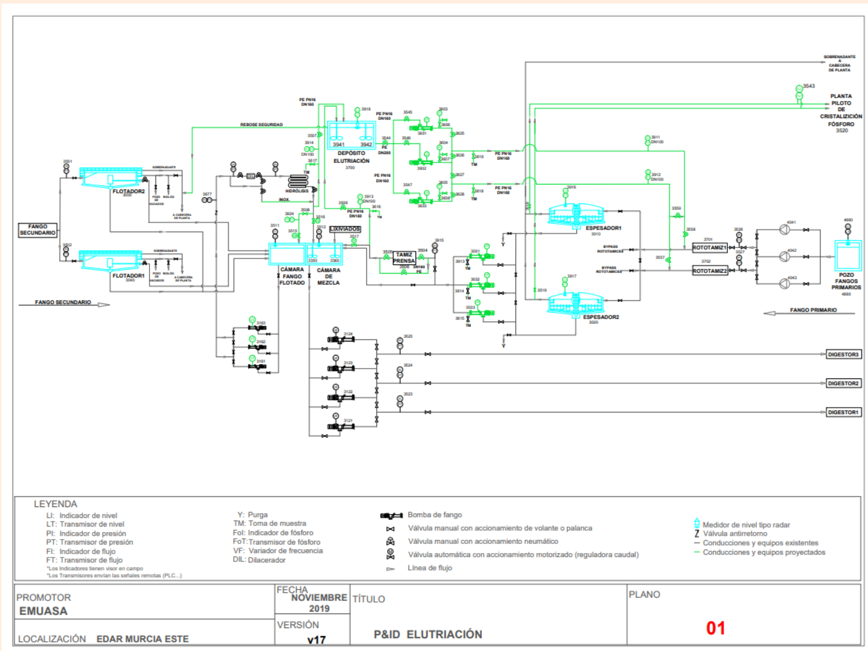

Figure 10. P&I diagram

2. ***Crystallization unit.*** J. HUESA was subcontracted for the construction of the pilot designed in action B.1.2. External piping and service supplies were installed by EMUASA. Due to several modifications on the design and delays on

equipment delivery, the timing planned for prototype manufacturing was extended. Construction started in June 2019, Factory Acceptance Tests (FAT) were performed late September 2019 in J.HUESA facilities; transport of the unit to Murcia Este WWTP and Site Acceptance Tests (SAT) were carried out in October 2019.

3. ***Nitrogen recovery unit.*** The nitrogen recovery unit was installed in Murcia Este WWTP in October 2019, external piping and services were previously installed by EMUASA. Membrane contactor was manufactured by J.HUESA following Action B.1.3 design, and in September 2019 it was integrated with the zeolite unit. The zeolite unit was also previously tested and prepared by Cetaqua, anticipating starting-up adjustments.

The control philosophy and the programming of the different units was defined during the design. Each unit has its own PLC from where the operation is easily controlled both on site and on remote. Remote connection to the pilots allowed monitorization, control and access to historic data and its download. Figure 11 shows a detail on the control system for crystallization unit.

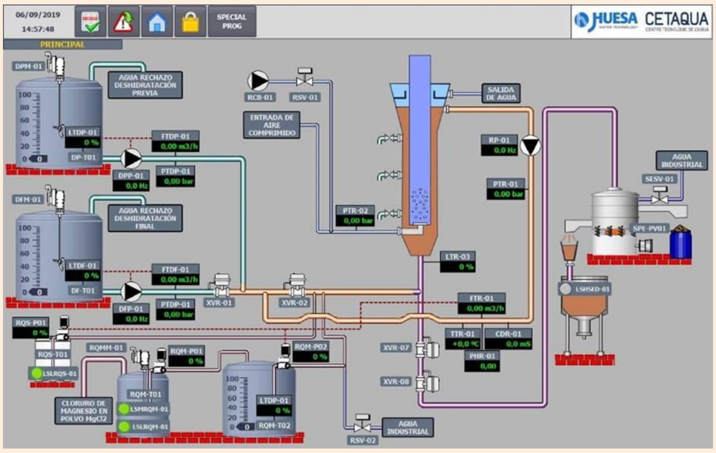

Figure 11. Visualization of the crystallizer control system

Design and construction details for crystallization unit and N recovery unit are included in Deliverables *D8_Design and technical specifications of the crystallization unit* (Annex 2.4) and *D9_ Design and technical specifications of the nutrient recovery unit* (Annex 2.5).

Discrepancies / reasons:

As a consequence of the delay of Action A1, the design of the different units that form the prototype was completed in July 2018 (4 months delay). The construction of the whole prototype was completed in October 2019, corresponding to 11 months of accumulated delay, mainly due to the modifications required in the design of the crystallization unit and the nitrogen recovery unit, the difficulties encountered during the implementation of the elutriation and delays on the equipment delivery; postponing the installation of both pilot units in Murcia WWTP until October 2019. Meanwhile, the zeolite unit was tested and adjusted by Cetaqua to improve its performance and reduce the start-up period. In the case of full-scale elutriation, the unpredicted need for a new tank and the geotechnical problems related with the tank construction cause that the new sludge line implementation finalized in September 2019.

Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D6. Simulations of different sludge line configurations for P recovery in Murcia Este WWTP.	100% completed
D8. Design and technical specifications of the crystallization unit	100% completed
D9. Design and technical specifications of the nutrient recovery unit	100% completed
D10. Implementation of the optimal sludge line configuration at full-scale in Murcia Este WWTP (technical specifications)	100% completed
M11. Mass balances and sludge line simulations	100% completed
M12. Implementation of a new sludge line configuration	100% completed
M13. Implementation of the crystallization unit	100% completed
M14. Implementation of the nutrient recovery unit	100% completed
M16. Validation of the performance of the overall prototype	100% completed

ACTION B2. Prototype operation and integration of results	
Responsible: Emuasa	**Status**: completed (100%)
Proposed start: November 2018 **Proposed end:** December 2020	**Actual start:** September 2019 **Actual end:** August 2021

Figure 12 shows B2 the schedule executed for the different prototype units (as it was approved in amendment), including start-up periods, operational periods and the operation stop because of Covid-19.

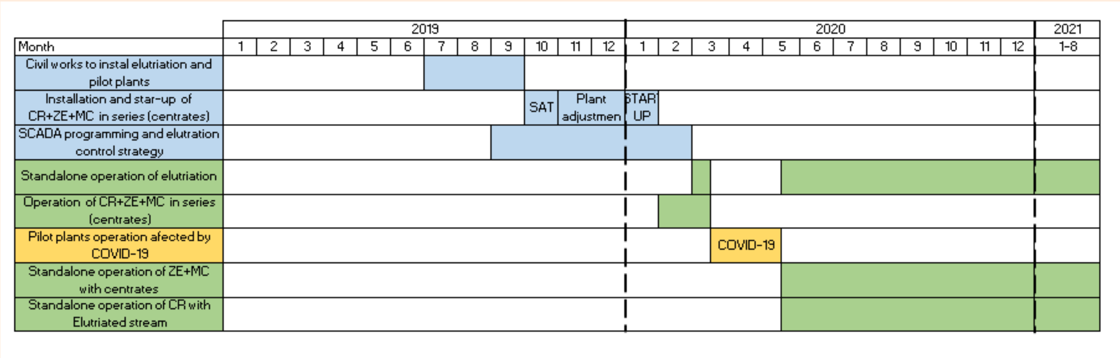

Figure 12. Chronogram for prototypes start-up and operation

Elutriation unit

The start-up process was carried out in October and November of 2019 and included hydraulic, electrical testing and the setting of online measurement equipment as the phosphate analyzer and the sludge blanket sensor. In December 2019 and January 2020 were the first tests of the new SCADA and between February and March 2020 the implementation and the validation of fuzzy control system.

Once start-up was concluded and the control loops adjusted, operation began in May 2020. Since then, several actions and modifications of the control strategies have been carried out to study how to implement the process in the Murcia-Este WWTP successfully (see Figure 12), achieving the highest phosphate (PO4) concentration in the overflow of the gravity thickeners without compromising the proper operation of the WWTP.

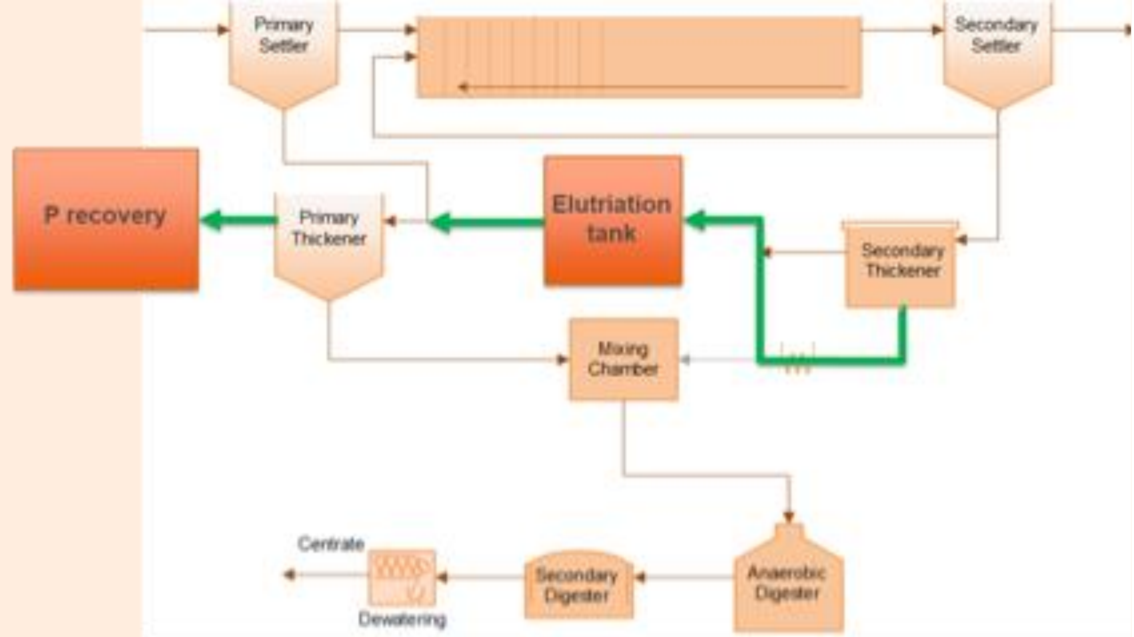

Figure 13. New sludge line configuration in the Murcia-Este WWTP

The description of the process configuration can be found in *Deliverables D6 (Simulations of different sludge line configurations for P recovery)* (Annex 2.3) *and D10 (Implementation of the optimal sludge line configuration at full-scale)* (Annex 2.6). It is important to remark that the elutriation process operation was performed with a phosphorus removal efficiency in the water line low and highly variable (48.6 ± 23.7 %) that limited the phosphorus recovery results.

The operational results of the elutriation took place in four different periods, in which different operating conditions were modified to achieve the highest PO4-concentration as possible in the recovery stream:

- Period 1, May – October 2020: In that period all the bio-sludge was sent into the Elutriation Tank to enhance the solubilization of the poly-P stored in the bacteria under anaerobic conditions. This was a set-up period in which several set-points and control loops configurations were tested trying to find the best way to operate the sludge line.
- Period 2, November – December 2020: Period with 100% of secondary sludge elutriated. During this period some settleability problems were detected in the primary thickeners. Therefore, it was changed the experimental procedure increasing step by sped the amount of biological sludge elutriated.
- Period 3, December 2020 – June 2021: In this period was tested the elutriation effect over the settleability of the mixed sludges increasing step by step the % of biological sludge elutriated: from 38 % until the 60 %.
- Period 4, June – November 2021: During this period at least the 80 % of the secondary sludge was elutriated and the process was operated under stabilized conditions. Along this period the % percentage of sludge elutriated was increased punctually up to 100%. The operation of the elutriation with an 80% of the biological sludge under stable conditions, achieved a P concentration in the recovery stream of 38.2 ± 8.4 mg $P\text{-}PO_4$ L-1 and a % of the influent P in

the recovery stream of 17.3 ± 4.8 %. It is remarkable that without elutriation this percentage was lower than 4%.

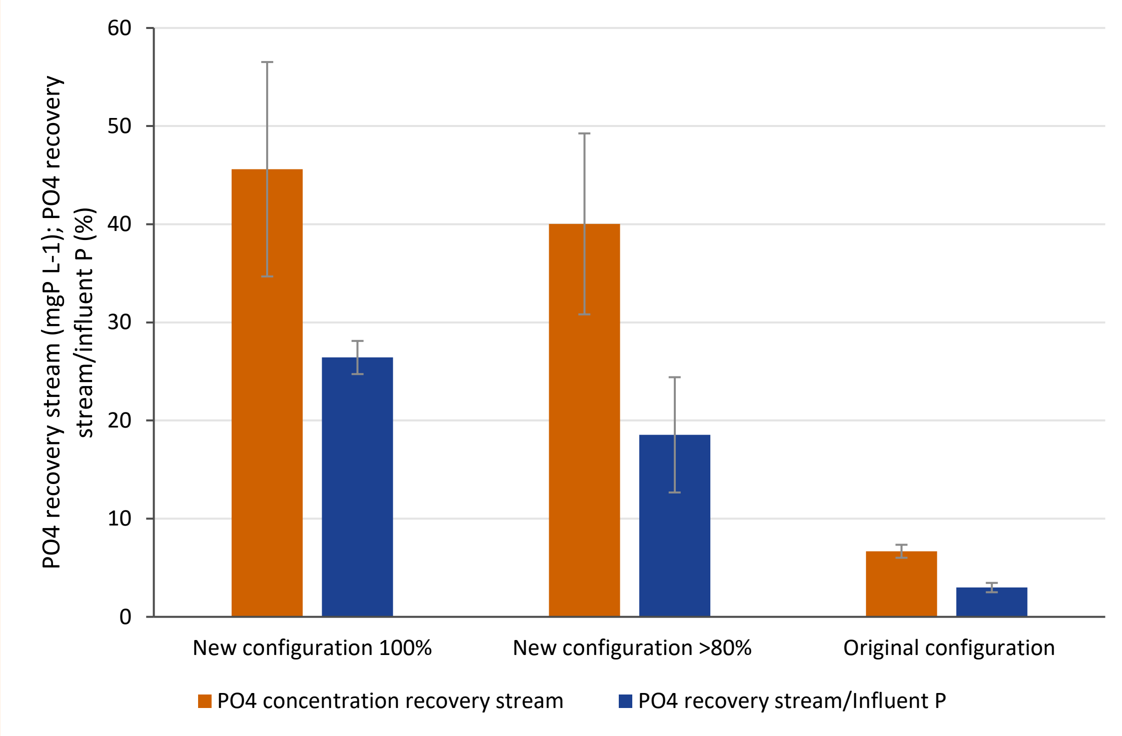

Figure 14. Comparison of phosphate recovery with and without elutriation

During this action some experiments were performed in order to study the settleability of mixed sludges and the fermentation process in the elutriation tank at different residence times.

Currently elutriation operation is steady in Murcia Este WWTP, treating 80% of the biological sludge, because higher proportion of sludge leads to problems related to the HRT of the digesters.

So far, the main effects observed are:

- ✓ There are not odor problems in the area, neither corrosion problems in the process units.
- ✓ The consumptions of antifouling reagent are lower, and the reduction of struvite precipitations is significant, allowing to reduce the periodicity of the physical cleanings of the centrifuges.
- ✓ There is a reduction in sludge production, energy consumption in dewatering centrifuges and polymer consumption in dewatering centrifuges due to the improvement of sludge dewaterability

These effects are quantified in comparison with baseline in LCA and LCC in Action B4.

Crystallization unit

Factory Acceptance Tests (FAT, September 2019) were carried out at J.HUESA factory in Sevilla, being supervised and revised both from prototype designers from Cetaqua and the head of operations from EMUASA. Site Acceptance Tests (SAT, October 2019) were held at Murcia Este WWTP, being there present members of EMUASA, Cetaqua and J.HUESA. A prototype operation guide was developed by J.HUESA, revised by EMUASA and CETAQUA and distributed to the WWTP personnel. In addition, personnel from Cetaqua and J.HUESA formed the operators who worked on the pilot on how to operate the pilots safely and effectively.

During the pilot plant construction, the experimental and analytical plan was determined. Several experiments have been planned and executed by combining different operational strategies in order to optimize the performance of the prototype. The operation schedule is shown in the Figure 12, with a stat-up period of 3 months.

Two different feeding streams were studied: first, centrates from dehydration, from the start-up in October 2019 until March 2020, then, supernatant from primary thickener (after elutriation), from June 2020 until August 2021. Monitoring plans were adjusted depending on the operation performance and the experimental plan. Different streams were monitored, including influent and overflow of reactor characterization daily to weekly (TSS, P-PO_4, N-NH_4, Mg, pH, Ca, K, etc.), chemical dilutions concentration when prepared (Mg, P-PO_4, N-NH_4). Also, struvite characterization was performed with different frequency for different parameters depending on the variability associated (granulometry, P, N, Mg content, TOC, trace components (Ca, K), as well as purity by XRD and SEM analyses, metal content, PAHs, pathogens and micropollutants).

Operation with centrates was complex due to high content in TSS (Total Suspended Solids) and discontinuous production flowrate on the WWTP. Also, struvite clogging problems were detected. During start-up period, protocols to reduce TSS to 0.3-1 g/L and to avoid clogging problems were implemented, also, a semi continuous supply of centrates to the crystallizer was possible. Figure 15 shows how TSS in centrates was reduced and TSS reduction in the reactor as consequence. During operation with centrates, concentrations in centrates of P-PO_4 was significantly variable, affecting the stability of the operation and the P recovery rate as struvite, as it is shown in Figure 16.

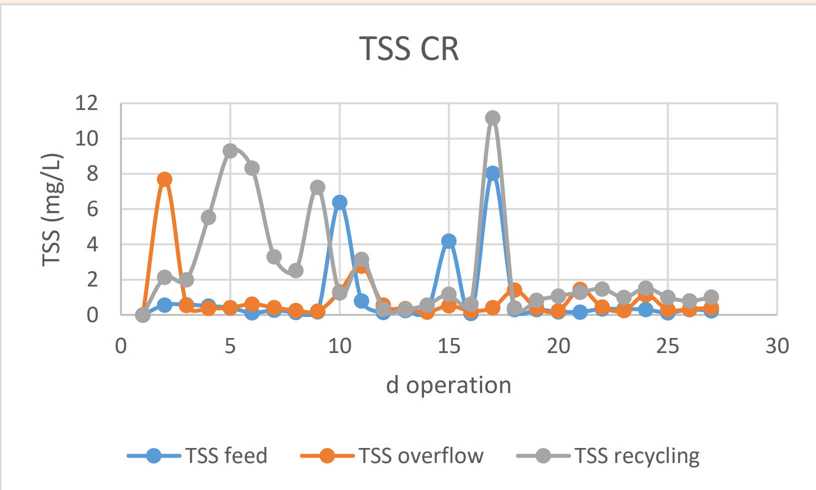

Figure 15. TSS in feed, recycling and overflow in crystallization reactor during operation with centrates

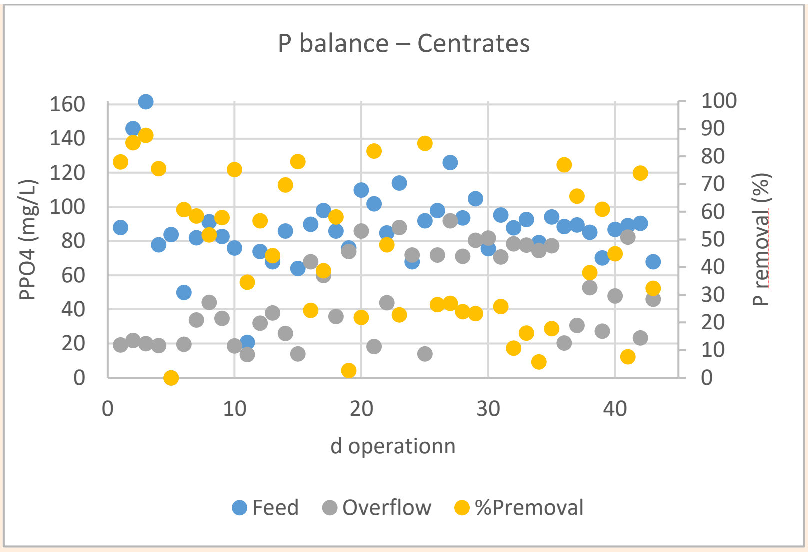

Figure 16. P-PO_4 concentration in reactor's feed and overflow and P removal for centrates operation

During operation with supernatant from primary thickeners, continuous operation was achieved. Different parameters were analyzed to stablish optimal P recovery rate as struvite, such as P-PO_4 concentration in reactor feed, Mg/P and N/P molar ratios; pH control was critical parameter to assure stable operation and struvite quality.

Finally, optimal operation conditions were determined to maximize P recovery and obtain high-quality struvite, and used for chemical consumption determination and, ultimately, for scale up, LCA and LCC performed in B4.

Technical assessment for crystallization unit showed a 85% of P recovery for P-PO_4 concentration in the inlet of 100 mg/L (Figure 17) showing optimal continuous operation at pH 8.2 and molar ratios of 1.3 for Mg/P and 4 for N/P.

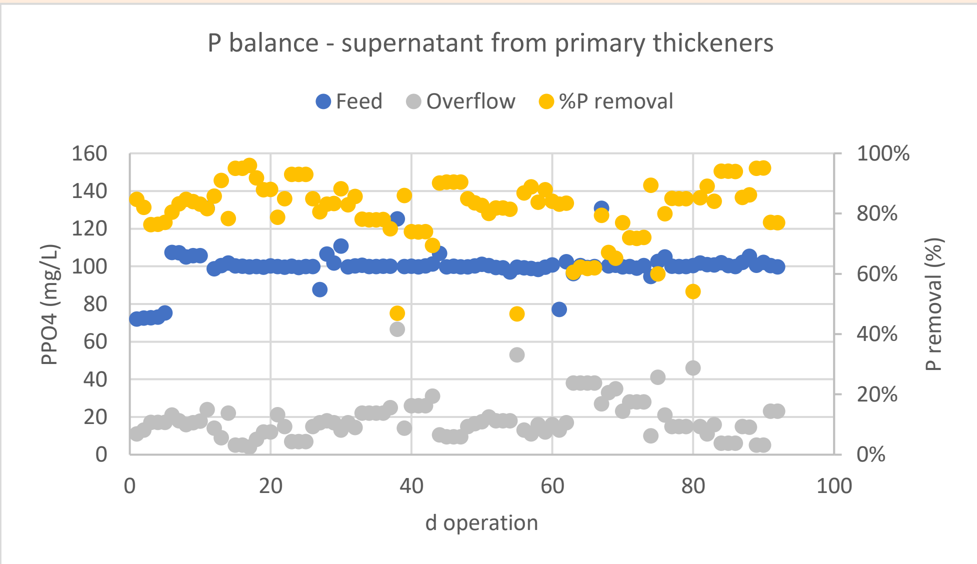

Figure 17. P-PO_4 concentration in reactor's feed and overflow and P removal for supernatant from primary thickeners operation

Struvite monitoring during operation by means of microscope images and harvestings allowed to quickly assess the overall performance of the crystallization process. Figure 18 shows struvite harvested and a microscopic view of coffee-shaped granules produced in Murcia Este WWTP.

Figure 18. Struvite harvested and struvite under microscope from crystallization process

Phosphogreen crystallization for P recovery as struvite is a robust technology that can operate under different P-PO_4 feeding concentrations, achieving 85% of P recovery for an initial P-PO_4 concentration of 100 mg/L of P-PO_4, under molar rations of 1.3 Mg/P and 4 N/P, and pH of 8.2. Continuous operation, low TSS and stable pH are critical for stable operation, although the process can handle deviations during short periods of time without compromise struvite quality. Chemical consumption of crystallization process if related to NaOH to pH adjustment and $MgCl_2$ as Mg source, at 0.4 kg NaOH/kg of struvite and 0.19 kg $MgCl_2$/kg of struvite, for feeding stream with 84 mg/L of Mg and pH of 7.21.

Struvite produced during operation complies with quality requirements defined in new European Fertilizers Products Regulation (EU FPR 2019/1009), with a main granule size of 0.5-1 mm diameter, a minimum content of P_2O_5 of 25.9%. Main impurities are TOC and Ca, without compromise the quality of the struvite. Other trace toxic compounds, such as metals, micropollutants, PAHs and pathogens were determined under limit values.

Nitrogen recovery unit

Factory Acceptance Tests (FAT, September 2019) were carried out at J.HUESA factory in Sevilla, being supervised and revised both from prototype designers from Cetaqua and the head of operations from EMUASA. Site Acceptance Tests (SAT, October 2019) were held at Murcia Este WWTP, being there present members of EMUASA, Cetaqua and J.HUESA. A prototype operation guide was developed by J.HUESA, revised by EMUASA and CETAQUA and distributed to the WWTP personnel. In addition, personnel from Cetaqua and J.HUESA formed the operators who worked on the pilot on how to operate the pilots safely and effectively.

The operation of the prototypes (led by Cetaqua and executed by EMUASA) and the integration of results (Cetaqua) started with several operating problems due to the high TSS content of the stream, which required the optimization of the pretreatment in order to avoid continuous stops due to high pressure (Figure 19). On the other hand, MC pilot plant had several parts that had to be replaced due to corrosion from concentrated nitric acid.

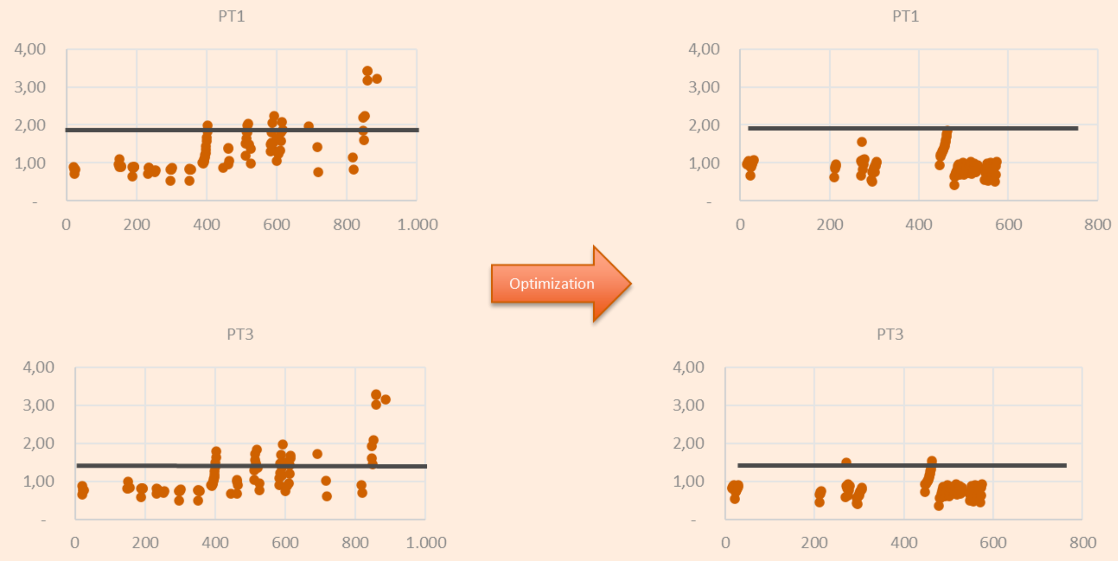

Figure 19. Reduction of the pressure in the filtration before and after the optimization

The methodology for the operation of the N recovery treatment train was based on developing 3 complete adsorption-desorption cycles in order to produce enough N rich stream in zeolites to feed the MC pilot plant. $N\text{-}NH_4$ was analyzed every 2 hours with kits to follow the decay in concentration in both pilots, along with periodical analysis of P, COD and TSS as well as pH. Pressure, pH, and conductivity were also monitored real time to control the operation. Also, punctual complete analytics were carried out in order to characterize other important parameters (heavy metals, ions and OMPs) from zeolites feed, effluent and regeneration stream as well as for the influent and fertilizer in the MC pilot.

Despite the operating problems, results demonstrated that zeolites with centrates load of 600-1000 mg $N\text{-}NH_4$/L, could achieve effluents with less than 150 mg $N\text{-}NH_4$/L (Figure 20) with a cation exchange capacity of 20 mg $N\text{-}NH_4/g_{zeo}$ and achieving a maximum concentration in the regeneration stream of 4.85 g N-NH/L which corresponds to a concentration factor of 6.5.

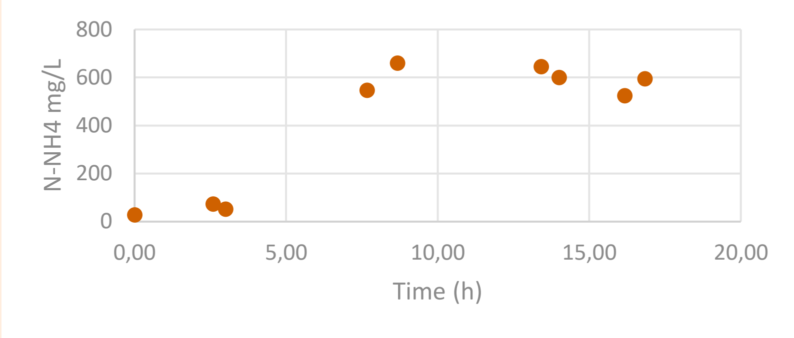

Figure 20. Zeolite's breakthrough curve

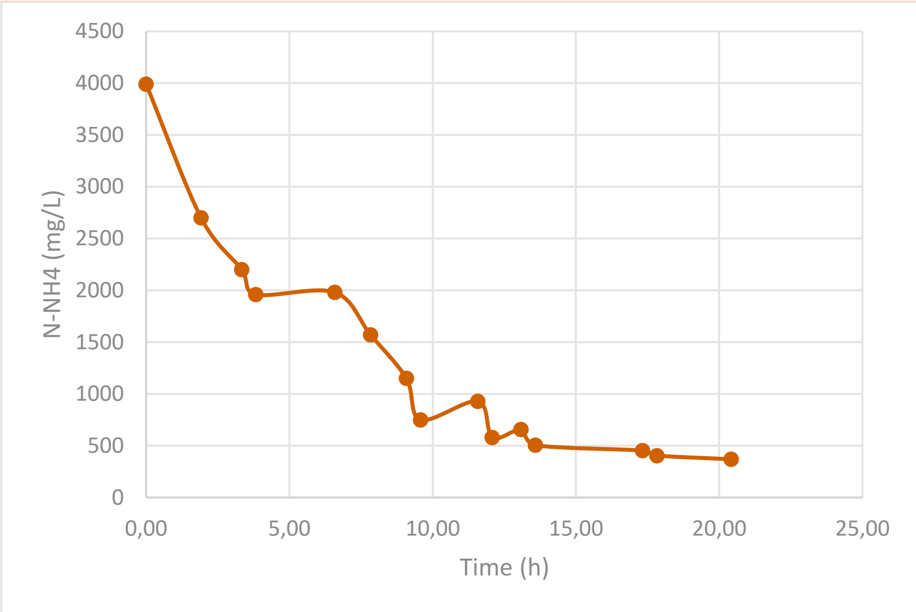

Figure 21. Performance of membrane contactors

In membrane contactors up to 91% of N-NH_4 is removed from concentrated stream (Figure 21), which allows to recycle NaOH back to zeolites unit. In membrane contactors up to 9 lots of fertilizers have been produced. N composition of the ammonium nitrate produced is shown in Table 1.

Table 1. Fertilizer characterization

	$N\text{-}NH_4$ (g/L)	$N\text{-}NO_3$ (g/L)	Nt (%)
1	9,7	67,30	7,7
2	22,6	235,46	25,8
3	15,3	95,04	11,0
4	8,2	65,79	7,4
5	12,4	101,40	11,4
6	14,4	140,46	15,5
7	13,2	69,33	8,3
8	18,4	148,01	16,6
9	12,3	127,12	13,9

This N recovery treatment train can recover up to 70% of ammonium contained in centrates, with efficiencies of 77% for zeolites adsorption columns and 91% for membrane contactors. Ammonium nitrate specific analysis showed that it is OMP and metal free, suitable for fertilizer use.

More results and conclusions over elutriation and P&N recovery pilots start up and operation are available in Deliverables *D13_Report on the start-up of the prototype* (Annex 2.11) and D20_ Report on the operation of the prototype (Annex 2.15).

Discrepancies / reasons:

Action B2 was planned to start on November 2018, but due to Action B1 delays on prototype implementation this action has started on October 2019; the project extension allowed to achieve robust results in order to assess technical viability of technological solution.

It is important to remind that in the proposal, 5 products were planned to produce and test: struvite, dirty struvite, ammonium nitrate, ammonium phosphate and ammonium sulphate. As reported in the first Progress Report, three of them were discarded after a meeting with the executive board for technical reasons. Dirty struvite and ammonium sulphate presented a lack of fertilizing interest compared to the others in our soil and water chemical composition. Ammonium phosphate, which only contains recovered N, was considered a less environmental-friendly strategy rather than combining ammonium nitrate mixed with struvite as a substitutive treatment, due to the use of both N and P recovered nutrients. These modifications in the fertilizing products to test were agreed in order to deeply study the most suitable combination of products considering the plant needs and fertigation management (fertilization and irrigation). The experiments have been prioritized in order to assure the reliability and transferability of the results.

Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D13. Report on the start-up of the prototype	100% completed
D20. Report on the operation of the prototype: Recovery of N and P from WWTP	100% completed
M19. Stable operation of the prototype	100% achieved
M30. Successful operation of the prototype for the recovery of N and P from wastewater	100% achieved

ACTION B3. Definition of fertilizers by optimal mixing of the products obtained and evaluation through field tests

Responsible: IRTA	**Status**: completed (100%)
Proposed start: February 2019 **Proposed end:** October 2020	**Actual start:** June 2018 **Actual end:** September 2021

Main activities during the reporting period:

Characterization of the products obtained

1. **Dewatered sludge from Murcia Este WWTP**

Cetaqua did a characterization of the sewage sludge from Murcia Este WWTP before the elutriation process, in order to validate its suitability for agriculture application, and these sludges were used in the open-air crops in Lleida. The heavy metals content and organic micropollutants (which are the main compounds that may represent a limitation for agricultural application) are not expected to change in a significant way. The results of such analysis indicate that its composition does not represent a limitation for its application in agriculture beforehand. However, the richness in nutrients is poor concerning the content reported for sewage sludge compost (ARC, 2015*) and contains a high humidity that often difficult the application. More specific data is provided in the Deliverable *D24 Field test results* (Annex 2.17).

* Agència de Residus de Catalunya, 2015. Informe de resultats analítics de mostres de compost de FORM, compost de fems, compost de fangs de depuradora I compost de restes vegetals realitzats als anys 2014 I 2015 al Laboratori Eurofins. Departament de Gestió de la Matèria Orgànica. Agència de Residus de Catalunya. Departament de Territori i Sostenibilitat de la Generalitat de Catalunya.

2. **Struvite**

In the proposal, two types of struvite were planned to test: dirty struvite and struvite. After discussion with the experts (ASG, IRTA) and the new EU-wide quality standards for struvite in the European fertilizer regulation (EC, 2019)*, the priority was given to perform the tests only with struvite since the properties and quality as fertilizer are expected to be much higher compared to the dirty struvite. The location of the pilot plant allows to directly produce struvite and since there is no limitation due to the quality of the influent fed to the Phosphogreen, the focus is only done on the production of struvite.

In order to cope with the delay of action B1, it was decided to start testing struvite from another municipal wastewater treatment plant placed in Denmark that has the same technology (Suez) that has been implemented in Murcia. This product was similar to the one that was produced by the crystallization unit designed and built during Action B1 located in Murcia Este. As an added value, it was possible to compare the struvite from Denmark with the one from Murcia and verify that there is any difference in terms of fertilizer capacity. Besides, the physico-chemical characterization of both struvites assessments showed similar values. More specific details are provided in the Deliverable *D17 Characterization of the different products obtained from WWTP and definition of optimal mixtures* (Annex 2.13).

* EC, 2019. Regulation (EU) 2019/1009 of the European Parliament and of the council of 5 June 2019 laying down rules on the making available on the market of EU fertilizing products and amending regulations (EC) no 1069/2009 and (EC) no 1107/2009 and repealing regulation (EC) no 2003/2003 (text with EEA relevance). European Parliament. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R1009

3. Ammonium salts

Three different ammonium salts were planned to test: ammonium nitrate, ammonium phosphate and ammonium sulphate. During the first meeting of the executive board, the ammonium sulphate was discarded to be tested because it is less effective and generally there is no need of sulphur in our soil conditions. The ammonium salts were obtained from the membrane contactors placed in UPC.

Among the two salts tested, it was decided to prioritize ammonium nitrate because its combination with struvite results in a more suitable fertilizer mixture due to the high nitrogen needs of the crops. More specific details are provided in the Deliverable *D17 Characterization of the different products obtained from WWTP and definition of optimal mixtures* (Annex 2.13).

Definition of optimal mixtures to produce high quality fertilizers

In terms of application of the struvite as a fertilizer, several studies on struvite agronomic efficiency have been focused on its potential as slow-release fertilizer applied to the soil. Nevertheless, the use of struvite in fertigation as a raw material (liquid fertilizer) for nutrient solution (NS) manufacture has not been studied so far. Thus, as a key objective of the application of struvite, to carry out the fertigation trial, it was essential to define in advance a dissolution protocol in order to avoid delays during Action B3. The dissolution tests were done under different pH conditions, the kind of acid (citric/nitric acid), and struvite particle size (granular/ground). Struvite was nearly fully solubilized at pH 4 and 1 with both acids and struvite sizes. These results lead to prepare a concentrated nutrient solution (cNS), which would have all nutrients concentrated before being mixed with irrigation water in a proportion 1:100 (v:v), using nitric acid at pH range 1-2 to obtain an appropriate pH in the final dripper NS, considering the irrigation water properties (pH and carbonates). From the practical point of view, the use of struvite in fertigation can be performed when preparing the fertilizers in an intermediate tank with a cNS. Further results about the struvite dissolution test are provided in the Deliverable *D24 Field test results* (Annex 2.17).

Three different compositions of nutrient solution (NS) were tested, differing on the P and N sources: i) struvite (STR) treatment, with 100% and 17±4% of P and N-recovered source, respectively; ii) struvite and ammonium nitrate (SAN) treatment, with 100% and 39±11% of P and N-recovered source, respectively; and iii) the conventional fertilization or control (CON) treatment, using solely synthetic mineral fertilizers. The recovered nutrients were the P and N from ground struvite (struvite from Denmark during 2019 campaign and from Murcia Este during 2020 and 2021 campaign) and the N-NH_4^+ from liquid ammonium nitrate (AN). The reference P fertilizer used in the CON nutrient solution was monopotassium phosphate (KH_2PO_4). Other commercial fertilizers were used to complete the NS and to diminish the pH: nitric acid, potassium nitrate, potassium sulfate, calcium nitrate, and micronutrients. The NS compositions consisted of standard nutrient solutions adapted for the different crops (adaptations from Muñoz et al., 2008; Ruano et al., 2010). The second growing campaigns' NS composition was adjusted from the results obtained in the first campaign. The protocol of fertigation with the detailed composition of the Nutrient solution for each crop and campaign are described in the *D24 Field test results*.

Definition of optimal mixtures to use dewatered sludge as a soil conditioner

The different fertilization plan of the plots was developed according to the following premises:

- Extractions from crops and productions have been based on Department of Agriculture data and previous ASG personnel experience.
- Surface cultivated for each crop and estimate production.
- The fertility of the soil. It is essential to know the type of soil and its characteristics at the initial point of the study. Therefore, in October 2018, soil samples were taken to perform a complete soil analysis for each plot.
- The fertilizer dose recommendations for winter cereals are based on the initial fertility of the soil and the phosphorus (P) and potassium (K) needs of the specific crop, which was based on the recommendations established by Villar. J.M. and Villar P (2016).
- The nutrient richness of the sewage sludge and pig slurry. The nutrient richness of the sewage sludge was taken from the analysis carried out by EMUASA. The richness of the pig slurry was obtained with the measures carried out by a conductivity meter and the tables of the Department of Agriculture of the Catalan Government
- Regulation of maximum doses of N to be applied in vulnerable areas (Decrete 136/2009), Decree 476/2004. Agreement GOV/128/2009 and Agreement GOV/13/2015.
- Regulation of maximum doses of sewage sludge to be applied (Real Decree 1310/1990).

- The sewage sludge or slurry were added before sowing as a base dressing in a single application at the beginning of the winter grain crop (barley or oats). In this way, the P needs of the double-cropping are satisfied. If necessary (sewage sludge is poor in K), the remaining potassium (K) is added with commercial fertilizer. These nutrients are considered poorly soluble and therefore will be available to plants throughout the production cycle. In the case of nitrogen (N), which is a soluble element, it is provided in various applications throughout the crops cycle. Once the base dressing fertilizer has been applied, the N needs are calculated based on the amount of $N\text{-}NO_3^-$, present in the soil just before flowering in the case of beans, and at the beginning of March in the case of barley or oats and then top dressing fertilizer were applied.

The quantities and types of fertilizers applied are shown in the Deliverable *D24 Field test results* (Annex 2.17).

Field tests under controlled conditions

Field trials with horticultural crops under controlled conditions (IRTA, Cabrils) (Figure 22) and on a real case study under open-air conditions (ASG, Lleida) (Figure 23).

Under controlled conditions in two greenhouses in Cabrils center (IRTA facilities at Barcelona, Catalonia) both recovered products, struvite and ammonium nitrate, have been tested in tomato, cauliflower and lettuce crops in soil as a 2-years crop rotation and in soilless system with perlite growing media (only tomato crop).

In Open-air conditions in Lleida (ASG) struvite has been tested for tomato, broccoli and lettuce in two locations, Agramunt and Castelldans. Both recovered products, struvite and ammonium nitrate, have also been tested for lettuce in Agramunt.

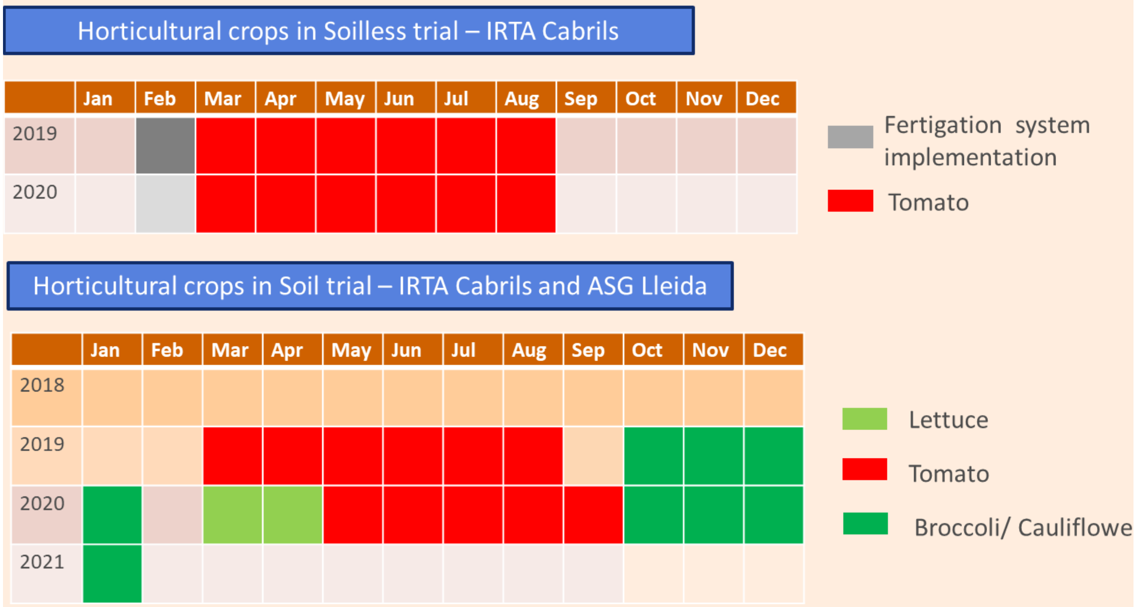

Figure 22. Experimental design of the field trial with horticultural crops under greenhouse conditions in IRTA, Cabrils.

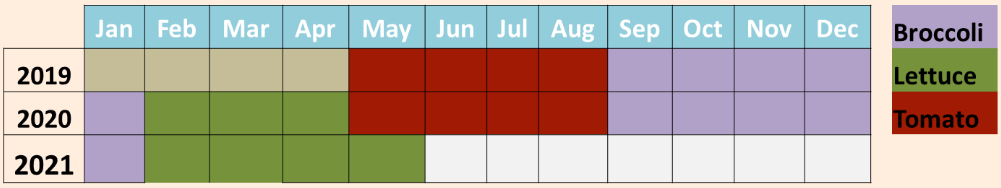

Figure 23. Experimental design of the field trial with horticultural crops on a real case study under open-air conditions (ASG, Lleida).

The main experimental results and conclusions obtained from the field trials are:

- For the first time, struvite has been used in fertigation in edible crops, as a raw material (fertilizer) for nutrient solution manufacture, and this use has been fully successful. However, it is important to consider the irrigation water composition, especially the bicarbonates, due to their function as solution buffer.
- LIFE ENRICH field trials showed that struvite and ammonium nitrate recovered products used as fertilizers in fertigation systems for tomato, broccoli, cauliflower, and lettuce crops were, in general, equally effective in total yield (fresh or dry matter) and quality product (fruit/inflorescence/leaves) compared to conventional fertilizers, both in the greenhouse conditions in soil and soilless growing media and at Open-air conditions. However, there were some differences in marketable yield for struvite + ammonium nitrate treatment, which promotes its use under consideration of the ammonium tolerance of the crop variety/species. Moreover, the similar P and N uptake results obtained by the different crops using recovered products and conventional fertilizers enhance the potential partial substitution of the use of P and N mineral fertilizers. In addition, the amount of the heavy metals regulated in fruits did not reach the permissible limit suggested by FAO/WHO, considering that recovered products used accomplished for the new legislative requirements for precipitated phosphate salts in the revised fertilizer directive (EC, 2019).
- Regarding the environmental impacts, soil analysis data after two years of crop rotations showed that the nutrient ($N\text{-}NO_3^-$, P(Olsen) and Mg^{2+}) concentration levels in soil at 0-30 cm depth were lower than the initial ones, suggesting that an optimal fertilization management was carried out. In addition, soil-plant-rhizosphere microbiota assessment revealed that fertigation has promoted a diversification of the bacterial and archaeal community, although not its growth in abundance, regardless of the composition of the NS and the raw materials used. An increase or non-significant differences in alpha diversity indexes of bacteria and archaeal communities at the end of the crop rotations compared with the beginning was observed, even after the long-term agricultural history of the soil used, underlying the importance of crop rotation among the practices that favor preserving the natural microbial communities. However, it is important to highlight that struvite + ammonium nitrate treatment, in

which nutrient solution has higher ammonium concentrations, tends to diminish its diversity.

- The nutrient solution composition results show that for soilless tomato cultivation under Mediterranean climatic conditions, the concentration of nitrogen in the nutrient solution can be reduced to a lower and dynamic 5-8-5 meq·L^{-1}, considering the development stage of the crop, without reducing yield or physical quality, which may cause the reduction of nitrogen leaching and its subsequent environmental impact to the water bodies.
- The dewatered sewage sludge exhibited no differences in arable crops production compared to commercial fertilizer. However, the low nutritional richness of the sludge makes its transport expensive.

More specific explanations are provided in the Deliverable *D24 Field test results* (Annex 2.17).

* P. Muñoz, A. Antón, A. Paranjpe, J. Ariño, J.I.Montero. High decrease in nitrate leaching by lower N input without reducing greenhouse tomato yield. Agronomy for Sustainable Development, Springer Verlag/EDP Sciences/INRA, 2008, 28 (4), pp. 489-495

Ruano, S. (2010). Guía práctica de la fertilización racional de los cultivos en España. Ministerio de Medio Ambiente y Medio Rural y Marino.

Field trials with arable crops on a real case study in ASG Lleida

The works of field conditioning started in June 2018, previous than planned. The experimental design of the arable field crops was (Figure 24) one treatment with sewage sludge and potassium chloride, and the other one with pig slurry, used as a fertilizer control. In Castelldans, the surface of both plots, sewage sludge and control treatment was 0.25 ha each. In Agramunt, the surfaces were 0.56 ha for each treatment.

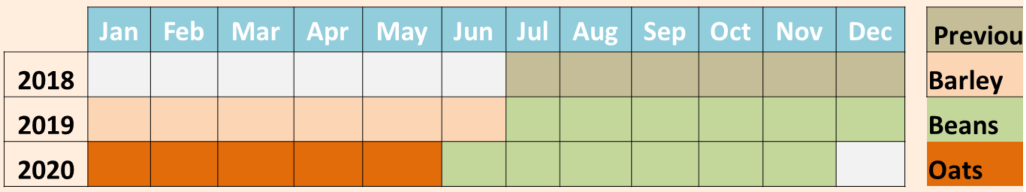

Figure 24. Experimental design of the field trial with arable crops on a real case study in ASG Lleida

Double cropping was grown in the 2019 campaign, barley (Hordeum vulgare, Planet®), and beans (Phaseolus vulgaris, Arrocina®). In Agramunt, barley was sown on January 19th and it was harvested in July. Then, beans were sown on July 24th. In Castelldans, barley was sown on January 29th, and the harvest was in July. Then, beans were sown on July 22nd.

In 2019 a short-cycle seed (Arrocina) was used, which was expected to reach physiolgical maturity of plant within 90 days. However, this did not happen in neither locations. Thus, we didn't get grain beans. Then, in 2020 it was decided to sow oats (Avena sativa, Prevision®) and change the variety of beans (Phaseolus vulgaris, Michigan®), to be sown in early June. In Agramunt, oats were sown on January 20th and were harvested on May 22nd. Beans were sown on June 10th and the harvest in grain was on October 30th. In Castelldans, oats were sown on December 19th and the harvest was on June 6th. Beans were sown on June 12th. However, due to the high temperatures of Castelldans, during flowering, no grain beans were obtained neither. The few grain beans obtained were from the second flowering, which is usually very scarce. There is a poor adaptation of the bean to hot zones. We have seen that in this area, it is not feasible to grow beans as a second crop.

The results of grain beans in Castelldans were obtained by drying the plant in a warehouse, as in the field it will not be possible to obtain it due to frost before harvest.

Irrigation management of the crops (frequency and volume) was mainly based on evapotranspiration data from the Ruralcat webpage, which is a service of the Catalan Government (https://ruralcat.gencat.cat/agrometeo.estacions) Then, irrigation volumes were modified according to the evolution of the water content in the soil.

The fertilization plan of the plots was developed according to the fertility of the soil, the crops extractions the planned productions and the nutrient richness of the sewage sludge, the potassium chloride and the pig slurry. The sewage sludge or slurry dose was added before sowing as a base dressing in a single application at the beginning of the winter grain crop (barley or oats). In this way, the P needs of the double-cropping are satisfied. If needed (sewage sludge is poor in K), the remaining potassium (K) was added with commercial fertilizer. These nutrients are considered poorly soluble and therefore were available to plants throughout the production cycle. In the case of nitrogen (N), which is a water-soluble element, it is provided in various applications throughout the crops cycle top dressing.

Barley production of 2019 of the sewage sludge treatment was lower than the control treatment one, both in Agramunt (-12%) and in Castelldans (-1%) (Figure 24).

Oats production of 2020 of the sewage sludge treatment was higher in Agramunt (6%) and lower in Castelldans (-6%) compared to the control treatment.

Beans grain production of 2019 of the sewage sludge treatment was higher than control in Agramunt (3%) (Figure 24). In contrast, production in 2020 showed lower values in the case of sewage sludge treatment (-1%).

As a summary, it is considered that the use of dewatered sewage sludge exhibited no significant difference in arable crops production compared to commercial fertilizer, although there is a trend of having higher yields with the control treatment.

Figure 25. Sowing barley in Castelldans and beans crop cultivation in Agramunt

Discrepancies / reasons:

Action B3 should start in February 2019. However, in order to anticipate potential operational problems during Action B3, some not forecasted activities have been carried out starting the Action on June 2018.

Regarding the described trials, few discrepancies were found. As it has been mentioned, the first growing campaign was carried out using struvite produced in Denmark; for the second growing campaign, struvite from Murcia Este was used. Moreover, some different management of the fertigation system was done between Cabrils and Lleida due to the different irrigation water compositions and the technical possibilities. While in Cabrils the irrigation water has a 7.7 pH, 1.3 $mS \cdot cm^{-1}$ electrical conductivity and 5.52 $meq \cdot L^{-1}$ of bicarbonates, in Lleida (Agramunt and Castelldans) it has a 8.4-8.7 pH, 0.24 $mS \cdot cm^{-1}$ electrical conductivity and 1.2-1.6 $meq \cdot L^{-1}$ of bicarbonates. The irrigation water used in fertigation in the Lleida area has a low bicarbonate concentration, resulting in a low buffering capacity of the acidity of the cNS. Thus, a solution of potassium carbonate was added to buffer the fertigation water.

Current state of the action and envisaged progress until next report:

This action has been completed. However, during the project it was identified the interest of an soil-rhizosphere-microbial community assessment, so some samples were taken and analyzed from the initial and final stages of the crop rotations in soil and the tomato crop during 2020 campaign in both growing media, soil and soilless, to determine the fertigation impact in the soil in general and in detail in the tomato crop, and relate microbiota data with nitrous oxide (N_2O) emissions. The sampling of the initial and final stages of the crop rotation is explained in the *D24 Field test results*. However, the N_2O emissions measures were few and results were not robust and microbiome results from the tomato crop still have to be analyzed due to the complexity of the data obtained. Thus, the study will continue in this line of work and results will be included in an article that is expected to be published in 2022.

Deliverables (D) and Milestones (M):

D17. Characterization of the products obtained and definition of optimal mixtures	100% completed
D24. Field test results	100% completed
M22. Characterization of the products obtained	100% completed
M24. Definition of fertilizer products by optimal mixing of the products obtained	100% completed
M36. Results of the field tests in the Research Center	100% completed
M36. Results of the field tests in the commercial plot	100% completed

ACTION B4. Technical, environmental and economic assessment of the LIFE ENRICH process (nutrients recovery from wastewater followed by fertilizers production).

Responsible: Cetaqua	**Status**: completed (100%)
Proposed start: September 2019 **Proposed end:** August 2020	**Actual start:** September 2019 **Actual end:** August 2021

Main activities during the reporting period:

The technical efficiency, the environmental impact and the economic feasibility of the LIFE ENRICH value chain (nutrients recovery and valorization in agriculture) were assessed for a full-scale process implementation in Murcia Este WWTP and through the LCA (Life Cycle Analysis, using the sorftware SimaPro) and LCC (Life Cycle Cost) methodologies. A comparison between the current situation (conventional scenario) and LIFE ENRICH scenario (P&N recovery) was performed within a defined framework that involves WWTP operation, not only nutrient recovery but the whole installation, and field fertilizing, regarding recovered nutrients P and N and also K and Ca macronutrients present in most used conventional fertilizers.

A full-scale nutrient recovery LIFE ENRICH process was considered for this study, taking into account a favorable yet realistic scenario for bio-P removal within the Murcia Este current sludge line configuration that includes elutriation. For P recovery, the phosphates come from the supernatant of primary thickeners, while ammonium for struvite precipitation is coming from both supernatant and centrates. N recovery is placed after P recovery unit to maximize ammonium recovery.

A LCI (Life Cycle Inventory) was performed to detail all inputs and outputs in WWTP and in the field regarding the 3 scenarios studied (conventional (baseline), N&P ENRICH, P ENRICH), including consumptions, production volumes and pricings, obtained from WWTP dataset facilitated by EMUASA, WWTP characterization from A1, technologies validation from B2 and crop trials from B3.

Murcia Este full-scale projection for N&P ENRICH scenario will produce 1,100 t/y of struvite and 1,937 t/y of ammonium nitrate (21%$_w$), which accounts for 42% of P recovery and 11% of N recovery (8.4% as AN) of total P and N present in wastewater influent. Considering market prices of 350 and 410 €/t of struvite and AN, revenues would be of 354 k€/y and 794 k€/y, respectively (total of 1.17 M€). The estimated CAPEX will be of 4.76 M€ for struvite production (75 k€ for elutriation process) and 1.39 M€ for AN production (total of 6.15 M€). Regarding operational costs of nutrient recovery technologies, OPEX for struvite production is 202 k€/y (183 €/t) and for AN, 891 k€/y (460 €/t), being the main costs NHO3 and zeolites (N recovery) and NaOH (P recovery) over other chemicals and energy consumption.

Also, LIFE ENRICH nutrient recovery process has other benefits regarding WWTP performance, which translate in OPEX savings for the installation. They come from improving sludge dewaterability, avoiding uncontrolled P precipitation problems, and reduce the nitrogen load to biological reactors. Results pointed out that, at full-scale for maximize P&N recovery, Murcia Este WWTP would benefit from savings of 7.4% in aeration requirements (nitrification) (31k€/y), 18% in dewatering energy consumption (8k€/y), 27% in polymer requirement for dewatering (52 k€/y), 20% in sludge disposal (119 k€/y), 85% in antiscaling and maintenance due to uncontrolled P precipitation (11k€/ and 14 k€/y respectively). This is a total savings of 235 k€/y. Overall, a positive margin of 322 k€/y would be achieved with a payback of 19 years, considering OPEX, revenues and savings.

Regarding environmental impact of LIFE ENRICH process implementation, a surface of 30 ha is considered to be fertilized using tomato crops as reference for soil nutrient requirements. Struvite and AN are considered in substitution of conventional fertilizers for P and N source, while potassium sulfate and calcium nitrate are considered for K and Ca balancing. Key environmental indicators studied show a significant reduction when using alternative LIFE ENRICH fertilizer of 20% in CO_2 eq emissions (considering both energy and chemical consumption in WWTP and also in conventional fertilizer production associated to field) and 58% in mineral resource scarcity as Cu eq emissions (mainly from the recycling of P source), among other reductions in other environmental impacts.

As struvite commercialization is a reality within the new EU Fertilizer Products Regulation 2019/1009 while AN commercialization regulation is slower, a scenario of only struvite production focused on P recovery was assessed besides the Full ENRICH scenario (struvite and ammonium nitrate production): Struvite ENRICH. For this case, only struvite production mentioned, along with its CAPEX, OPEX and revenues, are taken into account. Regarding WWTP savings, aeration savings are lower since only N from struvite is avoided to return to the biological reactors, which makes aeration savings to 6,5 k€. For P ENRICH scenario, margin will be positive at 419k€. In this scenario, a reduction of 23% of CO_2 eq emissions and 60% in mineral resource scarcity associated emissions would be achieved.

Murcia Este WWTP shows a great potential for nutrient recovery suitable for fertilization with positive economic and environmental impacts for both WWTP and cropland. These are encouraging results for the implementation of LIFE ENRICH value chain since both waster and agricultural sectors (including fertilizer industry) will benefit from implementation of LIFE ENRICH solution. The Full ENRICH scenario is the one selected as the best option to minimize nutrient recovery while minimizing the two main environmental problems associated to conventional fertilizers production: intensive energy consumption in N fertilizers and depletion of phosphoric rock for P fertilizers.

The specifics about technical, LCA and LCC analysis for Murcia Este WWTP full-scale process are gathered in Deliverable *D23_Technical, environmental (LCA) and economic (LCC) assessments of the Life ENRICH process* (Annex 2.18).

Discrepancies / reasons:

Some preliminary research was conducted along the previous months before the starting date. This research was focused on determining the data and the calculations needed for the LCI that feeds LCA and LCC analysis, and during Action B1, the base scenario of the treatment train was defined, as well as the products that can be obtained. This allowed to have a preliminary environmental and economic assessments which help to better adjust the LCA and LCC parameters and understand the dynamics between WWTP and field, maximizing the quality of the results.

Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D23: Technical, environmental (LCA) and economic (LCC) assessments of the Life ENRICH process	100% completed
M29: LCA-LCC data inventory available	100% completed
M23: Data questionnaire (for LCA and LCC) available	100% completed
M35: Technical, LCA and LCC assessment	100% completed

ACTION B5. Development of the business plan	
Responsible: Cetaqua	**Status**: completed (100%)
Proposed start: September 2019 **Proposed end:** February 2021	**Actual start:** January 2019 **Actual end:** November 2021

Main activities during the reporting period:

A business Plan for LIFE ENRICH value chain implementation in Spain was defined. As part of the Business Plan, a market analysis was performed regarding fertilizer industry, 2 business models were developed, a SWOT analysis was performed on the whole LIFE ENRICH value chain and the financial projections were determined. Legal framework played a key role on business development, from guiding analytics to assess fertilizers quality, to influence key players perception and positioning about alternative fertilizers. The Business Plan will lead the steps to make nutrient recovery as fertilizers in Spain a reality.

For the market analysis, struvite and ammonium nitrate are compared with their counterparts in conventional fertilizer industry, MAP (solid fertilizer) and chemically synthesized ammonium nitrate (liquid fertilizer), with which they are considered to compete. The market analysis (Figure 26) highlighted a great fertilizer market, with a total capacity production of 6,000 kt/year (2018) of which complex fertilizers (as MAP) account for 31.3% of the total while ammonium nitrate, for 19.1%. Regarding production capacity of LIFE ENRICH fertilizers in Spain, it was estimated that the market share would be of 0.6% for struvite (34 kt/y) and 1.2% for AN (73 kt/y), with room for alternative fertilizers entering the market. Also, market trends from World Bank estimates that, for 2029, MAP price could be higher that struvite price of 350 €/t, while alternative AN price would be still higher that the AN price, but only a 17% higher.

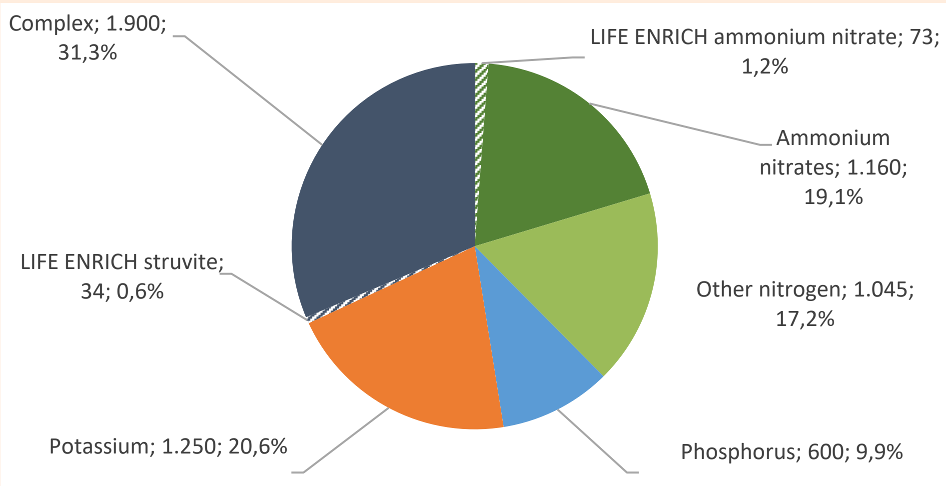

Figure 26. Distribution of production capacity in a scenario with LIFE ENRICH production, 2018 (kt)

Fertilizer regulation framework affecting Spain has been assessed through the project. Although it was found that many aspects are common for all European countries too, since laws are based on European Regulations and Directives. STRUBIAS pre-report established the quality and safety requirements for struvite and similar fertilizers (phosphate salts) that led the struvite analytical plan regarding struvite characterization. STRUBIAS final report showed minimum changes compared with the previous version, and the characterization requirements recommended were finally included in new EU Fertilizer Product Regulation 2019/1009 that accepted phosphate salts such as struvite from different sources including wastewater. This regulation derogated the previous EU Regulation 2003/2003 which did not accept struvite as marketable product on its use for conventional fertilizers manufacturing. Spain does not have a national regulation for struvite or other similar alternative fertilizers, so currently fertilizer national law only contemplates conventional mineral/chemically produced fertilizers. Struvite commercialization and use as secondary raw material for conventional fertilizers production will be allowed from July 2022, when EU Regulation come into force in all EU countries. Nevertheless, struvite can be already commercialized at national level if it is under REACH Regulation, and it can be sold to other countries for direct use or as secondary raw material, if they both have national laws that allow it (this is, the struvite has the End-Of-Waste status, which has to be adopted at national level). This is not new, but the EU regulation approval in 2019 has also served to encourage countries such as Spain with low or no involving in the production of alternative fertilizing products to start taking steps forward. The anticipation on harder discharge limits on WWTPs and the inclusion of new areas to sensitive zones where discharge limitations apply is also a compelling reason for WWTPs to be interested in nutrient recovery strategies like ENRICH.

The identification and feedback on LIFE ENRICH value chain of key players in Spanish market revealed useful insight on business model and plan definition and expectations, which were also shared with European key players. The incorporation of struvite as fertilizer in the new EU Fertilizer Products regulation (Directive 2019/1009) that will come into force in July 2022 is a major incentive for both fertilizer industry and farming sector to accept alternative fertilizers, not only struvite but AN too, as expected. Alternative fertilizers are perceived as a positive incorporation not only from an environmental point of view, but also as potential key element to cope with new agriculture and fertilizing policies, practices and taxes aimed to reduce environmental impact and preserve soil quality. Nevertheless, in front of a lack of mandatory use of alternative fertilizing sources/raw materials for fertilizing production, matching prices between alternative and conventional ones is a client request.

The fact that end users are willing to incorporate alternative fertilizing products is also a push factor for WWTP to implement nutrient recovery technologies such as LIFE ENRICH as they rely on selling for a positive economic balance of the process, which affects the decision on what new technologies incorporate to the wastewater treatment process. Nevertheless, initial investment is hardly affordable for WWTPs so administration involvement to financing LIFE ENRICH nutrient recovery process is required.

For the implementation of LIFE ENRICH value chain 2 business models were developed following CANVAS strategic management tool, one for the commercialization of the LIFE ENRICH technology, suitable for engineering companies, and one for the commercialization of LIFE ENRICH fertilizers, suitable for WWTP operators (see Figures 27 and 28).

The value proposition, customer target and engagement, as well as key activities, partners and resources were defined, along with cost structure and revenue streams.

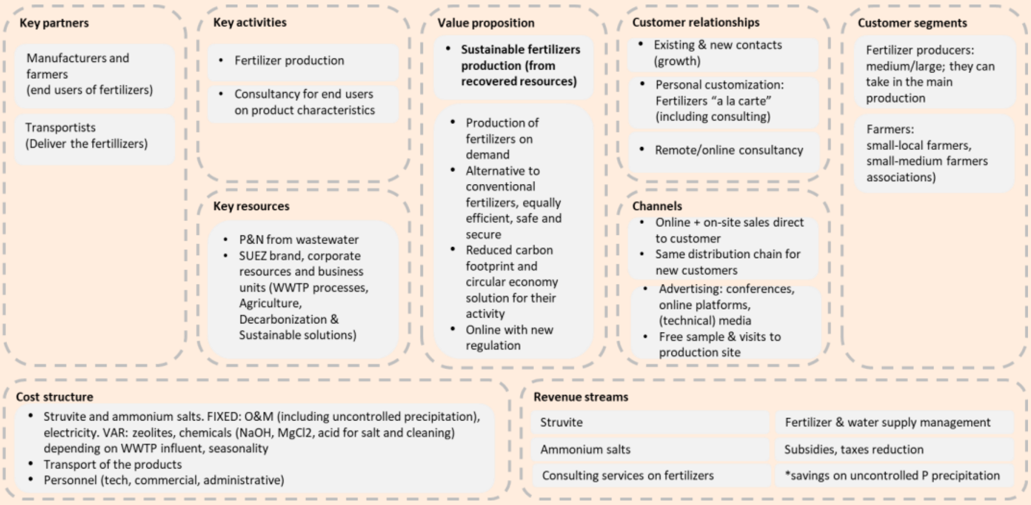

Figure 27. Business Model for commercialization of LIFE ENRICH fertilizers

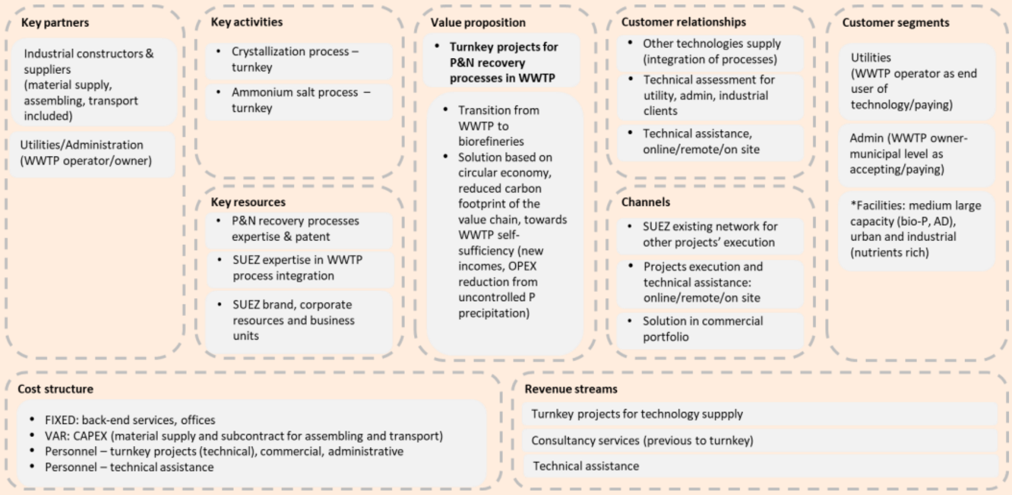

Figure 28. Business Model for commercialization of LIFE ENRICH technologies

Regarding financial projections, for WWTP implementation of technology it has been considered public administration funding to implement the process, so operator companies would obtain benefits from year one regarding nutrient recovery LIFE ENRICH process and fertilizer selling, as the economic assessment determined. Regarding the engineering company in charge of LIFE ENRICH process design and implementation for P&N recovery as struvite and AN, it has been estimated that in 5 years 5 WWTP will have implemented the technological solution in Spain. Also, turnkey projects with 1 year of execution has been considered as the selling strategy, thus, revenues are expected from year 1 after initial investment in year 0 to start first turnkey project. Moreover, a patent has been registered by Cetaqua based on LIFE ENRICH integrated P&N recovery technological train and it is expected to be accepted in early 2022; Cetaqua and the engineering company in charge of LIFE ENRICH process industrialization are related to the same corporate group (Suez Group), thus an agreement for exploitation will be reached to assure the success on the implementation of the Business Plan developed for Spain.

The SWOT analysis reflected all the inputs and insight from different value chain key actors, highlighting as strengths the positive environmental impact of LIFE ENRICH solution in WWTPs and cropland and OPEX reduction in WWTPs from process enhancing and fertilizers selling, while not competitive fertilizer pricing (due to high production costs or low conventional fertilizer prices) and typical slow legal framework adaptation would be the main weaknesses/threats, along with certain reticence in the use of alternative fertilizers regarding safety issues (the end-users demand reliable quality assessments). On the contrary, new environmental and circular economy policies concerning both fertilizers and wastewater are opportunities to strengthen the business. There is also an opportunity to enhance the environmental and economic impact by incorporating alternative chemical sources to conventional reagents for LIFE ENRICH fertilizers production.

C2M (Close to Market) initiative from NEEMO LIFE Team support to Cetaqua regarding business models and plan development was a key factor to structure and to facilitate comprehension of the business plan for all players involved in LIFE ENRICH value chain, which will help to implement it.

The details about market analysis for fertilizers can be found in Deliverable *D21_Market and competitor analysis for the nutrients recovered from WWTPs in Spain* (Annex 2.16). Deliverable *D25_Business plan for the agronomic valorization and commercialization of nutrients recovered from WWTPs in Spain* (Annex 2.19) integrates all the parts of the business plan for LIFE ENRICH value chain implementation in Spain.

Discrepancies / reasons:

Action B5 has started before the scheduled date by identifying and interpreting the EU and Spanish regulations affecting struvite production, thus anticipating the product quality standards that had to be accomplished.

Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D25: Business plan for the agronomic valorization and commercialization of nutrients recovered from WWTPs in Spain.	100% completed
D21: Market and competitor analysis for the nutrients recovered from WWTPs in Spain.	100% completed
M38: Completion of business plan.	100% completed
M31: Completion of market and competitor analysis	100% completed
M34: Completion of marketing plan	100% completed
M33: Completion of business model	100% completed

ACTION B6. Geographical replicability and transferability of the whole value chain	
Responsible: Cetaqua	**Status**: completed (100%)
Proposed start: September 2019 **Proposed end:** February 2021	**Actual start:** September 2019 **Actual end:** November 2021

Main activities during the reporting period:

Replicability of LIFE ENRICH solution was assessed in 3 WWTPs with different casuistic, showing the flexibility and potential of LIFE ENRICH solution and value chain:

- Baix Llobregat WWTP (2,000,000 PE) is one of the biggest WWTP in Spain and a reference for WWTP transition to Biofactories; it presents a high P&N recovery potential following the same configuration as Murcia Este WWTP. Replicability study showed a potential alternative fertilizer production of 1,806 t/y of struvite and 2,816 t/y of AN, with a total CAPEX of 9 M€.
- Cabezo Beaza WWTP (380,000 PE) is a WWTP with high biological P removal that concentrates phosphates and ammonium in the dewatering centrates, thus, P&N recovery train are implemented in series in this stream. Replicability study showed a potential alternative fertilizer production of 247 t/y of struvite and 311 t/y of AN, with a total CAPEX of 413 k€.
- Alt Maresme Nord WWTP (245,000 PE) is a WWTP that operates a sludge treatment platform (anaerobic digestion with biogas production) that manages sludge produced onsite along with those of other 5 surrounding WWTP. In this process configuration, P recovery after elutriation is performed in external sludge, avoiding serious uncontrolled P precipitation problems. N recovery takes place from centrates stream. Replicability study showed a potential alternative fertilizer production of 92 t/y of struvite and 1183 t/y of AN, with a total CAPEX of 1.1 M€.

General guidelines regarding technical assessment for LIFE ENRICH process implementation as well as operation were defined with the objective of select the best process configuration and optimize nutrient recovery minimizing operational risks. For this, it was essential the information provided by the WWTP operators (which also are stakeholders of the project) as well as operational feedback from EMUASA, UPV and CETAQUA during action B2. Also, the work done in B4 over Murcia Este WWTP (scaling, LCI, LCA and LCC) served to assess replication sites following same protocols.

Replicability assessment demonstrated the flexibility of ENRICH solution on adapting to different WWTP facilities and showed that all environmental and economic benefits can be achieved under differences circumstances.

Transferability of LIFE ENRICH value chain was also assessed in 3 European countries apart from Spain. The countries were selected based on different criteria, including potential market for technology implementation, potential market on nutrient consumption, legal framework and key players engagement, among others. Business models adaptation was performed based on each country particular context:

- Italy accounts for 3,034 WWTP, susceptible to implement LIFE ENRICH solution. Sludge production and sludge management costs are among the highest in EU, thus, WWTPs will benefit from implementing LIFE ENRICH process regarding sludge production reduction and its potential application to agriculture. Discharge non-compliances are also a driver for WWTPs on ENRICH solution implementation. Also, Italy has a high P&N consumption, of 529 kt N and 118 kt P per year, which offers great market opportunity for the incorporation of alternative fertilizers.
- Denmark accounts for 377 WWTP, susceptible to implement LIFE ENRICH solution. Also, 3 full-scale struvite production crystallization units are operating with crystallization technology integrated in ENRICH process, which indicates that faster and easier implementation of ENRICH solution and value chain can be expected regarding both P&N recovery. Also, Denmark has national approval to commercialize struvite, so it is expected a faster incorporation and market-share growth for alternative fertilizers. Denmark is the 7th EU country in specific fertilizer consumption, reaching a total fertilizer consumption of 252 kt N and 20.8 kt P per year.
- Netherland accounts for 360 WWTP, with several facilities recovering P and also national approval for struvite commercialization. Netherland is 1st specific fertilizer consumer country in the EU, being the potential market for alternative fertilizers of 207 kt N and 6 kt P per year. In this case, fertilizer industry is also engaged with sustainable fertilizers production, since ICL production site, one of the main fertilizer production facilities in Europe, already incorporates struvite as secondary raw material for fertilizers production. The end-users and administration commitment with alternative fertilizer use will pull the implementation of LIFE ENRICH solution.

After the feedback of value chain's key players at European level, the SWOT analysis shows that there are common main barriers for ENRICH value chain implementation among countries and key players, that come down to legal aspects (a lack of free trade and harmonized rules between countries on alternative fertilizers, which are expected to disappear in the short term with the coming into force of EU FPR in July 2022, but still current for AN; reticence regarding product safety specially from farmers, which would be significantly reduced when legislation established quality requirements that guarantee the safety) and economic (regarding potential high prices for fertilizers and high investments required for technology implementation on WWTPs). All stakeholders of the value chain involved share that government economic stimulation is a must to promote and stimulate the market for technology implementation and fertilizer products commercialization. Despite all, there is willingness from all parts to play their role in the nutrient recovery value chain and move towards a more sustainable wastewater, fertilizers production and agriculture sectors.

The feasibility of replicability and transferability of LIFE ENRICH value chain has been demonstrated, showing that LIFE ENRICH solution helps WWTPs and countries with different contexts to implement nutrient recovery strategies that benefits water and agriculture sectors from both an economic and an environmental perspective.

The details on the replicability and transferability assessment of the ENRICH vale chain are explained in Deliverables *D19_ Definition of the key characteristics of each player in the target countries* (Annex 2.14), *D27_ Legal framework: certification of the new products in the different geographies* (Annex 2.21), *D26_Adaptation of the business model to 2-4 EU countries* (Annex 2.20) and *D32_Replicability plan* (Annex 2.24).

Discrepancies / reasons:

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Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D19: Definition of the key characteristics of each player in the target countries	100% completed
D27: Legal framework: certification of the new products in the different geographies.	100% completed
D26: Adaptation of the business model to 2-4 EU countries.	100% completed
D32: Replicability plan.	100% completed
M25: Definition of the European countries to evaluate the replicability.	100% completed
M26: Contacts with relevant players at each country.	100% completed
M39: Market analysis of the selected European countries.	100% completed
M41: Guidelines for the implementation of the value chain in other European countries.	100% completed

ACTION C1. Monitoring of the impact of the project actions	
Responsible: Cetaqua	**Status:** completed (100%)
Proposed start: September 2017 **Proposed end:** February 2021	**Actual start:** September 2017 **Actual end:** November 2021

Main activities during the reporting period:

Selection of the LIFE performance indicators (KPIs)

The criteria for the KPIs selection was firstly response to the mandatory indicators and secondly to the indicators related to the environmental topic of the LIFE ENRICH project, which is Resource Efficiency, Green and Circular Economy. Sixteen KPIs had been selected, included in the categories: project setting and environmental and climate action, societal and economic outputs and outcomes. A new KPI was added, related to chemical reduction.

Quantification of the impact of the project

For each KPI, the impact of the actions of the project at the end of the project and also 3 years later were monitored. The KPIs values were reviewed taking into account the results of the project. Societal KPIs have been actualized and revised, scoring a good performance in involving new stakeholders and in media and scientific events presence.

Assessment of the socio-economic impact

A Cost-Benefit Analysis (CBA) approach has been used to evaluate all the weaknesses ('costs') and strengths ('benefits') of the proposed integrated ENRICH value chain in terms of socio-economic and environmental effects. The analysis complements technical, economic and environmental assessments executed in other project Actions, providing a holistic approach for the LIFE ENRICH value chain in the European framework. The study assesses the achievement of project's objectives and results, especially in terms of social perception, and its impact on the local economy and wellbeing where the project is developed.

The updated KPIs values at the end of the project have been defined in the Deliverable of the action C1 *D30_Life Performance Indicators at the end of the project* (Annex 2.23), while CBA is collected in *D28_Assessment of the socio-economic impact* (Annex 2.22).

Discrepancies / reasons:

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Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D11. Life Performance Indicators (Progress Report)	100% completed
D15. Life Performance Indicators (Mid-term Report)	100% completed

D21. Life Performance Indicators (Progress Report)	100% completed
D31. Life Performance Indicators at the end of the project	100% completed
D29. Assessment of the socio-economic impact	100% completed
M42. Impact effectiveness indicators achieved	100% completed

ACTION D1. Dissemination planning and execution	
Responsible: Cetaqua	**Status:** completed (100%)
Proposed start: September 2017 **Proposed end:** February 2021	**Actual start:** September 2017 **Actual end:** November 2021

Main activities during the reporting period:

Communication plan

A communication strategy for the LIFE ENRICH project (Annex 7.3.1) was designed and validated among all the project partners during the kick-off meeting. The strategy defines the key aspects to be considered in order to ensure the maximum impact of the project: main target groups, messages to be delivered, channels and tools to be used, etc. This strategy is constantly being updated and improved based on the analysis of the impact obtained. This document has been updated during the lifetime of the project, and the project reference and acronym have been included.

Communication Database

A Communication and Dissemination Database (Annex 7.3.2) was established at the beginning of the project and updated regularly with the objective of having a track record of all the communication and dissemination activities performed in the framework of the project. This tool has served to both the progress and the impact of the activities and materials developed.

Logo and applications

The logotype (Annex 7.3.3) and its entire visual identity were created in the early phase of the project. The logotype reflects the connection between water and agriculture thus referring to the main goal of the project: to boost circular economy between these two sectors. Based on the logotype primary colors, a set of different templates were delivered (Annex 7.3.4). Finally, the correct usage of the project's visual identity was described in the Identity Manual (Annex 7.3.5) with the aim of guaranteeing the coherence of the brand.

Project website

The project website (www.life-enrich.eu) is considered a powerful online communication tool that helps to reach a wide range of potential target groups. In this sense, it was decided to create an attractive website that includes a lot of visual support to gain more engagement with the audience. The website not only includes the basic information about the project, including the project acronym and reference, but also explains the context and the motivation of the project and describes the benefits that could bring the potential outputs of LIFE ENRICH. The website was launched in May 2018 and has received an average of 579 visits/month until the project ended. News relating to meetings and congresses assistance have been posted, additionally, project´s online communication is being reinforced through social media channels, mainly via Twitter, using the hashtag #LIFEENRICH. New sections, such as "Downloads" or a virtual tour (explained below) within "The Project" section have been recently added. In the "Downloads" section, all the dissemination materials, as well as some of the public Deliverables, will be available for download.

Leaflet

A project leaflet (Annex 7.3.6) was designed and produced in April 2018. This promotional material includes a set of infographics explaining the concept of LIFE ENRICH and a timeline summarizing all the actions to be carried out in the framework of the project. Additionally, the expected outcomes and their potential benefits were highlighted. To have a greater impact, it was decided to produce it in three languages: English, Spanish and Catalan, thus ensuring that it will reach any target the project is addressing. The printed versions of the leaflet have been distributed among the project partners and the online version is available on the project website. At the end of the project, an updated version of the leaflet, based on the first version but including some of the key results and indicators was produced and uploaded to the project website.

Notice board and stickers

Two Notice Boards have been produced. The first one (Annex 7.3.7), focused on the nutrient recovery from wastewater, was designed, produced and installed in February 2020 at the prototypes in Murcia Este WWTP. The second Notice Board (Annex 7.3.8), which explains the use of the fertilizers obtained, was installed in March 2021 in IRTA facilities. Besides, the LIFE sponsorship stickers have been designed and placed in all the prototype's equipment.

Video

Different videos have been produced throughout the lifetime of the project. First, a short animation video (Annex 7.3.9), focused on the context, objectives and expected results of the LIFE ENRICH project was produced in mid-2021. Besides, a set of 11 videos (Annex 7.3.10) have been produced to explain the technical development of the project, the role of each partner and the results obtained. The videos have been produced as follows:

- Welcome - Cetaqua
- The LIFE ENRICH project - Cetaqua
- WWTP (full scale units) - EMUASA
- Ellutriation tank (characterization and control) - UPV
- Ellutriation tank (full scale) – EMUASA
- LIFE ENRICH pilot plant (design) – UPC

- LIFE ENRICH pilot plant – Cetaqua
- LIFE ENRICH pilot plant (N recovery train) – Cetaqua
- Fertilizers – IRTA
- Field tests – ASG
- General video: his video summarizes the context, objectives and expected results explained directly by the project partners. Along with the short animation video, this general video will serve to introduce the LIFE ENRICH project briefly and effectively.

This set of videos will be used in the virtual tour as part of this multimedia experience. More information can be found below.

Layman's Report

The Layman's Report (Annex 7.3.11) addressed to general and technical audiences, gathers all the main information on the LIFE ENRICH project, from its ideation to the final conclusions. All the partners contributed to the development of this report. The document will be available on the website and promoted on social media and other channels.

General and technical media

Since its launch, the project has appeared in over 50 articles in different general and technical media, mainly focused on sustainability and the environment, in general. All the partners have contributed to the development and distribution of articles and press releases throughout the lifetime of the project.

Visits to the pilot

The virtual tour is a 360º interactive recording of the Murcia Este WWTP including relevant information, such as texts and videos on the key points of the plant in relation to the LIFE ENRICH project. This immersive experience, which can also be displayed as a virtual reality tour, helps the audience to understand how the project has been developed and have a virtual first-hand contact with the pilot plant and the prototypes. Next to each key point (known as hotspots), a short video is displayed, in which one of the project's partners will offer interesting information of this specific point of the plant.

Due to the COVID-19 pandemic, no visits to the pilot have been carried out for most of the lifetime of the project. Therefore, it was decided to produce this virtual tour, which will be available on the LIFE ENRICH project website (www.life-enrich.eu) for those who want to visit the plant and learn more about this project, with a special focus on technical audiences, potential end-users and the scientific community.

Informative sessions

Throughout the lifetime of the project, Cetaqua has organized 2 informative sessions with potential end-users of the technologies and products belonging to LIFE ENRICH vale chain developed. In both sessions, representatives of the Advisory Board and the stakeholders attended the meetings.

- In 2020 Cetaqua organized a Meeting with the Direction of Operations of SUEZ Spain (including members of Advisory Board) to present Cetaqua's work and developed solutions in nutrient recovery area, highlighting LIFE ENRICH project and results obtained.

- In 2021 another meeting took place between Cetaqua and representatives of SUEZ Spain (including members of Advisory LIFE ENRICH stakeholders) to share the results of the project and obtain their feedback as key players in business models.

Final workshop

The LIFE ENRICH final workshop, under the title "Nutrient recovery from wastewater to produce fertilizers for agriculture", was held on November 30th 2021, with over 300 registrations, and brought together 136 experts from different backgrounds.

This event aimed to:

1. Provide a space for presenting the LIFE ENRICH project's results: fertilizers from nutrient recovery in WWTP, field trials and business model proposed.
2. Discuss key challenges and solutions related to nutrients recovery from wastewater.
3. Provide a space that facilitates a dialogue among a diverse range of actors from academia, public administration, industry and farmers community on the multiple aspects of the use of struvite and ammonium salts as fertilizers for agriculture.
4. Find integrated solutions for water and agriculture and inspire action.

This event targeted all the involved actors in nutrients recovery from wastewater and their use as fertilizers in agriculture, including:

- WWTP operators
- Farmers & Producers of fertilizers
- Public entities
- Industry
- Research/academia entities

With an agenda full of first-level experts, including representatives from the European Commission, ESPP and some of the fertilizers' end-users, the themes of the event included (but were not limited to) the following:

- Nutrient recovery from wastewater (LIFE ENRICH technology).
- Economic & technical feasibility of use of struvite and ammonium salts as fertilizers for agriculture (LIFE ENRICH business models).
- Integration of NR from WW in the Farm-To-Fork EC Strategy from an economic and environmental point of view
- Current and future legislation on the use of struvite and ammonium salts as fertilizers
- Future of nutrient recovery: enhanced alternative fertilizers and other potential applications of recovered nutrients

Besides, the event served as a closing ceremony for the LIFE ENRICH project. Some dissemination actions, such as social media publications or a press release, were carried out in the framework of the final event.

ESPP support

The ESPP, being a reference organization in phosphorus awareness raising, has been used in order to introduce the LIFE ENRICH project to the European audience. In concrete, some information of the project, such as an introductory text or information on the final workshop, was prepared and included in the ESPP newsletter, reaching over 75.000 people. Networking activities organized by ESPP (General Assembly, open event such as webinars and conferences) were also of great impact regarding ENRICH networking and also action B6 on the adaptation of business models to European countries (since the project was presented to key players of different countries and also feedback was collected).

Dissemination in workshops and conferences

Since its launch, LIFE ENRICH has been presented in over 25 national, European and international congresses and conferences. The full list in which the project has been presented can be found in the Communication and Dissemination Database (Annex 7.3.9). Some relevant congresses are:

- 4th Green and Sustainable Chemistry Conference (Dresden, Germany), 2019
- 1st Summit of the Organic and Organo-mineral Fertilizer Industry in Europe (SOFIE) (Brussels, Belgium), 2019
- 3rd IWA Resource Recovery Conference 2019 (Venice, Italy), 2019
- 14th Mediterranean Congress of Chemical Engineering (MeCCE14) (Barcelona, Spain), 2020
- 5th International Conference on Ecotechnologies for Wastewater Treatment (ecoSTP) (Online), 2021
- 4th Phosphorus In Europe Research Meeting (PERM) (Online), 2021

On January 29th and 30th, Cetaqua hosted a LIFE platform meeting in Barcelona, Spain. The meeting, organized by the European Commission through the LIFE-Environment Programme focused on wastewater treatment.

The meeting, in which LIFE ENRICH took a relevant role, was helpful for the revision and implementation of the Urban Wastewater Treatment (UWWT) Directive. It showcased sustainable water treatment projects to policymakers, local authorities and wastewater treatment providers.

Feedback was provided to policymakers in several essential areas, such as circular economy of water and sludge; pollutants of emerging concern; urban run-off and storm water overflows; and monitoring.

Regarding scientific papers, LIFE ENRICH has published 8 scientific articles in some of the most relevant journals of the sector and has been mentioned in 1 external paper. Some examples are: Chemosphere, Agronomy-MDPI, Water Research and Agriculture. All the partners have contributed to these publications, and the links can be found on the project's website. The full list of publications is available in the Communication and Dissemination Database (Annex 7.3.9)

LIFE External Communication Team

In some specific occasions, such as the organization of the LIFE Platform Meeting or the LIFE ENRICH final workshop, the LIFE External Communication Team has given support to the LIFE ENRICH partners by sharing contents on social media and their website. These actions have helped to reach a wider European audience

Networking group

Some specific networking actions haven been carried out throughout the lifetime of the LIFE ENRICH project:

- Participation in over 25 events, where different networking activities to exchange information, knowledge and experiences with other projects and researchers were carried out. For example, LIFE ENRICH participated in the LIFE Kick-off Meeting in 2016, among others.
- Organization of the LIFE Platform Meeting in January 2020, in which several other relevant European projects participated.
- Networking with other projects and experts in the field at 4th Phosphorus In Europe Research Meeting (PERM), organized by ESPP

Discrepancies / reasons:

Due to the COVID-19 pandemic, no visits to the pilot plant were allowed. Therefore, in order to allow all the audiences to visit the prototypes of LIFE ENRICH, a virtual tour was created in late 2021-early 2022. This virtual tour shows the Murcia Este WWTP in a 3D scan (also available for virtual reality glasses) and allows the user to navigate through the different key points of the WWTP and the LIFE ENRICH pilot plants, where interactive bubbles show multimedia information (text, images or videos) explaining more about LIFE ENRICH.

This tour is available on the LIFE ENRICH website.

Current state of the action and envisaged progress until next report:

The communication activities continue to be active. An After-LIFE Plan has been drafted to define which potential communication and dissemination actions might be carried out after the project end.

Progress indicators, milestones and Deliverables:

D2. Logo and templates	100% completed
D5. Project website	100% completed
D7. Leaflet	100% completed
D14. Notice Board	100% completed
D18. Brochure	100% completed

D29. Layman's report	100% completed
D31. Project video	100% completed
M9. Logo and templates available	100% completed
M10. Website available	100% completed
M15. Sticking of all the equipment and material funded by Life	100% completed
M17. 3 communication in non-technical media	100% completed
M18. Reaching 1800 website visits	100% completed
M20. Distribution of 200 copies of the printed leaflet	100% completed
M27. Reaching 3600 website visits	100% completed
M28. Submission of 1 paper to scientific journal	100% completed
M32. 500 attendees to the pilot plant visits	100% completed
M40. Final workshop	100% completed
M43. 500 attendees to the final workshop / 1000 attendees to the pilot plant visits	100% completed
M44. 7 communication in non-technical media	100% completed
M27. Reaching 5400 website visits	100% completed
M28. Submission of 2 papers to scientific journal	100% completed

ACTION E1. Project Management	
Responsible: Cetaqua	**Status**: completed (100%)
Proposed start: September 2018 **Proposed end:** February 2021	**Actual start:** September 2018 **Actual end:** November 2021

Main activities during the reporting period:

The project management involved tasks of coordination between the different project beneficiaries, stakeholders, Advisory Board members in order to progress with the project activities and to achieve the goals defined in the proposal. The specific actions are summarized below:

- Project manual preparation and update

- Organization chart (Gantt) update
- Kick-off meeting, 5 EB meetings, 5 Monitoring meetings, 1 AB meeting
- Preparation of technical, administrative and financial updating documents for EB, M and AB meetings
- Reporting to EC: 1st Progress Report, Mid-Term Report, 2nd Progress Report, Final Report
- Stakeholder contacts and letter signing
- AB members contacts
- Coordination and application for 2 project amendments, including the management of a project partner leaving the consortium

Discrepancies / reasons:

Progress, Mid-term and Final reports were as well as Deliverables were reschedule according to delays and amendment agreements; therefore, some Deliverables were removed as they were no more considered as relevant. A Project Audit initially planned was also not needed. Delays and amendments were related to technical issues but also to the leaving of a project partner.

Current state of the action and envisaged progress until next report:

This Action is 100% completed.

Deliverables (D) and Milestones (M):

D4. Project Management Manual	100% completed
D12. Progress report	100% completed
D16. Mid-term report	100% completed
D22. Progress report	100% completed
D34. Final report	100% completed
M1. Kick-off meeting	100% completed
M21. Mid-term report validation	100% completed
M49. Final Report	100% completed

ACTION E2. After LIFE Plan	
Responsible: Cetaqua	**Status**: completed (100%)
Proposed start: January 2021 **Proposed end:** January 2021	**Actual start:** December 2021 **Actual end:** December 2021

Main activities during the reporting period:

The After-LIFE Communication Plan (Annex 7.3.12) for the LIFE ENRICH project is the main document outlining the communication and dissemination activities that will take place after the lifetime of the project.

The After-LIFE Communication Plan includes dissemination activities which connect research outputs and results and the key target audiences by means of appropriate communication tools.

Most tactics used during the lifetime of the project were successful and thus when possible will be continued once the project is closed. Some examples of potential communication and dissemination activities that could be carried out after the lifetime of LIFE ENRICH are provided in this Deliverable.

Discrepancies / reasons:

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Current state of the action and envisaged progress until next report:

Deliverable D34 completed. This Action will be completed at the end of 2024 (3 years after the project finish).

Deliverables (D) and Milestones (M):

D33. After LIFE Communication Plan	100% complete
M47. Definition of target audience of the After-LIFE Communication Plan	100% complete

5.2. Main deviations, problems and corrective actions implemented

The main deviations addressed which justify the delays or other difficulties experienced during the project are summarized in Table 2 below.

Table 2. Summary of the deviations and corrective actions in the report period.

Deviation (Action)	Cause/s	Actions taken/foreseen
A third analytical campaign not foreseen caused a delay of 4 months (A1)	It was required to obtain robust conclusions, essential for Action B1 (design).	Action B1 will be delayed accordingly to A1, but it was necessary to get reliable data and avoid future problems.
Prototype design and construction was delayed 11 months (B1)	4 months delay was caused from deviation in A1. Also, the elutriation affronted the unforeseen challenge of building a 700m^3 tank. The tank construction required a geotechnical study pointing the need of a heavy, underground structure to support the tank. Both the struvite crystallization and N recovery unit designs have been reviewed and adjusted with J.HUESA, the company in charge of the manufacturing. In addition, delivery of critical parts of the prototype, such as the reactor body for the crystallization unit or the membranes for the N recovery unit, were delayed.	It was expected that the whole prototype would be ready in October 2019. Taking into account this deadline, during prototype construction, experimental plan for Action B2 was modified prioritizing the most interesting experiments that give reliable data for the technical assessment of the technologies, the scaling-up and the transferability of the technology. In addition, efforts were put into advancing in Action B3.
Delay in prototypes operation and field tests (B2, B3)	Delays in Action B1 affected the start of Action B2, delaying the start of the operation to October 2019. Also, in October 2019, high content of solids in the influent to the P&N recovery units delayed their start-up, that started in January 2020.	Before the start-up of the prototypes in October 2019, analytical an experimental plan for prototypes operation in B2 was adjusted; also, efforts were put into advancing in Action B3 in order to anticipate potential operational problems.

	In addition, in 2020, due to COVID-19 pandemic the prototypes were stopped for almost 2 months and when the operation was restored it was under restrictions to access to the WWTP laboratory and to other workspaces.	From October 2019 until December 2019, modifications in the influent line were required to reduce the high amount of solids that obstructed the pilot plants. Also, an extension of the project was approved, allowing 15 months of prototype operation as expected; this allowed the obtention of robust data for technical assessment of prototypes (operation from June 2020 to August 2021, after start-up from January to March 2020) as well as the performance of crop trials with fertilizers from Murcia Este WWTP.
Modifications on field tests to cope the delays in the previous actions (B3)	Due to the delays in design and construction of the prototypes, and thus in B2, field tests were launched previously than planned, as commented, with recovered struvite produced in another WWTP plant in Denmark (Phosphogreen technology than the P recovery prototype) and ammonium salts produced in UPC with the lab-scale prototype (scaled-up in the project to pilot scale). Additionally, storm Gloria affected IRTA facilities, and the greenhouses had to be rebuilt, consequently the lettuce crops planned for January 2020 could not be performed. In March 2020 COVID-19 af-	Analytical procedures were performed with struvite and ammonium nitrate, obtaining reference values and identifying the most critical parameters. Furthermore, results have shown that all the fertilizers obtained were similar, confirming that results obtained with different origin fertilizers were valid. Greenhouse and open-air tests have been carried out using struvite and ammonium salts produced at Murcia Este WWTP during 2020 and 2021.

	fected the operation of the prototypes in Murcia so the availability of struvite and ammonium salts was limited.	
Early start of business plan (B5)	Action B5 has started before the scheduled date with the aim to anticipate the product quality standards that have to be achieved.	Some relevant advances in EU and Spanish regulations affecting struvite production have been identified, i.e. release of STRUBIAS report. Hence, more focus has been done before than initially scheduled to integrate this relevant information within the project.
Delay on technical, environmental and economic assessment of the Life ENRICH process (B4)	Delays on Action B2 and B3 accordingly caused delays on B4, since final results from technical assessment of technologies in WWTP in B2 and evaluation of the agronomic properties of the products obtained in B3 were needed for technical, environmental, and economic evaluation of LIFE ENRICH process over the value chain.	Previous research was made before Action start in order to define the dataset required and the baseline scenario, allowing to obtain preliminary results that led to a better LCA and LCC adjustment and results. Delay accumulated in B4 was 10 months.
CETAQUA assumed tasks in the development of the business plan and the geographical replicability and transferability of the whole value chain (E1)	In July 2019 AQUATEC, which was responsible of Action B5 and participated in Action B6, expressed his willing to leave the consortium. An internal reorganization caused that fertilizer business unit disappeared thus losing interest in LIFE ENRICH project.	Since AQUATEC leave, huge efforts were made in order to find another partner within Suez Group. Suez Agriculture Business Global Line was found to be the most suitable partner for such tasks; however, they did not have enough personal resources to carry out Action B5 and B6 tasks. The final decision was made on March 2020: CETAQUA assumed Actions B5 and B6 and Suez Agriculture would advise CETAQUA in such tasks

		without budget. In addition, SUEZ Agriculture is a member of the Advisory Board, to follow up overall project results and participate in the technical discussions with other Advisory Board members as well as with other partners.
Delay on development of the business plan and geographical replicability and transferability of the whole value chain (B5, B6)	Delays on B4 affected Actions B5 and B6, since results obtained in B4 were needed for the development of business plan and replicability and transferability of the value chain.	Actions B5 and B6 were delayed 9 months each, accordingly with the finalization of B4 with the project extension, in order to take into account final results from B4. In addition, C2M initiative from NEEMO LIFE Team give support to Cetaqua regarding business plan development in Action B5.
Project delays (E1)	Leaving of a partner of the consortium (Aquatec) and several technical delays already explained in the correspondent deviations.	Two amendments were approved in order to certificate the modification of the consortium, consolidate that Cetaqua will assume the tasks assigned to the partner that left, and extend the project duration (9 months) in order to assure the consecution of project objectives.

5.3. Evaluation of Project Implementation

Action	Objectives	Results achieved	Evaluation
A1	To characterize the full-scale WWTP where the prototype will be installed and monitor the nitrogen and phosphorus fate in the WWTP. To collect the required data for the design of the different units (Action B1).	Baseline conditions of the water and sludge lines of Murcia Este WWTP. Selection of the site inside the WWTP to locate elutriation, P recovery and N recovery units.	Achieved. Described in Deliverable D1. Action delayed because more data was needed to assure reliability for Action B1.
A2	To define and to protocol two tests under greenhouse and outdoor field. To define full-scale trials incorporating evaluation with arable crops if necessary.	Selection of the species for the field tests. Fertilization requirements. Definition of the field trials in three locations (Cabrils, Agramunt and Castelldans). Definition of KPIs and analytical tests to assess it.	Achieved. Described in Deliverable D3.
B1	Design and construction of the different units that form the global prototype: new sludge line configuration in Murcia Este WWTP (elutriation), crystallizer (P recovery as struvite) and membrane contactors (N recovery as ammonium salts).	Design and construction of the sludge line configuration for elutriation. Design and construction of the crystallization unit. Design and construction of the nitrogen recovery unit. Quantification of the uncontrolled P precipitation and the potential recovery of nutrients.	Achieved. Described in Deliverables D6, D10, D8 and D9. Design of the pilot units was delayed due to several modifications required by the manufacturer and delay in material supply. An elutriation tank was not foreseen in the proposal, its construction was complex due to the

			geotechnical characteristics of the site. The accumulated delay due to A1 and B1 longer execution is 11 months.
B2	Prototype operation and integration of results	Operation and manual protocols developed for P and N recovery units' operation and monitoring. Elutriation process, P recovery unit and N recovery unit where operated and monitored and robust datasets were obtained. Technical validation of the technologies was performed with results obtained during operation.	Achieved. Described in Deliverables D13 and D20. Operation of prototypes had a delay of 8 months due to accumulated delays from B1, start-up problems due to high content solids in the feeding stream and due to COVID-19 pandemic restrictions.
B3	To determine if the 5 products obtained in the pilot plant can be used in fertigation systems. To get the best formulations of fertilizers for future commercial use. To establish protocols of fertilization for horticultural and arable species.	2 products were finally selected to evaluate: struvite and ammonium nitrate. Dirty struvite and ammonium sulphate presented a lack of fertilizing interest compared to the others in our soil and water chemical composition. Ammonium phosphate, which only contains recovered N, was considered a less environmental-friendly strategy rather than combining ammonium nitrate mixed with struvite as a substitutive treatment, due to the use of both N	Achieved. Described in Deliverables D17 and D24. This action was started earlier than planned in order to anticipate potential operational problems related to struvite dissolution. Struvite and ammonium nitrate from another origin but with very similar characteristics were tested.

		and P recovered nutrients. Characterization of the dewatered sludge from Murcia Este WWTP. Development of a protocol for struvite dissolution based on tests with struvite. Greenhouse tests in IRTA Cabrils and open-air tests in ASG Lleida and Agramunt with sludge, struvite and ammonium nitrate from Murcia Este WWTP.	
B4	To compare the technical efficiency, the environmental impact and the economic feasibility of the LIFE ENRICH process (nutrients recovery and valorization in agriculture) with the current situation (nutrients removal and chemical fertilizers production).	Murcia Este WWTP full-scale technical assessment, including fertilizer production capacities and operational benefits from LIFE ENRICH process implementation. LCI, defining dataset and calculations needed for LCA and LCC analysis. 2 ENRICH scenarios were considered of interest to compare with baseline scenario: P&N recovery and only P recovery, taking into account Spanish and European legal context. Technical and economic feasibility and positive environmental impact of LIFE ENRICH solution was demonstrated.	Achieved. Described in Deliverable D23. Action delayed 10 months to incorporate final results from technical assessment in B2.
B5	Development of the business plan	Market and competitor	Achieved.

		analysis for produced fertilizers. Assessment on Spanish legal framework for fertilizer commercialization. Detailed definition of the business models. 2 business models were defined: one for fertilizers commercialization and one for technology commercialization. Marketing plan for launching the products within the business plan. Busines plan for LIFE ENRICH value chain in Spain, including financial projections for each business model and SWOT analysis	Described in Deliverables D21 and D25. Action delayed 9 months to take into account results from B4.
B6	Geographical replicability and transferability of the whole value chain	Contribution to EU regulation/certification initiatives for agricultural valorization of recovered nutrients from WWTP. Adaptation of the business model to 3 EU countries apart from Spain: Denmark, Italy and Netherland, including technical assessment of the replicability of the value chain in other EU countries, market analysis and SWOT analysis. Replicability study of LIFE ENRICH process on 3 WWTPs and selection of the top 5 WWTP for project replication.	Achieved. Described in Deliverables D19, D26, D27 and D32. Action delayed 9 months to take into account results from B4.

		General guidelines about the implementation of the value chain proposed in EU countries.	
C1	To measure, to monitor and to report the impact and outputs of the project actions at the end of the Project and 3 years after de project ends as compared to the initial situation, objectives and expected results.	Selection of the LIFE key performance indicators (KPIs). Quantification of the impact of the project through KPIs quantification (at the beginning, during and at the end of the project).	Achieved. Described in Deliverables D30 (KPIs) and D28 (Assessment of the socio-economic impact). Addition of a new KPI focused on chemical reduction.
D1	To share knowledge and experiences with other similar projects. To allow general and specialised public to access information about the project and to raise awareness about the LIFE 2016 Programme. To promote the widest possible application of project's methodologies and outcomes. To raise awareness among local authorities, general public, national/regional bodies and agricultural companies and communities. To improve relationships stakeholders and increase the project´s presence in mass media.	Communication and Dissemination Plan Logo and templates Project website (avg. 579 visits/month) Leaflet (250 printed copies) 2 Notice Boards 1 Brochure (online) Layman's Report (online) 12 Project videos 2 Informative sessions 27 attendances to workshops and conferences 17 appearances on general media 38 appearances on technical media (including 8 scientific publications and 1 mention) Final workshop (136 attendees)	Achieved. Described in different dissemination materials. This action was delayed affected by B1 and B2 delays. Communication activity significantly increased once the prototypes were implemented in October 2019 and, therefore, the impact increase was noticeable in mid-2020. In addition, COVID-19 affected communication activities regarding visits to WWTP. As an alternative, an online virtual tour of the WWTP and LIFE ENRICH prototypes was developed and

			it is currently available on the internet (project's website and other webs) for public access.
E1	To guarantee that LIFE Program obligations are met. To ensure, monitor, document and report the progress of project actions. To efficiently allocate, track and record human and financial resources. To establish a fruitful legal framework and to regulate intellectual property. To obtain an independent final audit report and receive full financial contribution.	Project Management Manual Grant & Partnership Agreement Subcontractor agreements Stakeholder support letters EC & Internal Reports Financial contribution reception EB and AB meetings	Achieved. 2 amendments were approved to reorganize project consortium and responsibilities after a project partner leaving as well as to extend the project duration (9 months) to ensure the consecution of project objectives. Described in Deliverables D4 (Project Management Manual) and D34 (Progress Report, Mid Term Report and Final Report).
E2	To assure the extension of the results obtained from the dissemination and communication actions after the project end. To identify target audience in the scientific and research community, as well as potential users of the project outcomes.	The After-LIFE Communication Plan is a Deliverable of the project as well as it is summarized as a separate chapter of the Final Report. The project's website is available for consultation.	Achieved. Described in Deliverable D33. The project's website will be available during After-LIFE period of 3 years from the end of the project (until November 2024)

5.4. Analysis of benefits

6.4.1 Environmental benefits

The main objective of the LIFE Enrich project is the implementation of the circular economy concept through the demonstration of the whole value chain for nutrient recovery in urban wastewater treatment plants (WWTPs) and its further reuse for agriculture purposes. In this case, the nitrogen and phosphorous presented in the sludge line of the WWTP are recovered as fertilizer by-products (ammonium nitrate and struvite, respectively) after an elutriation process for releasing and concentrate phosphates present in sludge after biological P removal. This process configuration at Murcia Este WWTP has several benefits for the installation. First sludge dewaterability is improved due to elutriation implementation, thus, chemical and energy consumption in dewatering stage are reduced (27% reduction in polymer consumption, 18% reduction in dewatering energy consumption), as well as sludge production (20% reduction in sludge production). Second, nitrogen recovery, mainly as ammonium nitrate but also as struvite (it contains P, Mg and N) reduces N load to biological reactors (in 234 ton/y of N from AN and 63 ton/y from struvite) and thus N_2O emissions are reduced too by 11% and aeration energy consumption is reduced by a 7.4%. Third, the process configuration selected allows to recover P before it enters anaerobic digestor, thus, minimizing uncontrolled P precipitation. This allows to reduce antiscaling consumption by 85%.

It is also noteworthy that the technical replicability study performed in other 3 WWTPS showed that LIFE ENRICH process is flexible and can be adapted to different WWTP configurations offering environmental benefits for both water and agricultural sectors when implementing LIFE ENRICH value chain.

For other WWTPs contexts, other benefits from LIFE ENRICH process implementation were identified. In many WWTP with P discharge limitations, P removal is usually driven by chemical precipitation with ferric chloride or alumina, which use would be reduced while still complying with discharge limitations. Also, for those WWTP with N & P discharge limitations and biological nutrient removal, N&P recovery can help reduce discharge loads minimizing the impact in the energy consumption of biological reactors, since N&P loads to reactors would be reduced. More WWTP in the future will benefit from this as 1) regulation is expected to enlarge areas with discharge limits as well as reduce N&P discharge limits, and 2) WWTP implementing P&N biological removal is increasing.

Environmental assessment showed that N-fertilizers (ammonium nitrates) energy consumption associated to their production would be reduced through LIFE ENRICH production process in 80% (from 3.52 kg CO_2 eq/kg N in conventional AN to 0.68 kg CO_2 eq/kg N recovered in alternative fertilizers), which is the main negative environmental impact associated to N-fertilizers.

Moreover, and LCA analysis considering the entire WWTP facility as well as energy and chemical consumption for conventional fertilizer production fully assessed the environmental impact of LIFE ENRICH value chain implementation. Results showed that a total CO_2 emissions reduction of 20% (5.7 t CO_2 eq/d) and 58% reduction in mineral resource scarcity mainly related to P recovery (118 kg Cu eq/d) can be achieved through the whole LIFE ENRICH value chain implementation.

Regarding sludge application, it has been demonstrated the feasibility of agricultural direct application of sludge, combined or not with alternative fertilizers (struvite and AN). LIFE ENRICH process implementation would allow a safe and sustainable reuse of sludge with agricultural purposes. Also, struvite use in fertigation systems and flexibility in mixing struvite, AN and sludge for optimal fertilizer mixtures depending on the crops requirements has been demonstrated, targeting the most relevant greenhouse and open-air crops in both Spain and EU. In the EU-15 tomato, lettuce, cauliflower, broccoli (tested in LIFE ENRICH project), and onions (similar horticultural crops susceptible to use LIFE ENRICH fertilizers) account for nearly 40% of the total area cultivated (2018); while cereal production of wheat and spelt, barley and oats (tested in LIFE ENRICH project) account for 63% of cereal production in EU-27 (2018). A wide part of agricultural sector at European level could benefit from the use of LIFE ENRICH fertilizers.

Environmental outputs are detailed in Deliverable from action C1, and details about LCA analysis and replicability assessment are gathered in Deliverables from actions B4 and B6, respectively.

6.4.2 Economic benefits

WWTPs OPEX are expected to be reduced due to the minimization of uncontrolled struvite precipitation downstream anaerobic digesters. From one side, in Murcia Este WWTP a reduction of 85% in antiscaling consumption was determined (11 k€/y), related with struvite precipitation in pipes. From the other side, a reduction of 85% (14k€/y) of the costs related to external maintenance was determined, related with struvite precipitation in centrifuges. These costs may vary from one WWTP to another, as it was determined in the replicability assessment in other 3 WWTPs.

WWTPs OPEX reduction also comes from the improvement in sludge dewaterability, which in Murcia Este WWTP accounts for chemical and energy consumption in de-watering stage reduction: 27% reduction in polymer consumption (52k€/y), 18% reduction in dewatering energy consumption (8k€/y), as well as sludge production: 20% reduction (119 k€/y).

For those WWTPs such as Murcia Este that does not have obligation or problems regarding N discharge, the reduction of N load to biological reactors can be translated in aeration energy savings, while maintaining same N discharge levels. In this case, for Murcia Este WWTP, savings from aeration were estimated at 31 k€/y (956 kWh/d reduction). If there are discharge limits for N&P, the recovery of N&P through LIFE ENRICH solution could have a potential aeration energy savings while prioritizing discharge limits compliance.

Total savings for Murcia Este WWTP full-scale LIFE ENRICH implementation are of 235 k€/y.

Fertilizers produced are expected to be sold with a revenue for Murcia Este WWTP of 1.17 M€/y (385 k€/y from struvite and 794 k€/y from AN), while OPEX was estimated of

1.1 M€/y (202 k€/y from struvite production and 891 k€/y from AN pro-duction). Considering OPEX from N&P recovery process, OPEX savings of 235 k€/y regarding baseline, and revenues from fertilizers selling, a total OPEX reduction by 3.3% is expected.

CAPEX associated with Murcia Este full-scale process will be 6.15 M€. Considering revenues, savings and OPEX, payback time would be 19 years.

In addition, the implementation of LIFE ENRICH value chain through the proposed business models created would imply a business structure with some administrative/technical/commercial jobs places creation, along with jobs creation related with sludge managing for agricultural purposes.

Economic outputs are detailed in Deliverable from action C1, and details about LCC analysis and replicability assessment are gathered in Deliverables from actions B4 and B6, respectively.

6.4.3 Social benefits

The above-mentioned creation of jobs would have a positive impact on the social network around the benefited WWTPs. In a different way, transition to a circular economy relating waste management with agricultural production in a professional, full-scale, effective, and safe way serves as an example for the society and pushes for a wider knowledge and application of circular and environmentally friendly strategies on the whole population.

Additionally, nutrient recovery would endure the European agriculture industry by reducing its dependence of mineral fertilizers and their price fluctuations.

Social benefits are complex to measure and occur under slow dynamics, so its monitoring is limiting on how this project reach the society through its website, printed leaflets or brochure distribution and appearance in media. Action D1 is the one focused on achieving the indicators stated on the Action C1 Deliverable related to social benefits.

6.4.4 Replicability, transferability, cooperation

This project includes an analysis and the definition of business models to replicate and export the proposed models to other plants both in Spain and other countries of the European Union (Actions B5 and B6). The technical features of the project do not limit its application in a geographical way, so its worldwide implementation would be possible.

Phosphate rock market is global, being produced mostly in Iraq, China, Algeria, Syria, Jordan, South Africa, the US and Russia; and then distributed all over the world. Thus, the market targets for a nutrient recovery strategy that would reduce phosphate rock consumption may be found globally.

Global warming and GHG emissions is also a worldwide problem in which fertilizer industry plays a major role regarding energy consumption, especially in N fertilizers. Any territory could benefit from production and use of alternative fertilizers as the ones produced in this project. Lastly, the whole world would benefit from specific territories reducing the environmental impact associated to fertilizer industry.

The business models coming out of this project are strongly cooperative, as it im-plies private companies in charge of WWTP management, water and agriculture regulation public bodies and private companies or NGO who would end using the produced fertilizers. Therefore, replication could be market-driven from any of these parts if proper communication can generate an interest. A policy-dependent pull could even occur if regulations to penalize mineral fertilizers, to give rise to recovered ones.

The adaptation of businesses models to European countries was made attending to different casuistic in each country, paying attention to different needs, realities and future expectations in waste(water) management and agricultural practices. Moreover, transferability assessment also analyses synergies between the countries studied, reinforcing the robustness of the business models.

It is still to be discovered how society will respond in front of food produced using waste recovered nutrients. Acceptance may occur with the help of media, administrations and large food-related companies, showing those a message of safety around these food products. It is encouraging that our society is progressively evolving towards a higher consciousness on environmental problems and taking actions at social and individual level. Regarding food consumption and elaboration, certain social groups could pull for sustainable fertilizing products and practices as they are the ultimate end-users of the value chain. In this sense, the society itself could contribute to the acceptance of alternative fertilizers and even enhancing the existent demand.

6.4.5 Best practice lessons

All partners of this project know and apply quality protocols on the work they realize. Good Laboratory Practices, Good Manufacturing Practices, ISO norms and standardized protocols are applied in every action when relevant. Moreover, an effort is being done to reduce this project's carbon footprint. The objective of the project itself includes energy and chemicals reductions which lower carbon emissions. In addition, equipment is designed to be energy-efficient, travelling and paper use is limited and the different partners apply carbon management strategies to approach a carbon neutral activity.

6.4.6 Innovation and demonstration value

The business model developed in this project comprises a value chain that rises from waste to end, marketable, food products, passing through fertilizers. Moreover, two business models were developed in order to better embrace the complexity of the value chain proposed through two main worldwide social, economic, and industrial sectors tightly linked to environment, as they are (waste)water and agricultural (including fertilizers) sectors. The definition of the models and how they connect actors and stakeholders of those different industries and administrations is innovative since no other business model have been found to be exploitable at this grade.

Nitrogen and phosphorus integrated recovery is not found worldwide, being highly innovative. Of the different units of the project, the treatment train of ammonium concentration by zeolites and recuperation by a membrane contactor present a fully new option on N recovery. Both struvite crystallization and elutriation are well-known, but integration of both strategies is still lacking on good, reliable results. In addition, both N and P recovery are fully integrated in the proposed solution; a Spanish patent was registered based on ENRICH process.

Moreover, by testing the produced fertilizers on crops, new data on how those affect to crop growth, composition and safety of consume is generated. Struvite in fertigation system was also demonstrated for the first time, combined with ammonium salt also produced within the same facility.

Altogether, these innovative aspects of this project give it an added value to stand out when compared with other similar and somehow limited business models.

Additionally, LIFE ENRICH results has led to the new H2020 Walnut project (101000752), which started in 2021, about developing technological solutions to redesign nutrient supply chains from wastewater and brines. The project will carry out 5 pilot demonstrations; specifically, Cetaqua, coordinator of LIFE ENRICH project, will develop a production system for Smart Biofertilizers consisting of an Opti-blend system capable of combining ENRICH fertilizers struvite and AN with potassium and plant growth stimulants (PGBs) of biological origin.

6.4.7 Policy implications

Recycled nutrients are nowadays in the way of being included in the EU Regulation. For struvite and other similar phosphate salts, they have been included in the new EU Fertilizer Products Regulation 2019/1009 in 2019, and will come into force in July 2022, which will imply its use as direct fertilizers or raw material for fertilizing products in EU State Members, this is encouraging for WWTP to implement process and for fertilizer industry and farmers, that are more willing to incorporate this products since harmonic regulation is not only good for commerce, but also reassure the safety of the products at European level. The STRUBIAS report elaborated by JRC of EC, has been major policy breakthrough to adapt the EU FPR. The report pro-poses EU FPR criteria for phosphate salts and struvite, biochars - pyrolysis and gasification materials, and thermal oxidation materials (ashes) for now. It set the criteria nowadays included in EU FPR for struvite and pushed for its incorporation in the regulation. It also implicated the whole stakeholder community from 2017 regarding P recovery as struvite at European level. Also, it allowed to set quality standards and select analytical parameters regarding struvite production, as it happened in ENRICH project, way before the EU FPR included the product in it, as regulation changes usually take time.

Ammonium salts produced from nutrient recovery, yet not included in regulations, are expected to follow the path as for struvite and in a short period of time, since many questions regarding product safety and protocol to adapt the current regulations have been answered for struvite. The policies adaptation for struvite consideration is a major step for all recovered nutrients. Also, STRUBIAS report is a living work which continues to lead the way in the regulation of recovered nutrients and other valuable products that can be obtained from WWTP and other alternative sources mor sustainable that conventional ones.

End-of-Waste status must be granted at national level. Nowadays, only struvite has EoW status in Belgium, Netherlands and Germany, but the new EU FPR opens the door to change this situation in the short-term.

Another important policy aspect is that trademark products can be sold as fertilizers at national level, for that, the product must the registered under REACH regulation. This is the case of Phosphocare™ (from Phosphogreen process in Denmark), Crystal Green® (Pearl process in United States/United Kingdom) and BIOSTRU© STRU-VITE (NuReSys process in Belgium).

The ENRICH project have assessed the feasibility of the use of the recovered products in the pilot plants for the fertigation of tomato, lettuce, cauliflower and broccoli, with the collaboration of the European Sustainable Phosphorus Platform (ESPP), thus having a solid base from where it can climb up as a success model. Moreover, the business plan for Spain has been defined based on the results obtained and the business models developed, and the business models have been adapted to other European countries taking into account the synergies and context of key players and the current and expected regulations in each country.

In order to make the results viable and contribute to the update of the legal framework, the administration has been involved in the project. The Ministry of Agriculture of Spain is one of the Stakeholders of the project. ENRICH team is aware that the involvement of Administration in this kind of projects is essential, if an impact on policies is desired.

Apart from the new business models and the future global fertilizer regulation, LIFE ENRICH project is in line with many stablished European Directives and policies, as shown in Figure 29.

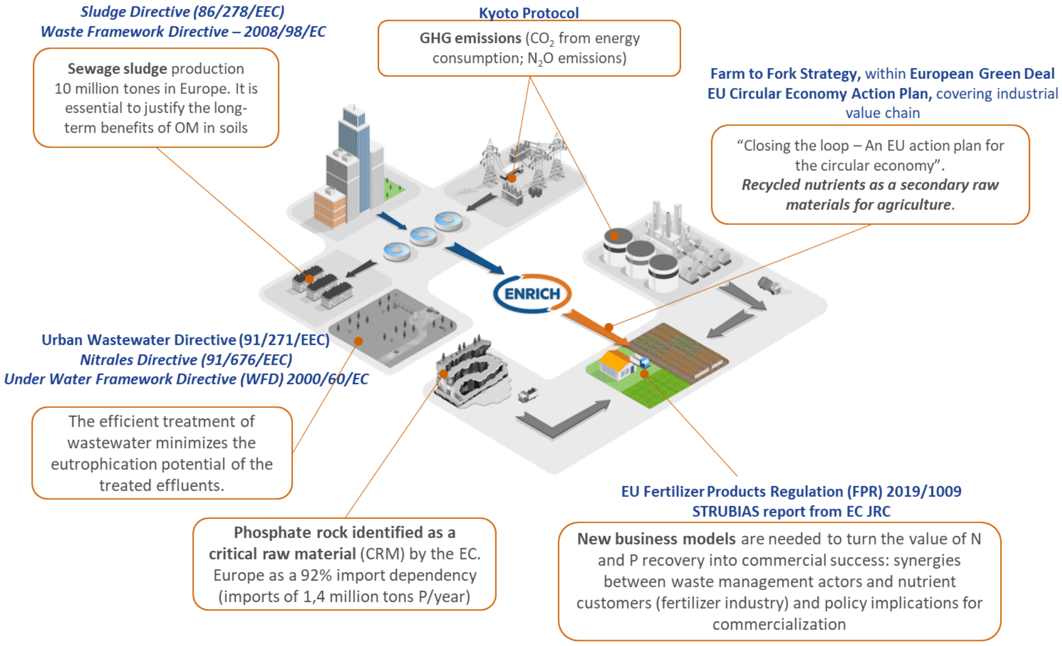

Figure 29. European Directives, Regulations and Initiatives in line with the Life ENRICH project

6. Key Project-level Indicators

Those indicators had been previously defined in the official proposal to track the positive effects produced by the project in the environmental and socio-economics aspects. The indicators reflect the parameters used for the policy making by the EU wherever is possible, complemented by context parameters and economic indicators.

The criteria for the KPIs selection was response firstly to the mandatory indicators and secondly to the indicators related to the environmental topic of the LIFE ENRICH project, which is resource efficiency, green and circular economy. The Table 3 shows the selected KPI indicators to monitor the impact of the actions of the project.

Table 3. Key Performance Indicators of LIFE ENRICH project

Indicator number	Category	Indicator
1.5	Project setting	Project area/length
1.6	Project setting	Humans (to be) influenced by the project
3.1	Environmental and Climate action outputs and outcomes	Waste management
4.1	Environmental and Climate action outputs and outcomes	Resource efficiency – energy
4.4	Environmental and Climate action outputs and outcomes	Resource efficiency - circular economy
5.1	Environmental and Climate action outputs and outcomes	Chemicals
8.1	Environmental and Climate action outputs and outcomes	Greenhouse gas emissions
10.2	Societal outputs and outcomes	Involvement of non-governmental organizations (NGOs) and other stakeholders in project activities
11.1	Societal outputs and outcomes	Website
11.2	Societal outputs and outcomes	Other tools for reaching/raising awareness of the general public
12.1	Societal outputs and outcomes	Networking
13	Societal outputs and outcomes	Jobs
14.1	Economic outputs and outcomes	Running cost/operating costs during the project and expected in case of continuation/replication/transfer after the project period
14.2	Economic outputs and outcomes	Capital cost expected in case of continuation/replication/transfer after the project period
14.3	Economic outputs and outcomes	Future funding
14.4	Economic outputs and outcomes	Continuation/replication/transfer after the project period

In Deliverable D30 from Action C1 (Annex 2.23) the updated values of the indicators are presented.