SAVING-E

Final Report
LIFE14 ENV/ES/000633

LIFE Project Number

LIFE14 ENV/ES/000633

Final Report

Covering the project activities from 01/10/2015[1] to 31/03/2019

Reporting Date[2]

29/06/2019

LIFE SAVING-E

Two-Stage Autotrophic N-remoVal for maINstream sewaGe trEatment

Data Project

Project location:	Spain
Project start date:	01/10/2015
Project end date:	31/03/2019
Total budget:	1,168,068 €
EU contribution:	672,645 €
(%) of eligible costs:	57.72%
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[1] Project start date

[2] Include the reporting date as foreseen in part C2 of Annex II of the Grant Agreement

1. Table of contents

2. List of key-words and abbreviations

ACA: Agència Catalana de l'Aigua

BNR: biological nitrogen removal

CAS: Conventional Activated Sludge

CO_2: carbon dioxide

DAM: Depuración de Aguas del Mediterráneo

DO: Dissolved oxygen

EIP: European innovation partnership

EU: European Union

FTE: Full time equivalent

GHG: Greenhouse gases

HRAS: high-rate activated sludge reactor

PE: person-equivalent

PLC: Programmable Logic Controller

SAVING-E: Two-Stage Autotrophic N-remoVal for mainstream sewage treatment

TRL: Technology readiness levels

UAB: Universitat Autònoma de Barcelona

UASB: Upflow Anaerobic Sluge Blanket

UAnSB: Upflow Anammox Sludge Blanket

UWWT: Urban Wastewater Treatment

WssTP: European Water Supply and Sanitation Technology Platform

WWTP: Wastewater treatment plant

3. Executive Summary

SAVING-E aims at demonstrating, at pilot scale and with real urban wastewater that the energetic balance of an urban WWTP can be severely improved at both, high and low temperatures thanks to the implementation of the autotrophic biological nitrogen removal (BNR) in the mainstream. Therefore, the main expected output is to demonstrate and to disseminate that the use of SAVING-E technology results in significant positive impacts such as: (i) energy savings and (ii) reduction of overall operational costs, compared to current technologies for treating urban wastewaters.

In this sense, the implementation actions (B-actions) have included the design, construction, start-up and operation of the pilot plant located in the urban Rubí WWTP (Barcelona, Spain) and the technical and economic analysis of upgrading different types of urban WWTPs using SAVING-E technology. Moreover, the technical, environmental, economic and social impacts of implementing SAVING-E technology have been assessed in monitoring actions (C-actions) at local, national and European level. Besides, the dissemination actions (D-actions) aim to promote the project outputs, in order to create a platform for communication between the project and stakeholders and to have measurable impacts. Finally, the project management and monitoring of the project progress (E-actions) has ensured the project coordination among the different beneficiaries.

At the moment of the final reporting, all the actions have been completed:

B.1 Design of the SAVING-E pilot plant: This action dealt with the design of the SAVING-E pilot plant. The design included: a high rate activated sludge reactor for organic matter removal, a secondary sludge settler, an airlift reactor for partial nitritation and an upflow anaerobic sludge blanket reactor for anammox process. This action was successfully achieved on December 2015.

B.2 Construction of the SAVING-E pilot plant: SAVING-E pilot plant was constructed by an external company, selected by an open tendering procedure, following the design performed in action B.1. The total volume of the three reactors and the settler is 1.7 m^3 for treating a maximum inflow of 3 m^3 d^{-1}. The pilot plant was installed in Rubí WWTP (Barcelona, Spain) over a supporting structure of 2.4m x 4.0m x 3.3m. The construction of the SAVING-E pilot plant started on January 2016 and finished on June 2016.

B.3 Start-up of SAVING-E pilot plant: The start-up of SAVING-E pilot plant started on June 2016 and finished on March 2017. Successful start-up of the pilot plant was achieved. Each one of the three reactors in the SAVING-E pilot plant has its specific starting-up protocol. The starting up procedure for conventional activated sludge wastewater treatment plants is simple and no relevant challenges are usually highlighted. However, the specific treatment configuration aiming a significant reduction of the energy consumption used in the SAVINF-E pilot plant requires of very specific starting-up strategies for the reactors related to nitrogen removal. An effective starting up strategy of the partial nitritation and the anammox reactor units is of paramount importance. The performance of the process is linked to the capacity to produce a granular sludge with certain capacities for each one of the reactors. Since the microbial species responsible for those biochemical transformations are slow growers, particularly challenging starting up was expected for such an installation. During the design of the described starting up strategies special attention was paid to use protocols specifically compatible with future full scale applications. In particular, the advanced control strategies and the design of the partial nitritation reactor are to be highlighted.

B.4. Operation of SAVING-E pilot plant. After the start-up carried out in Action B.3, the three biological reactors of the SAVING-E technology were connected and operated in an integrated manner for getting the process performance at long term treating a real urban wastewater. This action finished in March 2019, four month later as initially planned. This extra time was needed to operate the pilot plant at low temperature taking advantage of the winter season. Successful operation of the SAVING-E pilot plant treating real urban wastewater at mild and low temperatures was achieved. To evaluate the effect of the SAVING-E technology over the increase of methane production and the reduction of oxygen consumption, three different cases were considered for Rubí WWTP: (i) Case 1: the current configuration removing only organic matter (Only COD removal); (ii) Case 2: a modified configuration with removal of organic matter and nitrogen by conventional technologies; (iii) Case 3: Implementation of the SAVING-E technology.

The three scenarios were compared in terms of percentage of increase of methane production and percentage of reduction of oxygen consumption. The comparison of cases 1 and 3 shows that the implementation of the SAVING-E technology in Rubí WWTP would increase up to 35% the production of methane and it would allow the nitrogen removal spending only 10% more of oxygen than the current configuration removing exclusively organic matter. The comparison of cases 2 and 3 shows that the implementation of the SAVING-E technology instead of the implementation of a conventional technology for removing nitrogen in Rubí WWTP would increase up to 35% the production of methane and it also would save up to 35% of the oxygen consumption.

B.5. Technical and economic analysis for upgrading different types of urban WWTPs with SAVING-E process. In this action the following tasks were carried out: (i) a comprehensive analysis of the Spanish and European context related to urban wastewater treatment and nutrient removal, (ii) a study of the retrofitting of the Rubí WWTP, focusing on technical and economic transferability analysis, (iii) a study of the retrofitting of standard types of urban WWTPs in Spain and EU for implementing SAVING-E process.

C.1 Technical and environmental impacts of SAVING-E technology. Some of the technical and environmental indicators are defined in each implementation action, but in this monitoring action special attention was paid to monitor the energy consumption, process efficiencies and carbon footprint for implementing SAVING-E technology at full scale. Life Cycle Inventory (LCI) for the initial situation of the project (baseline values of Rubí WWTP in years 2014, 2015 and 2016) was obtained. The impacts refer to 1 m^3 of treated wastewater, which is the most common functional unit in wastewater-related Life Cycle Analysis (LCA). Same functional unit was used for SAVING-E implementation at Rubí WWTP. Therefore, LCIs include: Organic matter and nitrogen removal efficiencies, energy consumption of each single process and subunits, biomass and biogas generated, biogas quality and additives used at the different treatment stages, their packaging, their transport to the WWTP, the wastes generated and their treatments or final disposal, the transport of wastes to their respective treatment plants and the maintenance material. This assumption translates into an electrical consumption from local grid of 0.06 kWh/m^3 of treated wastewater for SAVING-E technology implemented at Rubí WWTP compared to the 0.22 kWh/m^3 of the current configuration.

C.2 Socio-economic impacts at local, national and EU level for implementing SAVING-E technology

In this action, the socio-economic impacts for implementing SAVING-E technology were evaluated following several indicators:

1. **Economic impact** measured through several indicators:
   - Costs of retrofitting existing WWTP and building new WWTP.
   - Return of investment and economic savings by SAVING-E implementation.
2. **Social impact** measured through:
   - Employment
   - Training programs
   - Networking
   - Workshops

D.1 Definition of exploitation strategy. SAVING-E visibility, branding and deliverables preparation: The SAVING-E exploitation strategy was defined as planned. Moreover, a set of templates (word, power point and excel formats) were created to be used on the entire project. On May of 2016, the brochures, roll-up, poster and photo-call were printed. All the participants in the action were successfully implicated on them.

D.2 Website design, operation and back-office. Presence in social networks: The main communication channels for SAVING-E were created (webpage, Twitter and LinkedIn) as it was scheduled. The website is available in English, Spanish and Catalan. The main outcomes of the impact of the website are: (i) Users: 3739; (ii) Sessions: 5394; (iii) Number of sessions per user: 1.44; (iv) Number of page visits: 14291; (v) Pages per session: 2,65; (vi) Average duration of the session: 02:25 min;

(vii) Bounce rate: 43.96%. SAVING-E twitter account has a community of 364 "true" followers, mainly composed by stakeholders on the SAVING-E technology. Each tweet of the project had an average of 5 retweets.

D.3 Networking with other projects: Throughout the project, we have done networking with different LIFE projects, including two LIFE projects with similar topics: (i) LIFE InSiTrate (LIFE12 ENV/ES/000651); (ii) LIFE CELSIUS (LIFE14 EN/ES/00023); (iii) LIFE reWINE (LIFE15 ENV/ES/000437) and (iv) LIFE DeNTreat (LIFE16 ENV/IT/00345). This networking included several meetings with information exchange.

D.4 Attendance and organization of specialized workshops, seminars, conferences, fairs and other events: Throughout the project, we have organized and participated in several events to disseminate the objectives and results of the project. The most relevant events organized by SAVING-E team were: (i) INAUGURATION DAY of the pilot plant (June 2016 in Rubí, Spain); (ii) WINTER SCHOOL (January 2018 in UAB, Spain); (iii) SAVING-E WORKSHOP (June 2018 in Valencia, Spain) and (iv) INFODAY (March 2019 in Barcelona, Spain). A total number of 200 people assisted to these events.

D.5 Notice boards, publications and press releases: The media coverage of the SAVING-E project happened basically at three periods:

1. Several press news was published regarding to the start-up of the project on TV news, webpages and Spanish and Catalan newspapers. Also, it appeared in online newspapers and journals.
2. Other press notices have been released after the official inauguration day of the pilot plant with a significant impact on national and local press media.
3. Finally, press notices have been released after the final event of the project with a significant impact on national and local press media.

Considering the audience of the media that published news about the SAVING-E project, a total audience of between half a million and a million people can be estimated. Regarding the on-site panel, it has been located on main entrance of the Rubí WWTP, where the project is implemented. Moreover, newsletters of the project were launched and summarize the main outcomes achieved in the project and the dissemination and networking activities.

D.6 Layman's report: A report of 16 pages with the main information (problem targeted, objectives, results, dissemination and contact data) was carried out in electronic and print versions.

E.1 Project management by UAB: UAB, as coordinator, has been the intermediary between the associated beneficiaries and the European Commission.

The Partnership Agreement were successfully created, accepted and signed by the whole consortium of the project. Then, it was established the Project Management Manual which details the guidelines for the direction and the coordination of the project. Moreover, SAVING-E project established the rules for the management of the technical and financial issues and the reporting system.

Internal progress reports were planned every six months and they were arranged to provide the executive board with all the information necessary to be able to evaluate properly the progress of the project. The internal progress report included the following documents: Technical progress reports, financial statement of expenditure, timesheets, personnel costs, invoices and tickets related to all expenses and proof of payments and accounting records according to each associated expense. The "Projectplace" platform (supported by WssTP) was being used as a way to contact and to share documents between the beneficiaries throughout the SAVING-E project.

Throughout the project, the communication between the partners was fluently and no significant problems were encountered on the management of the project.

E.2 Audit. According to the change in **Article II.23.2 (d) – Certificate on the financial statements**, the initial requirement for our project to present a 'certificate on the financial statements', foreseen in Action E.2, changed and it was not mandatory for our project. Consequently, the Action E.2 was not carried out.

E.3 After LIFE Plan. SAVING-E consortium has developed an After LIFE Plan (see deliverable E3.1 for more detailed information).

This After LIFE Plan is based on two main blocks:

1. Full development and exploitation of SAVING-E technology

According to the Technology Readiness Levels (TRL), SAVING-E project should increase the TRL of this technology from TRL 4 to a TRL 6 (Prototype system, tested in intended environment close to expected performance). According to the results presented in this Final Report, this objective has been almost accomplished but some technical issues regarding a subsequent scale-up of the technology have not been completely solved. Consequently, this part of the After LIFE Plan has been planned to increase the TRL up to a pre-commercial level (TRL 8) within 4 or 5 years.

2. Dissemination and Communication

The dissemination and communication activities of the After LIFE Plan can be divided in three types:

- Maintenance and upgrading of the SAVING-E webpage during the next 5 years after the end of the project, that is, up to 2023.
- Publication of results of SAVING-E project in four scientific articles in the next two years.
- Presentation of results of SAVING-E project in several scientific-technical conferences in the next two years. The costs associated to the attendance and participation of these events will be assumed by SAVING-E consortium with own resources.

E.4 Compilation of information for indicator tables: The Key Project-level Indicators (KPI) were compiled to make the evaluation of the LIFE+ program in the most accurate manner, although the nature and scale of the SAVING-E project made difficult to adapt them to the project nature.

4. Introduction

SAVING-E deals with the radical re-engineering of current wastewater treatment processes in order to improve energy trades and flow of materials. For many years now, the EU has been taking steps towards the reduction of nitrogen and phosphorous loads in the environment, notably through the adoption of the Urban Waste-Water Treatment Directive (91/271/EEC; UWWT) and the Water Framework Directive (Directive 2000/60/EC; WFD). However, only 6 Member States (Denmark, Finland, Greece, Austria, Germany and The Netherlands) have an overall UWWT compliance higher than 90% for tertiary treatment (mostly targeting at the elimination of nitrogen and phosphorus or the reduction of bacteriological pollution), while the rest of Member States has less than 60% of implementation, including Spain. So that, there is an urgent need for implementing cheap and efficient tertiary treatments, but in fact, the classical treatment applied for nitrogen removal, nitrification followed by heterotrophic denitrification, is a very energy-demanding process, with the corresponding emissions of greenhouse gases. Currently, urban wastewater treatment plants (WWTPs) are net energy-consumers systems and this consumption can be quantified as 4,000-8,000 GWh/year in the EU, i.e. 480-960 M€/year, with an equivalent associated emission of ca. 3-6 Mtons CO_2/year.

In this sense, the challenge of SAVING-E is to radically redesign the urban WWTPs in a way they become energy-producers rather than energy consumers, without affecting its performance or even improving it. SAVING-E aims at demonstrating, at pilot scale and with real urban wastewater that the energetic balance of an urban WWTP can be severely improved at both, high and low temperatures (as low as 10ºC) thanks to the **implementation of the autotrophic biological nitrogen removal (BNR) in the mainstream**.

SAVING-E technology uses most of the entering organic matter for biogas production purposes by designing a first biological step with low oxygen consumption and high biomass production, i.e. with very low sludge residence time. Then, SAVING-E technology will remove nitrogen biologically in the mainstream without the need of organic matter. SAVING-E uses the autotrophic BNR for this aim with a novel two-step approach. This novel approach consists of two reactors, a first aerobic partial nitritation reactor followed by a second Anammox reactor. The application of autotrophic BNR to the mainstream reduces severely the aeration costs and the novel two-step approach for autotrophic BNR represents an improvement compared with autotrophic BNR in one-step because is able to work stably at very low temperatures.

SAVING-E technology has been tested at pilot scale and at long term in a relevant environment treating real urban wastewater. The implementation actions include the design, construction, start-up and operation of the pilot plant in the urban WWTP of Rubí (Barcelona). The pilot plant has been operated during 30 months at different temperatures to demonstrate the stability of the process. To demonstrate the applicability of SAVING-E technology in any urban WWTP of any Member State of EU, the implementation actions have been completed with a technical and economic analysis of upgrading different types of urban WWTPs. Moreover, the technical, environmental, economic and social impacts of implementing SAVING-E technology have been assessed in monitoring actions at local, national and European level.

The consortium used different dissemination actions to promote the project outputs, to create a platform for communication between the project and stakeholders and to have measurable impacts. Directing the project outputs and results towards the right channels is one of the key factors for the success of a project like SAVING-E and essential to ensure a lasting impact on the water sector. These dissemination actions were aimed to a wide range of stakeholders, including: scientific community, water professionals-technical staff, water professionals-decision makers, university and vocational training students, primary and high-school students and general public.

At short-term, the main expected result of this project was to demonstrate and to disseminate that the use of SAVING-E technology versus current technologies for treating urban wastewaters will result in significant positive impacts such as: (i) energy savings, (ii) reduction of CO_2 emissions and the associated carbon footprint, and (iii) reduction of the operational costs.

At long-term, the main expected results of SAVING-E project are its contribution towards the accomplishment of the following EU policies: (i) EU Water Framework

Directive (Directive 2000/60/EC; WFD), (ii) Urban Waste Water Treatment Directive (91/271/EEC; UWWT), (iii) Marine Strategy Framework Directive, (iv) the “Blueprint to Safeguard Europe’s Water Resources”, (v) the 7th Environmental Action Programme and the LIFE regulation (Regulation (EU) 1293/2013) and (vi) EIP on Water, thanks to the demonstration of a new technology (at TRL 6: system prototype in operational environment) able to improve the actual compliance of the nitrogen discharges of the European urban WWTPs.

Secondly, regarding: (i) Resource Efficient Europe strategy, (ii) EU Energy Efficiency Directive and (iii) United Nations Framework Convention on Climate Change Kyoto Protocol, SAVING-E project has contributed in the following sectors: (1) reduction in the use of fossil fuels via: -increased energy efficiency and -substituting for renewable resources; (2) reduction of energy intensity of water treatment; (3) reduction of GHG emissions; (4) reduction of acidification in marine resources resulting from GHG emissions.

Finally, about: (i) European strategy for growth and (ii) the Strategic Plan for Internationalization of the Spanish economy, SAVING-E project has contributed to create a new professional profile for the water industry through a significant part of its dissemination actions (Networking, Winter School, Workshop, Infoday).

5. Administrative part

General coordination and management of the project includes those activities concerning coordination of all beneficiaries’ participation. Management also refers to reporting to European Commission (EC). In this sense, the project progress is tracked in terms of expenditure, resource use, implementation of activities, delivery of results and management risks. Figure 1 shows the SAVING-E organization chart.

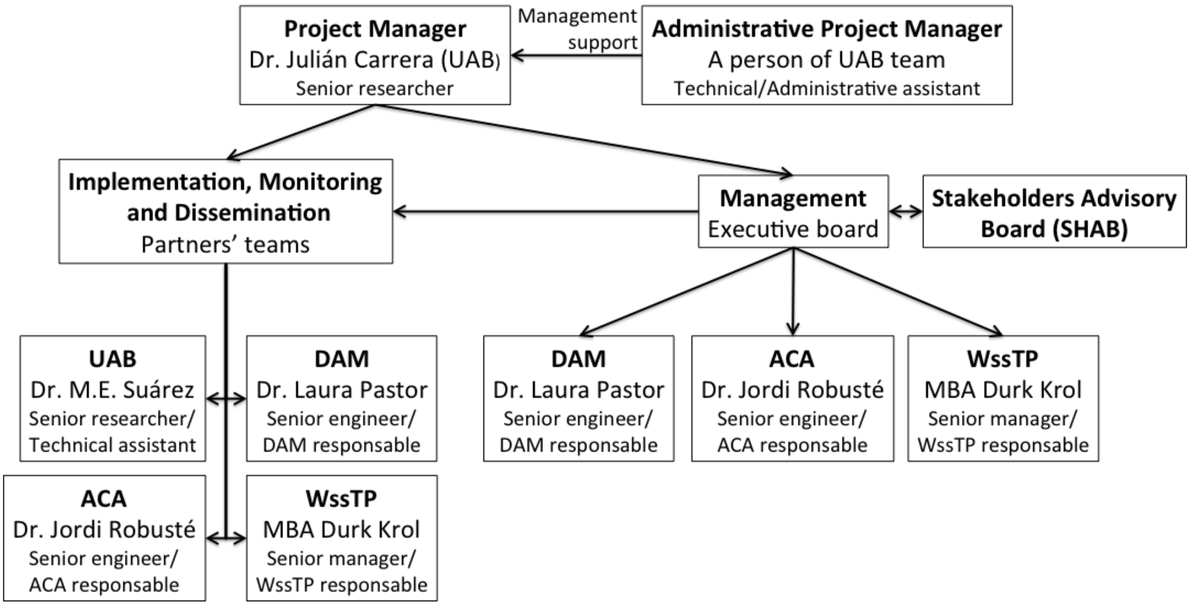

Figure 1. SAVING-E organization chart.

Firstly, it was established the Project Management Manual which details the guidelines for the direction, the coordination of the project, the management of the technical and financial issues and the reporting system. At the same time, it was defined the Stakeholders Advisory Board. Moreover, the Partnership Agreement has been successfully created, accepted and signed by the whole consortium of the project.

On the one hand, UAB, as coordinator, was the intermediary between the Associated Beneficiaries and the EC and it was performing all tasks assigned to it. In particular, UAB was in charge of: (i) to coordinate technical, legal, financial and administrative issues according to the approved proposal in terms of results, schedule and budget, always taking into account the common provisions; (ii) to validate and control of the quality of partners' progress and deliverables, ensuring the implementation of the specific procedures of the project; (iii) to prepare, collect and compile technical and financial reports and to submit reports and communicate with the EC; (iv) to organise and lead the project meetings; (v) to manage knowledge and innovation and oversee the scientific and societal context potentially related to the project and to evaluate project results and transferability potential; (vi) to monitor and document personnel costs and project expenses and receive and distribute the EC contribution.

The responsibilities of the associated beneficiaries (WssTP, DAM and ACA) were: (i) preparing and participating in the project meetings related to their contribution and giving feedback in the preparation of progress reports and (ii) performing satisfactory technical and financial operation and management of the actions in which each beneficiary is in charge of paying and filing invoices, etc.

Internal progress reports were planned every six months and they were arranged to provide the executive board with all the information necessary to be able to evaluate properly the progress of the project. This schedule was a suggestion that the coordinator and the associated beneficiaries adapted to the needs of the project and to its members' availability. The internal progress report included the following documents: Technical progress reports, financial statement of expenditure, timesheets, personnel costs, invoices and tickets related to all expenses and proof of payments and accounting records according to each associated expense. The "Projectplace" platform (supported by WssTP) was being used as a way to contact and to share documents between the beneficiaries throughout the SAVING-E project.

Throughout the project, the communication between the partners and monitoring team was fluently and no significant problems were encountered on the management of the project.

Regarding the communication with EASME, we sent the Mid Term Report on March 2017 and a Progress Report on March 2018. In both cases, the answer of EASME was positive with some indications and recommendations that we followed during the rest of the project and during the preparation of this Final Report. Finally, personnel from EASME, visited our facilities in UAB and Rubí WWTP on March 2019. During this visit, all the technical and some administrative issues of the project were presented and discussed.

Regarding to amendments to the Grant Agreement, we received two letters from EASME with indication for making the amendments to initial Grant Agreement. All those indications have been followed. We want to highlight the change in **Article II.23.2 (d) – Certificate on the financial statements** because the initial requirement for our project to present a 'certificate on the financial statements', foreseen in Action E.2 of the project, changed and it was not mandatory for our project. Consequently, the Action E.2 was not carried out and the cost for the audit has been allocated to personnel costs.

6. Technical part

6.1. Technical progress (per Action).

6.1.1. Actions B. Implementation actions

Table 1. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action B.1.

Action B.1	**Design of the SAVING-E pilot plant**
Responsible:	UAB
Participants:	DAM
Objectives:	Design of the SAVING-E pilot plant using experimental data achieved by UAB in previous research studies at lab-scale.
Schedule	Foreseen start date: *October 2015* / Foreseen end date: *November 2015* Actual start date: *November 2015* / Actual end date: *December 2015*
Main outcomes:	For implementing the SAVING-E concept, a pilot plant was designed with the following stages: **<u>A high-rate activated sludge reactor for organic matter removal</u>**. This reactor performs the removal of the organic matter. The effluent of this stage is the influent of the next one and sewage sludge goes to anaerobic digestion (not included in the prototype). The effluent of this stage is the influent of the next one. The airflow is introduced from the bottom of the reactor through a diffuser to produce homogeneous distribution of the air, supplying the oxygen needed for the biomass and for mixing purposes. The reactor has a square form. The total volume of the reactor is 0.29 m3 and it has been designed to work at different reaction volumes. Three effluent tubes at different heights have been designed to have several reaction volumes: 0.25, 0.19 and 0.13 m^3. These volumes allow testing three different hydraulic retention times (HRT), keeping constant the wastewater flow. A sampling point is

	required to take representative samples from the reactor. At the bottom, a discharge line is needed to empty the reactor. **A secondary sludge settler** that receives the effluent from the aerobic reactor. The purpose of the settler is the separation of the biomass from the treated wastewater. The treated supernatant undergoes to further treatment (nitrogen removal steps). Part of the settled material (biomass) is returned to the reactor and the other part is purged from the system to maintain a fixed sludge retention time. The settler has a cylindrical form. The settler has a volume of 0.47 m^3. This compartment was designed with an overflow rate of 8 m^3 m^{-2} d^{-1} at and a HRT of 3.5 h. At the bottom, a line is needed for biomass recycle. The biomass is pumped from the settler to the reactor. After the pump, a biomass purge line is required and two valves regulate the recycle and the purge. A sampling point is required in the effluent line towards the airlift reactor. **An airlift reactor performs the partial nitritation process**. Airflow is introduced from the bottom of the reactor through a diffuser to produce homogeneous distribution of the air, to supply the oxygen needed for the biomass and for mixing purposes. The airlift reactor consists of a cylindrical tank (downcomer), where the wastewater and the granular biomass are in contact and the biological reactions take place. An inner tube in the reactor body allows proper mixing and oxygen transfer (riser). A gas-liquid-solid separator at the upper part of the reactor allows an efficient separation of the solid particles, the gases and the treated wastewater. This reactor is fed with the wastewater from the high rate activated sludge system. The design of the airlift reactor is divided in two parts, the body of the reactor and the in-built secondary clarifier at the top (head). The reaction volume of the airlift reactor was designed with the total Kjeldahl nitrogen (TKN) concentration of the inflow of Rubí WWTP, the applied flow-rate in the pilot plant and the previously achieved nitrogen loading rate (NLR) at lab-scale. The airlift reactor has a total volume of 0.40 m^3. A height-to-diameter downcomer ratio of 5.0 and a cross sectional area of the downcomer to the riser ratio of 1.08 were used to design the cylindrical body of the airlift reactor. For the separator, a head-section to downcomer diameter ratio of 2.0 was applied. The airlift reactor receives two inflows: the effluent from the high-rate activated sludge system and reject wastewater from the dewatering process of the digested sludge. The reject water will be used to control the ammonium concentration in the bulk liquid of the airlift reactor. Two sampling points are required to

	take representative samples from the reactor. At the bottom, a discharge line is needed to empty the reactor. The effluent of the airlift reactor is in the top. A carbonate dispenser is needed for the pH control. **An Upflow Anammox Sludge Blanket (UAnSB) reactor**. This is the last compartment of the SAVING-E pilot plant and it performs the anammox process. The UAnSB reactor is fed with the effluent from the airlift reactor performing partial nitritation. The UAnSB reactor consists of a cylindrical tank where the wastewater flows in an upward direction through an anaerobic sludge bed. A gas-liquid-solid separator at the upper part of the reactor allows an efficient separation of the solid particles, the produced gases and the treated wastewater. The design of the UAnSB reactor is divided in two parts, the cylindrical body of the reactor and the in-built separator at the top (head). The UAnSB reactor has a total volume of 0.50 m^3. The UAnSB reactor has been designed to work with two different reaction volumes. At half volume of the cylindrical body, a mobile diffuser allows to reduce the volume that is needed for the start-up period. Four sampling points are required to take representative samples from the anammox sludge bed. At the bottom of the reactor, a discharge line is needed to empty the reactor. The effluent of the UAnSB reactor is in the top, where a sampling point is needed. The total volume of the pilot plant is 1.7 m^3 and it has been designed to treat an inflow from 1 up to 3 m^3/d. Moreover, a cooling system was designed to be able to operate the pilot plant at 10-12ºC at long-term. More technical details about the design of the SAVING-E pilot plant can be found on the deliverable B1.1. The demonstration of the feasibility of the SAVING-E process at these low temperatures is required to extend its application to the northern countries in EU.
Planning and problems encountered:	This action was finished with a delay of one month because Dr. Carlos Ramos was contracted by UAB on November 2015 instead of October 2015, as planned in the proposal, due to legal restrictions.
Progress indicators – milestones and deliverables:	Progress indicators presented in the technical application form: • *Design of the volume of each reactor.* **Achieved** • *Connections between reactors, airflows and inflow defined.* **Achieved** • *Instrumentation and closed control loops defined and designed.* **Achieved**

	Deliverables: • **B1.1 Pilot plant and automatic control loops design guides** Milestones: • MB1.1 (Design of the pilot plant). **Achieved**.

Table 2. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action B.2.

Action B.2	**Construction of the SAVING-E pilot plant**
Responsible:	DAM
Participants:	UAB
Objectives:	Construction of the SAVING-E pilot plant, including all the material elements and the control algorithm following the design guide defined in Action B.1.
Schedule	Foreseen start date: *December 2015* / Foreseen end date: *May 2016* Actual start date: *January 2016* / Actual end date: *June 2016*
Main outcomes:	SAVING-E pilot plant was constructed by an external company following the design performed in action B.1. The constructing company of the pilot plant was selected by an open tendering procedure. In this procedure, the constructing company was selected based on two main criteria: (i) best value for money and (ii) proven experience. For detailed information about the tendering process, see deliverable B2.1. Pictures of the SAVING-E pilot plant can be found in the web page. The pilot plant was installed in Rubí WWTP over a supporting structure, which has been built to be easily manageable and movable. In this way the pilot plant is a self-contained and robust module, easy to transport and to relocate in case of need. The dimensions are 2.4 m x 4.0 m x 3.3 m and the building materials are stainless steel and tramex. A schematic diagram of the SAVING-E pilot plant can be found in the web page. The pilot plant is a two-stage process based on the application of a high-rate activated sludge system to redirect the organic carbon to anaerobic digestion and an autotrophic biological process to remove nitrogen via nitrite. The last is a two-step process where, in first place, an airlift reactor with granular biomass performs partial oxidation of the entering ammonium to

	nitrite. Then, in second place, the remaining ammonium and the nitrite are directly converted to nitrogen gas by the anammox in a UAnSB reactor with granular biomass. The total volume of the three reactors and the settler is of 1.7 m^3. Moreover, six different cylindrical storage tanks of different volumes have been installed. The volume depended on its function on the SAVING-E pilot plant. Detailed information about the dimensions and characteristics of each process unit can be found on deliverable B2.1. Furthermore, SAVING-E pilot plant includes several automatic control loops regulated by a Programmable Logic Controller (PLC), including: • Dissolved oxygen (DO) concentration in the two aerobic reactors. • pH in the airlift reactor. • Ammonium concentration in the airlift reactor. • Temperature in each reactor. Feeding and biomass recirculation pumps and automatic valves (biomass purge and airflow regulation) are also controlled by the PLC. Airflow valves were used as the final control element of the control loop of DO concentration in the aerobic reactors. Several level and temperature sensors are also used. Temperature in all the reactors is monitored by PT1000 sensors and an electrical resistance or a cooling equipment is used to heat or to cool the recirculation water of storage tank. Then, this water is pumped to the reactors jackets for allowing the desired temperature set-point. The electrical cabinet includes all the elements necessary for protection and control, PLC, control software and remote monitoring. The PLC allows control and monitoring of the whole pilot plant. More details and technical data about the automatic system control of the SAVING-E pilot plant can be found in deliverable B2.2.
Planning and problems encountered:	This action started on January 2016 instead of December 2015 due to the delay of one month in Action B.1. However, the action finished at the beginning of June 2016 as previously planned.
Progress indicators – deliverables:	<u>Progress indicators presented in the technical application form:</u> • *Offers of every element of the pilot plant filled.* **Achieved** • *Orders and delivery requirements defined.* **Achieved** • *Delivery of materials and equipment done.* **Achieved** • *Pilot plant finished and installed.* **Achieved** • *Algorithm control implemented.* **Achieved** • *Operation manual finished.* **Achieved**

	Deliverables: • **B2.1 SAVING-E pilot plant** • **B2.2 Operation System Manual** Milestones: • MB2.1 Construction and installation (including hydraulic and electrical tests). **Achieved**.

Table 3. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action B.3.

Action B.3	**Start-up of the SAVING-E pilot plant**
Responsible:	UAB
Participants:	DAM
Objectives:	Inoculation and start-up of the SAVING-E pilot plant built in action B.2.
Schedule	Foreseen start date: *June 2016* / Foreseen end date: *February 2017* Actual start date: *July 2016* / Actual end date: *March 2017*
Main outcomes:	In the SAVING-E technology, there are three different biological processes (one for each reactor) and each one requires a specific type of biomass and start-up. These biomasses have to be grown using a proper inoculum and a specific start-up procedure for each reactor: **HRAS reactor for organic matter removal**. This reactor was inoculated on July 2016 with activated sludge from the Rubí WWTP. From the beginning, this reactor has been operated in continuous mode with a settling unit treating wastewater coming from the outlet of the primary treatment of Rubí WWTP. The start-up of this reactor at the design organic loading rate has been successfully completed. Detailed information about the results of the start-up of this reactor can be found in deliverable B3.1. Throughout the start-up period, the values of the main operational parameters of HRAS reactor were: • Reaction volume: 0.25 m^3 • Dissolved oxygen (DO) concentration: 1.3 ± 0.3 mg O_2 L^{-1} • pH: 7.6 ± 0.3 • Temperature: 16 ± 3 ºC

	• Inflow: 2.2 ± 0.4 $m^3\ d^{-1}$ • Sludge Retention Time (SRT): 4 ± 1 d • Hydraulic Retention Time (HRT): 3 ± 1 h • Total Suspended Solids concentration [TSS]: 3.3 ± 1.4 g L^{-1} In a few days after the inoculation of the HRAS reactor, a stable removal of the total organic matter (measured as Total Chemical Oxygen Demand, COD_{total}) around 70% was achieved. This percentage has been maintained throughout the whole start-up. However, after three months, a significant deterioration of the settling capacity of the activated sludge was detected in the HRAS system since the Sludge Volumetric Index at 30 min (SVI_{30}) increased to more than 400 mL g^{-1}. This deterioration was probably due to the low SRT applied in the HRAS system and the decrease of the wastewater temperature (below 10 ºC). Despite this significant increase of the SVI_{30}, the settler was able to retain practically all the solids. However, to improve the aggregation of the biomass it was decided to add a small amount of polyelectrolyte on a daily basis. After several days, the SVI_{30} decreased below 150 mL g^{-1}, which is the threshold to consider a good settling capacity of the sludge. This good settling capacity has been maintained for the rest of start-up period. **<u>Airlift reactor for partial nitritation</u>.** This reactor was inoculated on July 2016 with an activated sludge from an urban WWTP. One of the main results achieved during this was to establish a protocol for a successful start-up of the partial nitritation reactor of the SAVING-E technology. In the start-up of this reactor, two objectives should be accomplished: • **Achievement of a granular sludge** from the conventional floccular activated sludge used as inoculum. • **Achievement of partial nitritation** (oxidation of half of the inlet ammonium to nitrite) instead of the complete nitrification (oxidation of the inlet ammonium to nitrate), which is the main activity of the used inoculum. Consequently, the start-up protocol is as follows: • **<u>To work with the reactor in SBR (Sequencing Batch Reactor) mode</u>** to promote granulation of the biomass by

	progressively reducing the settling time. In this SBR operational mode there are 4 stages: filling, reaction, settling and decantation. Aeration begins when the filling stage starts to provide proper mixing between biomass and raw wastewater. A volume exchange ratio of 0.3 was applied in the whole start-up. The end of the reaction phase is determined by the ammonium control loop of the reactor. An ammonium concentration set point is fixed and the aeration stopped when the ammonium concentration in the airlift achieves this concentration. This set point was periodically modified according to the ammonium concentration of the influent. Finally, the time of the settling stage was also modified to enhance the granulation of the biomass. Thus, the settling time was set at 30 min at the beginning and it was progressively decreased to 20, 15 and 10 min in different periods of the start-up. • **To fed the reactor with reject water from the dewatering of the digested sludge**. This wastewater contains a high ammonium concentration (around 700-800 mg N L^{-1}) which helps to establish a robust partial nitritation process removing the nitrite-oxidizing bacteria activity. The complete start-up of this reactor with the design nitrogen loading rate, partial nitritation and granulation of the biomass has been successfully achieved. Detailed information about the results of the start-up of this reactor can be found in deliverable B3.1. **UASB anammox (UAnSB) reactor**. UAnSB reactor was inoculated with an enriched anammox granular sludge cultivated during months in the laboratory of the UAB-team at UAB facilities. From the beginning, UAnSB reactor has been operated in continuous mode and it has been fed with the effluent produced by the airlift reactor to avoid the external addition of nitrite to the UAnSB influent during the start-up. Moreover, a recirculation flow has been used during the start-up to increase the upflow velocity in the UAnSB reactor until a proper value. Finally, the temperature control loop of the reactor was used to operate a high temperature to promote the growth of the anammox bacteria. This growth is favored by high temperatures in the reactor and consequently, a temperature of 33 ºC was the set point of the control loop during the start-up.

	The values of the main operational parameters of UAnSB reactor throughout the start-up were: • Reaction volume: 0.1 m^3 • pH: 8.1 ± 0.3 • Temperature: 33 ± 1 ºC • Inflow: 0.35 ± 0.14 m^3 d^{-1} • Recirculation flow: 0.72 m^3 d^{-1} • Upflow velocity: 0.3 ± 0.1 m h^{-1} • Nitrogen loading rate: 0.52 ± 0.13 kg N m^{-3} d^{-1} The average applied nitrogen loading rate (NLR) during the start-up has been 0.52 ± 0.13 kg N m^{-3} d^{-1}, with approximately a 50% of nitrogen removal resulting in a nitrogen removal rate of 0.24 ± 0.04 kg N m^{-3} d^{-1}. It was decided to maintain this percentage of nitrogen removal rate to avoid limitation by substrate in the UAnSB during the start-up.The complete start-up of this reactor with the design nitrogen loading rate has been successfully achieved. Detailed information about the results of the start-up of this reactor can be found in deliverable B3.1.
Planning and problems encountered:	The procedure of the start-up of the SAVING-E was modified regarding the originally proposed in the technical application form. In the previously proposed procedure, the three biological reactors were supposed to be simultaneously inoculated. This procedure assumed that the wastewater fed to the UAnSB reactor had to be supplemented with nitrite. To solve the addition of external nitrite, it was decided to postpone the start-up of the UAnSB reactor until the start-up of the airlift reactor was almost complete. Consequently, the start-up of the HRAS and airlift reactors were initiated on July 2016, but the start-up of the UAnSB reactor was initiated on February 2017. Thus, the UAnSB could be fed with a wastewater containing ammonium and nitrite coming from the airlift reactor in the appropriate concentration and the external addition of nitrite was avoided. Despite the change in the procedure of the start-up, the action finished at the beginning of March 2017, only one-week late from the originally planned.
Progress indicators – deliverables:	Progress indicators presented in the technical application form: • *Achievement of 75% of the organic loading rate of design at 25ºC in the aerobic reactor for organic matter removal in 2 months.* **Achieved**

	• *Achievement of 75% of the nitrogen loading rate of design at 25ºC in the airlift reactor for partial nitritation in 4 months.* **Achieved** • *Detection of Anammox activity in the UASB reactor after inoculation.* **Achieved** • *Achievement of 75% of the nitrogen loading rate of design at 25ºC in the UASB reactor for Anammox process in 7 months.* **Achieved** Deliverables: • **B3.1 Start-up manual of the pilot plant** Milestones: • MB3.1 Successful start-up of the pilot plant. **Achieved**

Table 4. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action B.4.

Action B.4	**Operation of SAVING-E pilot plant**
Responsible:	UAB
Participants:	DAM
Objectives:	This action deals with the integrated operation of SAVING-E technology in the pilot plant. After the start-up carried out in Action B3, the three biological reactors of the SAVING-E technology will be connected and operated in an integrated manner for getting the process performance at long term treating a real urban wastewater.
Schedule:	Foreseen start date: *March 2017* / Foreseen end date: *November 2018* Actual start date: *March 2017* / Actual end date: *March 2019*
Main outcomes:	**High-rate activated sludge (HRAS) reactor** After the end of the start-up, the HRAS reactor was continuously operated during 800 days. The influent of HRAS reactor was a flow-rate from 1 up to 2 $m^3\ d^{-1}$ of real mainstream wastewater coming from the effluent of the primary settlers of the of the Rubí WWTP. The aim of the HRAS operation was to demonstrate that SAVING-E technology can achieve the following objectives:

	• To increase the production of secondary sludge comparing with a conventional urban WWTP. Obviously, the urban WWTP used for comparison was Rubí WWTP. • To increase the anaerobic biodegradability of the secondary sludge comparing with a conventional urban WWTP. • To achieve higher OLRs than a conventional urban WWTP. • To maintain a high COD removal and an acceptable sedimentability in the HRAS reactor. • To ensure the absence of nitrification in the HRAS reactor. Throughout the whole operational period, the HRAS reactor was operated at three different Sludge Retention Times (SRT) (2, 4 and 5 days). Detailed information about the operation of this reactor can be found in deliverable B4.1. The main results achieved can be summarized as follows: • A high COD removal (higher than 70%) was achieved in any situation, including periods of very low temperature (around 10 ºC). • The above described COD removal was achieved applying high OLRs, between 5 to 10-fold the OLR applied in Rubí WWTP. It means that the HRAS system would need 5 to 10-fold lower volumes than the aerobic COD removal system of Rubí WWTP. As expected, the low the SRT is, the low can be the applied OLR. • An acceptable sedimentability was achieved, SVI lower than 300 mL g^{-1}, except at very low temperature (lower than 12 ºC). This limitation can be solved with the addition of small quantities of polyelectrolyte. • At low temperatures, there is a complete absence of nitrification since the delta ammonium perfectly matches with the ammonium consumption for growth and there isn't nitrate production. However, at high temperatures (> 20 ºC), the SRT has to be fixed at 2 days to ensure the absence of nitrification. Regarding the objectives of increasing the biomass and the methane production, these objectives were assessed by calculating the observed yield (biomass produced by substrate consumed) and the biochemical methane potential (methane produced by biomass consumed), respectively.

	The observed growth yield (Yobs) was calculated with experimental data of COD removal and solids production from the SAVING-E pilot plant and the Rubí WWTP. The BMP was measured by specific batch tests performed with secondary sludge coming from the SAVING-E pilot plant and the Rubí WWTP. The main results achieved regarding these items can be summarized as follows: • The observed growth yield achieved a value as high as 0.48 kg VS kg^{-1} COD in the HRAS system of SAVING-E pilot plant when a SRT = 2 days was applied. In contrast, the observed growth yield was only 0.31 kg VS kg^{-1} COD in the activated sludge system of the Rubí WWTP working in usual conditions (SRT = 14 days). • The increase on the observed growth yields means that the production of secondary sludge in the SAVING-E process can be up to 55% higher than the produced in the Rubí WWTP. • The BMP achieved values as high as 0.27-0.28 m^3 CH_4 kg^{-1} VS with the secondary sludge from the HRAS system of SAVING-E pilot plant. In contrast, BMP is only 0.16 m^3 CH_4 kg^{-1} VS with the secondary sludge from the Rubí WWTP working in usual conditions (SRT = 14 days). • The increase on the BMP means that the production of methane with the secondary sludge of the SAVING-E process can be up to 75% higher than the produced with the secondary sludge of the Rubí WWTP. **Partial nitritation airlift reactor** As explained in Action B.3, the start-up of the partial nitrification airlift reactor requires a specific and special procedure. This procedure mainly consists of: 1. To operate the airlift as a Sequential Batch Reactor (SBR) instead of a continuous reactor. 2. To use an influent with a high ammonium concentration, the reject water coming from the dewatering process of the digested sludge. However, these operational conditions are very different than the needed for treating the mainstream flow coming from the

	HRAS system. The operational conditions during the usual operation of the airlift reactor are: 1. To operate the airlift as a continuous reactor. 2. To use as influent the mainstream flow coming from the HRAS system and the reject water as actuator element for maintaining the desired ammonium concentration set point in the effluent of the airlift reactor. Consequently, after the achievement of the objectives of the start-up of this reactor: (i) stable partial nitritation (oxidation of ammonium to nitrite) instead of nitrification (oxidation of ammonium to nitrate) and (ii) granulation of the activated sludge biomass used as inoculum, a transition period was designed to achieve the usual operational conditions. The first step in the transition period was the change of the SBR operation to a continuous operation. This change implies having a good separation of the granules in the separator of the top of the reactor. In a first attempt, the separation wasn't good enough and most of the biomass was lost. This problem supposed to perform a new start-up of the reactor and to modify the separator by building a new internal piece for it. After the new start-up and the modification of the separator a second attempt was performed and the change from SBR to continuous operation was successful. Detailed information about the operation of this reactor can be found in deliverable B4.1. The main results of this transition period were: (i) the partial nitritation process was maintained, (ii) the NLR was also maintained and (iii) the particle size of the granules was also basically maintained. During this transition period, the temperature was also progressively decreased from 30 ºC up to 15 ºC to match with the mainstream conditions. As a logical consequence of the temperature decrease, the applied NLR was decreased from 1.0 to 0.5 kg N m^{-3} d^{-1}. From these results, it can be inferred that: • On one hand, the biomass concentration was maintained in the airlift reactor because the NLR was maintained. This means that the modified separator worked reasonably well. • On the other hand, the nitrate formation was not detected so the change to continuous operation and the decrease of the temperature did not affect to the efficiency of the process.

	The last step to the usual operation conditions was the change of the influent. So, the reject water was replaced by the effluent of HRAS system. This change implied that the influent ammonium concentration decreased from 500-600 mg $N\text{-}NH_4^+$ L^{-1} up to 30-60 mg $N\text{-}NH_4^+$ L^{-1}. At the same time, the final configuration of the ammonium control loop was activated. This fact implied that there were two inflows to the airlift reactor: (i) a constant flow of effluent from the HRAS reactor and (ii) a variable flow of reject water from the ammonium control loop. The operation at mainstream conditions and low temperature (15 ºC) was successful during two months. The main results of this important operational period were: • A satisfactory NLR was maintained (around 0.3-0.4 kg N m^{-3} d^{-1}). • The partial nitritation was maintained with a suitable ratio of nitrite to ammonium in the effluent to the next anammox reactor. • The granulation of the biomass was maintained. **<u>Upflow Anammox Sludge Blanket (UAnSB) reactor</u>** After the inoculation described in action B3.1, the UAnSB reactor was operated in continuous during 600 days treating real wastewater coming from the previous partial nitritation airlift reactor. Temperatures of the reactor ranged between 20-33 ºC. Detailed information about the operation of this reactor can be found in deliverable B4.1. The main results achieved during this operation can be summarized as: • The average nitrogen removal rate (NRR) achieved was 0.24 kg N m^{-3} d^{-1}. This NRR is 5 to 10-fold higher than NLRs applied in classical nitrogen removal systems of the current urban WWTPs. However, the achieved NRR was conditioned by the performance of the previous airlift reactor, especially during the start-up process of that reactor. Probably, the NRR in the UAnSB reactor could be even higher in a constant operational period of both reactors. • The average value of the measured nitrite consumed/ammonium consumed ratio (1.3) is an undoubtable confirmation that the main biological activity in the UAnSB reactor was the anammox process. • Moreover, the average value (0.06) of the another stoichiometric ratio (nitrate formed/(ammonium+nitrite)

consumed) indicates that there was also a small heterotrophic denitrification activity that removes part of the nitrate formed in the anammox process. This is an interesting result because the nitrate formed in the UAnSB would be part of the nitrogen content of the WWTP effluent and should be as low as possible.

- The average particle size was always maintained at values higher than 0.4 mm. This means that the granulation of the biomass was successfully maintained at all the tested operational conditions.
- In general, the results show a good performance of the UAnSB at 20ºC but it was not possible to have time to test lower temperatures. The operation at lower temperatures should be further studied before doing the scale-up of this reactor.

Global results of increase of biogas production and reduction of oxygen consumption

The aim of the SAVING-E technology is to improve the energy balance in the urban WWTPs by: (i) increasing the energy production through the increase of the methane production and (ii) decreasing the energy consumption by reducing the oxygen consumption in the biological process.

To evaluate the effect of the SAVING-E technology over the increase of methane production and the reduction of oxygen consumption, three different cases have been considered for Rubí WWTP:

- Case 1. The current configuration removing only organic matter.
- Case 2. A modified configuration with removal of organic matter and nitrogen by conventional technologies.
- Case 3. Implementation of the SAVING-E technology.

The calculations of methane production and oxygen consumption have carried out using:

- Data of the full-scale Rubí WWTP (annual flow rate, biogas production, methane content of the biogas, primary sludge production, secondary sludge production, observed growth yield, influent and effluent COD and ammonium concentrations and efficiency of organic matter removal).
- Experimental data obtained from the SAVING-E pilot plant (anaerobic biodegradability of the secondary sludge,

	observed growth yield, efficiency of organic matter removal and efficiency of nitrogen removal). • Bibliographic data (stoichiometry of the biological processes and anaerobic biodegradability of the primary sludge). The **methane produced** is the same in the three cases because in all cases the primary sedimentation step will be the same. The methane production from secondary sludge will be the same for cases 1 and 2 because the biological organic matter removal will be very similar in both cases. However, there is a significant increase of the methane production from secondary sludge in the case 3 because the observed growth yield achieved with the HRAS system of the SAVING-E technology is higher than the achieved with the current configuration of Rubí WWTP. The lowest **oxygen consumption** is for case 1 because only organic matter is removed in this case. In cases 2 and 3, the oxygen consumption is due to the organic matter and nitrogen removal. It can be observed that the oxygen consumption is significantly lower in case 3 than in case 2. It means that SAVING-E technology saves a significant energy consumption comparing with a conventional technology for treating urban wastewater with COD and nitrogen removal. **As general conclusions**: • The comparison of cases 1 and 3 shows that the implementation of the SAVING-E technology in Rubí WWTP would increase up to 35% the production of methane and it would allow the nitrogen removal spending only 10% more of oxygen than the current configuration removing exclusively organic matter. • The comparison of cases 2 and 3 shows that the implementation of the SAVING-E technology instead of the implementation of a conventional technology for removing nitrogen in Rubí WWTP would increase up to 35% the production of methane and it also would save up to 35% of the oxygen consumption.
Planning and problems encountered:	This action started on March 2017 and was finished on March 2019, four month more than initially planned. This extra month was needed to operate the pilot plant at low temperature taking advantage of the winter season. Some problems related to poor granulation of the nitrifying biomass in the airlift reactor have delayed the operation of the

	SAVING-E pilot plant at low temperature during the winter season of 2017. Part of these problems was related to the design of the separator of the airlift reactor and consequently, the separator was redesigned and improved. The last part of the experimental part of this action, the operation at mainstream conditions and low temperature (15 ºC) was successful during almost two months. However, after this period, the formation of nitrate in the reactor and a decrease of the ammonium oxidation activity to nitrite were detected in the airlift reactor. Both negative results were a consequence of the following factors: • On one hand, it was not possible to maintain a low DO concentration in the airlift reactor (1-2 mg O_2 L^{-1}) when temperature decreased. In fact, throughout the operational period at mainstream conditions, DO concentration was close to saturation (8 mg O_2 L^{-1}). Consequently, it was not possible to maintain the limitation by oxygen of the nitrite-oxidizing bacteria activity and finally, nitrate was formed. The impossibility of maintaining a low concentration was due to the configuration of the airlift reactor required, in order to keep the granules in suspension, an air flow higher than the air flow required for the biological activity. • On the other hand, the decrease of the biological activity was due to the accumulation of a high amount of biomass in the bottom of the airlift reactor. Instead of the high air flow applied for maintaining the granules in suspension, a significant part of the biomass was accumulated in the bottom of the reactor due again to an ineffective design of this part of the reactor. • Both problems could be solved with a better design of the bottom of the reactor and the aeration valves. Unfortunately, there was no time to make those modifications within the time limits of the project and it is a topic to improve in the scale-up of the technology. Finally, the performance of the last reactor (UAnSB reactor) was totally influenced by the performance of the previous reactor (Partial nitritation airlift reactor). Specifically, the suitable control of the nitrite/ammonium ratio in the influent of the airlift reactor is basic for a good performance of the UAnSB reactor. This ratio depends on the online ammonium probe and the performance of this commercial probe has some limitations. In a future scale-up of the SAVING-E technology, the selection of the best online ammonium probe will be an important factor.

Progress indicators – deliverables:	Progress indicators presented in the technical application form: • *Maintenance of the proper morphological properties of the granular biomasses (average diameter higher than 0.2 mm and SVI_5/SVI_{30} = 1.* **Achieved** • *Absence of nitrite-oxidizing bacteria activity in the airlift reactor.* **Achieved** • *Maintenance of the [nitrite]/[ammonium] ratio in the effluent of the airlift reactor in the range between 1.0-1.4.* **Achieved** • *Maintenance of the [nitrite]/[ammonium] consumed ratio in the UASB reactor in the range between 1.0-1.4.* **Achieved** • *Maintenance of the [nitrate formed]/[ammonium consumed] ratio in the UASB reactor in the range between 0.1-0.4.* **Achieved** • *Measurement of an anaerobic biodegradability of the secondary sludge higher than 50%.* **Achieved** Deliverables: • **B4.1 Manual of operation of the integrated SAVING-E process at high and low temperatures** Milestones: • MB4.1 Successful operation of the SAVING-E pilot plant treating real urban wastewater at ambient temperature. **Achieved** • MB4.2 Successful operation of the SAVING-E pilot plant treating real urban wastewater at 10ºC. **Achieved but at 15 ºC because wasn't possible to decrease the temperature of the whole pilot plant up to 10 ºC.**

Table 5. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action B.5.

Action B.5	**Technical and economic analysis for upgrading different types of urban WWTPs with SAVING-E process**
Responsible:	DAM
Participants:	ACA, UAB
Objectives:	Technical and economic analysis about how the current WWTPs could be upgraded with the SAVING-E technology at Catalan, Spanish and European levels. Determination of the cost-efficient transferability of SAVING-E technology.
Schedule:	Foreseen start date: *July 2017* / Foreseen end date: *June 2018* Actual start date: *July 2017* / Actual end date: *December 2018*
Main outcomes:	The main outcomes obtained so far are: • At European level, the urban wastewater treatment could be improved. There are still substantial differences between Member States, especially on the implementation of more stringent treatment for removing nitrogen (N) and phosphate (P) • At European level, one of the challenges in the wastewater treatment sector is related to reach high quality of the effluent from WWTP while optimizing their energy consumption. More efficient technologies for wastewater treatment and production of renewable energy (e.g. biogas) are attractive alternatives for self-sufficient operation of WWTPs. • In Spain, the activated sludge systems are the technologies most implemented for the urban wastewater treatment: Extended aeration and conventional activated sludge. It important to consider that these technologies are high energy demand, mainly by aeration process. • There is clear evidence that WWTPs should become in facilities for resource recovery. The valorization of the organic matter for energy production (biogas), nutrient recovery as well as more optimized, robust and compact treatment processes should be implemented in all WWTPs. • The implementation of the SAVING-E technology in existing WWTP is promising. The results obtained from the operation

	of the pilot plant indicates really interesting energy savings, considering both nitrogen removal by combining partial nitritation and anammox processes, as well as energy production through anaerobic digestion of A-stage sludge recovery. • After simulation study, the implementation of the SAVING-E technology in the Rubí WWTP will allow nitrogen removal in spite of current space limitation, organic matter valorisation and reduction of both sludge production and energetic consumption ratio. Indeed, simulation study shows the SAVING-E implementation could increase the energy self-consumption in Rubí WWTP from 48% to 80%. • Information compiled in Action B.5 indicates that Conventional Activated Sludge (CAS) and Extended Aeration (EA) are the biological processes widely implemented in wastewater treatment plants in Europe, Spain and Catalonia. This report presents the analysis of the SAVING-E implementation in existing WWTP where CAS and EA are already implemented. • According simulation study, the hybrid option (CAS/EA + SAVING-E) and SAVING-E total implemented are feasible options in existing WWTP. The High Rate Activated Sludge process (HRAS – A stage) is relatively easy to implement by modifying biological process performance. However, the B-stage must be constructed due specification of granular reactor performance. • The Payback all cases evaluated is lower 4 years. However, more information to be collected in order to accurate the costs of SAVING-E implementation.
Planning and problems encountered:	This action started on July 2018 and finished on December 2018 due to some problems related to lack of information from European countries about their current situation related to wastewater treatment and nutrient removal. To solve this problem, other information sources than those planned were consulted (European Reports, websites from private and public institutions, others).
Progress indicators – deliverables:	<u>Progress indicators presented in the technical application form:</u> • *Achievement of enough data to assess the European context analysis related to urban wastewater treatment and*

	nutrient removal at least in three southern and three northern countries. **Achieved** • *Achievement of enough data to define three or four types of urban WWTPs in Spain and EU*. **Achieved** Deliverables: • **B5.1 Report of the Spanish/European situation of the urban wastewater treatment and nutrient removal** • **B5.2 Report of SAVING-E process implementation in Rubí WWTP: technical and economic transferability analysis** • **B5.3 Report of SAVING-E process implementation in standard types of urban WWTPs in Spain and EU: technical and economic transferability analysis** Milestones: • MB5.1 Compilation data Spanish/European context analysis. **Achieved** • MB5.2 Compilation technical/economic WWTPs Spain/EU data for implementing the SAVING-E. **Achieved** • MB5.3 Compilation technical/economic data study of the retrofitting of Rubí WWTP for implementing the SAVING-E. **Achieved**

6.1.2. Actions C. Monitoring actions

Table 6. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action C.1.

Action C.1	**Technical and environmental impacts of SAVING-E technology**
Responsible:	UAB
Participants:	ACA, DAM
Objectives:	To measure and document the effectiveness and the environmental benefit of the project actions as compared to the initial situation objectives and expected results.
Schedule:	Foreseen start date: *April 2017* / Foreseen end date: *March 2019* Actual start date: *April 2017* / Actual end date: *March 2019*

Main outcomes:	The main outcomes obtained so far are: • Life Cycle Inventory (LCI) for the initial situation of the project (baseline values of Rubí WWTP in years 2014, 2015 and 2016) was obtained, but lot of problems were encountered (see next section). The impacts refer to 1 m^3 of treated wastewater, which is the most common functional unit in wastewater-related LCAs. To do so, we used the WWTP's average treated effluent for the period 2014-2016, which was 27,000 m^3 d^{-1}. Same functional unit was used for SAVING-E implementation at Rubí WWTP. • The system boundaries were established from gate to gate, i.e., the construction and demolition of the WWTP were excluded and we focused only on the operation stage. We made this assumption due to fact that an upgrade of the Rubí WWTP for removing nitrogen using conventional biological nitrogen removal will have the same construction and demolition impacts that an upgrade using SAVING-E technology. • The LCI of Rubí WWTP includes: Organic matter and nitrogen removal efficiencies, energy consumption of each single process and subunits, biomass and biogas generated, biogas quality and additives used at the different treatment stages, their packaging, their transport to the WWTP, the wastes generated and their treatments or final disposal, the transport of wastes to their respective treatment plants and the maintenance material. • Regarding the LCI of the SAVING-E pilot plant, the data gathering process was finished including: Organic matter and nitrogen removal efficiencies, biomass (55% increase compared to current configuration) and biogas generated (61% production increase with respect to current configuration), biogas quality (75% of CH_4 content compared to 57% of CH_4 content of the current configuration) and additives used (10% more polyelectrolyte is needed for HRAS reactor compared to current configuration), their packaging and their transport to the WWTP. Regarding energy consumption it was assumed that implementation of SAVING-E technology will only need 10% more oxygen than the current configuration of Rubí WWTP which only remove organic matter (action B.4), while the rest of process and subunits remains more or less the same. This assumption translates into an electrical consumption from local grid

	of 0.06 kWh/m^3 of treated wastewater for SAVING-E technology implemented at Rubí WWTP compared to the 0.22 kWh/m^3 of the current configuration.

- The Life Cycle Analysis (LCA) impact categories chosen were the following (Table 1):

Table 1 Recipe (H) midpoint impact categories: abbreviations and equivalent units

Acronym	Indicator	Units
CC	Climate Change	kg CO_2 eq
OZDP	Ozone Layer Depletion	kg CFC-11 eq
TA	Terrestrial Acidification	kg SO_2 eq
FE	Freshwater Eutrophication	kg P eq
ME	Marine Eutrophication	kg N eq
HT	Human Toxicity	kg 1,4-DB eq
POP	Photochemical Oxidant Formation	kg NMVOC
PMF	Particulate Matter Formation	kg PM_{10} eq
TET	Terrestrial Ecotoxicity	kg 1,4-DB eq
FET	Freshwater Ecotoxicity	kg 1,4-DB eq
MET	Marine Ecotoxicity	kg 1,4-DB eq
IR	Ionising Radiation	kBq U_{235} eq
ALO	Agricultural Land Occupation	m^{2}a
ULO	Urban Land Occupation	m^{2}a
NLO	Natural Land Occupation	m^2
WDP	Water Depletion	m^3
MDP	Metal Depletion	kg Fe eq
FDP	Fossil Depletion	kg oil eq

- The results of the impact assessment (Figure 3 in deliverable C.1.1) denote the potential improvement of the SAVING-E technology. There is an improvement in environmental impact in the majority of indicators. SAVING-E technology provides increased savings in energy consumption (up to 23%) and thus, the avoided impacts of scenario SE are apparent. Moreover, if the energy produced through cogeneration processes is quantified as avoided emissions, scenario SE environmental impact from energy is only a quarter part of the one exerted by the baseline scenario. Besides these avoided impacts, energy efficiency plays a role in reducing the environmental impacts of the system, particularly in climate change (CC) and fossil depletion (FDP). The largest improvement is achieved in terms of marine eutrophication. The new technology allows a higher nitrogen removal rate and thus, the nutrient discharge into the environment is reduced. As a result,

<table>
<tr><td></td><td>the emissions of the WWTP in terms of marine eutrophication (ME) has been divided by four.
• Regarding environmental impacts caused by the use of chemicals, there is an increase in their contribution, primarily due to a 10% increase in the demand for polyelectrolyte once the SAVING-E technology is functionally active. Nevertheless, it seems that the energy credits will compensate for the tradeoffs of implementing the new treatment technology in Rubí. Hence, the results indicate that an increased self-sufficiency potential through enhanced biogas production offsets the slight increase in the environmental impacts of the WWTP associated with the demand for chemicals.
• In our assessment, energy self-sufficiency implies that the WWTP will reduce its dependence on conventional energy sources (e.g., local grid). An incremental widespread implementation of self-sufficiency approaches in this and other sectors could lead to a reduced demand for fossil energy and thus improve the environmental performance of the energy system. In other words, the environmental impacts of the WWTP might increase through the new technology, but it theoretically reduces the demand for conventional energy production and prevents this production from taking place.

Additionally, we performed an analysis of the potential effects of policy on the environmental impacts of circular economy innovations. WWTPs might not be a country’s biggest energy consumer (1 to 3 % of energy needs of a country), but wastewater treatment is a public service that needs to go through updates to increase its efficiency. We showed that environmental policy has a large impact on the environmental performance of innovative technologies applied into WWTP. The results could provide important insights for a more in-depth analysis of technological change and environmental policy in this area. At the same time, our results could serve business stakeholders, policy decision-makers and the wider public to inform debates about renewable energy goals and possible alternative policy pathways in Spain and Europe. (Deliverable D5.2 Publication of a scientific article in a high-impact journal).</td></tr>
<tr><td>Planning and problems encountered:</td><td>This action started on April 2017, but the first milestone (MC1.1 Compilation of all the experimental and theoretical data needed for the energy consumption assessment and LCA) was partially completed for Rubí WWTP in December 2017, 6 months more</td></tr>
</table>

	than the originally planned. These 6 extra-months were needed for allowing us to check and reconciliate the huge amount of data coming from different sources (ACA, DAM and the new enterprise operating Rubí WWTP since September 2016). Globally it was very difficult to collate the information coming from different sources and databases and to reconciliate them into useful units for performing LCI. Similarly, data needed from SAVING-E pilot plant was not collected until December 2018 once deliverable B4.1 (Manual of operation of the integrated SAVING-E process at high and low temperatures) and milestones MB4.1 (Successful operation of the SAVING-E pilot plant treating real wastewater at ambient temperature) and MB4.2 (Successful operation of the SAVING-E pilot plant treating real wastewater at 10ºC) were achieved. Therefore, milestone MC2.2 (Quantification of the technical and environmental impacts of SAVING-E process) was completed 3 months later than the originally expected, while the deliverable C1.2 (Report containing Material Flow Analysis to study the potential use of the SAVING-E processes in a national scenario (Spain)) will be replaced by an energy flow analysis due to the fact that the date from SAVING-E pilot plant allows us to confirm that the flow of materials of the current operation of Rubí WWTP compared to the implementation of SAVING-E technology remains the same.
Progress indicators – deliverables:	<u>Progress indicators presented in the technical application form:</u> • *Inventory analysis. The result will be a database that will include the processes, all the energy and material inputs and outputs.* **Achieved.** • *A set of global environmental indicators or environmental impact categories for a conventional system based on Rubí WWTP and a WWTP based in SAVING-E technology.* **Achieved.** • *Estimation of the CO_2 avoided emissions per each process and of the energy saving potentials.* **Achieved**. • *Comparison of impact factors of Rubí WWTP and a WWTP based in SAVING-E technology.* **Achieved.** • *Increase of the biogas production compared to the current urban WWTPs.* **Achieved.** • *Reduction of the nitrogen discharge compared to the current urban WWTPs.* **Achieved.** • *Energy saving in the nitrogen removal process compared to the current urban WWTPs.* **Achieved.** • *Energy saving in the global treatment process compared to the current urban WWTPs.* **Achieved.**

	• *Reduction of greenhouse gas emission reduction compared to the current urban WWTPs*. **Achieved.** Deliverables: • **C1.1 Report containing the database including processes/energy and material inputs/outputs and environmental impacts of Rubí WWTP and a WWTP based in SAVING-E technology** • **C1.2 Report containing Material Flow Analysis to study the potential use of the SAVING-E processes in a national scenario (Spain)** • **C1.3 Report of technical and environmental impacts for implementing SAVING-E technology at regional, national and EU contexts. These deliverables are scheduled for October 2018 and December 2018, respectively.** Milestones: • MC1.1 Compilation of all the experimental /theoretical data needed for the energy consumption assessment and LCA. **Achieved.** • MC1.2 Quantification of the technical/environmental impacts of SAVING-E process. **Achieved.**

Table 7. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action C.2.

Action C.2	**Socio-economic impacts at local, national and EU level for implementing SAVING-E technology**
Responsible:	DAM
Participants:	ACA, UAB
Objectives:	The aim of the socio-economic impact report is to provide the EU with the necessary elements for assessing the environmental, economic and social impacts of the SAVING-E implementation in new and existing wastewater treatment plants (WWTP).
Schedule:	Foreseen start date: *July 2018* / Foreseen end date: *March 2019* Actual start date: *July 2018* / Actual end date: *March 2019*

Main outcomes:	Definition of SAVING technology as a product and service. Economic impact measured through several indicators: • Costs of retrofitting existing WWTP and building new WWTP. • Return of investment and economic savings by SAVING-E implementation. Social impact measured through: • Employment • Training programs • Networking • Workshops Deliverable C2.1 presents in detail the evaluation and measurement of the socio-economic impacts.
Planning and problems encountered:	Some problems related with lack of information were identified. Other sources of information were consulted in order to obtain relevant information about indicators.
Progress indicators – deliverables:	<u>Deliverables:</u> • **C2.1 Socio-economic impact report of implementing SAVING-E technology at local and EU level.** <u>Milestones:</u> MC2.1 Economical evaluation of SAVING-E impact at local and EU level. **Achieved** MC2.2 Social impact SAVING-E at local and EU level. **Achieved**

6.1.3. Actions D. Public awareness and dissemination of results

Table 8. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action D.1.

Action D.1	**Definition and exploitation strategy. SAVING-E visibility, branding and deliverables preparation**
Responsible:	DAM
Participants:	UAB

Objectives:	Creation of the SAVING-E corporate brand for a successful dissemination of the project.
Schedule	Foreseen start date: *October 2015* / Foreseen end date: *March 2016* Actual start date: *October 2015* / Actual end date: *April 2016*
Main outcomes:	Firstly, it was created SAVING-E brand identity in order to identify the project and give it visibility. A complete design of a corporative logo for the project has been achieved. The logo was based on the acronym of the project and it was included two complementary elements: a blue drop on the letter "i" and the recycling symbol between the word "SAVING" and the letter "E". The inside of this element is composed by three images: the first one shows the wastewater, the second one a microscopy image of the anammox bacteria and the last one clean water, in order to close the cycle. Moreover, a set of templates (word, power point and excel formats) were created to be used on the entire project. An evaluation of the target audience were performed, and it was defined the target group's needs. Based on the data collected for the definition of the target audience it has been created the SAVING-E communication material. A first promotional brochure has been produced which gives a general overview of the project and its objectives. In addition, it includes the project technology and the results expected of this implementation in plain language. The brochure has been produced in English, Spanish and Catalan. Moreover, a roll-up and a poster with a brief description about the project and a photo-call have been done to promote the project on the events such as official inauguration day, conferences, fairs or workshops.
Planning and problems encountered:	This action was performed as initially planned, but it was finished on April 2016, one month later due to delay in the final designing of the roll-up, poster and photo-call. The creation of the SAVING-E logo and templates for a fast identification of the project were performed on November 2015. On May of 2016, the brochures, roll-up, poster and photo-call were printed. All the participants in the action were successfully implicated on them.

Progress indicators – deliverables:	<u>Progress indicators presented in the technical application form:</u> • *Definition of the exploitation strategy*. **Achieved** • *Definition of the target group's needs*. **Achieved** • *Creation of the SAVING-E corporate brand*. **Achieved** <u>Deliverables:</u> • **D1.1 Target audience report** • **D1.2 SAVING-E brand manual** • **D1.3 Dissemination templates** <u>Milestones:</u> • MD1.1 Data for defining the audience. **Achieved** • MD1.2 (material for dissemination activities). **Achieved**

Table 9. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action D.2.

Action D.2	**Website design, operation and back-office. Presence in social networking**
Responsible:	WssTP
Participants:	UAB, DAM
Objectives:	Creation of the SAVING-E website and social network profiles, such as twitter and linkedIn, as a dissemination channel of the project.
Schedule	Foreseen start date: *October 2015* / Foreseen end date: *March 2016* Actual start date: *October 2015* / Actual end date: *March 2016*
Main outcomes:	Internet is one of the main channels for communication. The creation of the website has been used as a tool for publishing the project's evolution and the activities carried out. Project website (www.saving-e.eu) was created to be used as a main communication tool for the project. Through the website it is possible to access to all the information related to the project, including a detailed description. The website is divided in different sections such as: • <u>Home</u>: a general overview of the project • <u>Project</u>: detailed information about the project (environmental problem targeted, goals, workplan, activities & results)

	• Partners: composition of the project's consortium • Media Corner: the latest news, photo gallery and useful links • Events Calendar: all the relevant upcoming events • About LIFE: information about LIFE programme • Contact: a contact form for all those interested in the project The website is available in English, Spanish and Catalan. The main outcomes of the impact of the website are (data from March 2016 up to March 2019): • Users: 3739 • Sessions: 5394 • Number of sessions per user: 1.44 • Number of page visits: 14291 • Pages per session: 2,65 • Average duration of the session: 02:25 min • Bounce rate: 43.96% The creation of the social networking profiles has allowed increasing the dissemination and it has been used for posting the events that are taking place. SAVING-E has Twitter and Linkedin profiles, which were integrated on the webpage. SAVING-E twitter account has a community of 364 followers, mainly composed by stakeholders on the SAVING-E technology. Each tweet of the project had an average of 5 retweets.
Planning and problems encountered:	No problems encountered. The action was performed as initially planned, and the SAVING-E webpage was launched on March 2016. At the same time, social networking profiles were created and linked to the webpage. SAVING-E consortium decided not to make use of Facebook, as the primary goal of our communications is to disseminate the project advances to a targeted audience and Facebook does not seem to offer an additional benefit, compared to the other two networks (Twitter and LinkedIn), towards this end.
Progress indicators – deliverables:	Progress indicators presented in the technical application form: • *Building of the website offline for testing and backup*. **Achieved** • *Adequate indexing of SAVING-E documents generated along the project.* **Project Place, a private space area, has been used to share all kind of documents of SAVING-E (meeting minutes, deliverables, presentations, templates, etc.). In this space all the partners have access**.

	• *Number of visits to the website*. **The average of visits per month was 150. The average number of pages seen per visit was 2.65.** • *Number of followers in the social networks.* **At the end of the project, SAVING-E twitter profile had 363 followers**. • *News uploads*. **Webpage has been updated according to the activities and events performed.** Deliverables: • **D2.1 Official website launch** • **D2.2 Creation of the SAVING-E profiles in social networking**

Table 10. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action D.3.

Action D.3	**Networking with other projects**
Responsible:	WssTP
Participants:	UAB, DAM, ACA
Objectives:	Establish networks with other relevant projects in order to collate information and experiences on the same or similar topic as the SAVING-E field and other complementary topics which will complement the project ongoing.
Schedule	Foreseen start date: *October 2015* / Foreseen end date: *March 2019* Actual start date: *October 2015* / Actual end date: *March 2019*
Main outcomes:	Since the beginning of the project it has been established contact with different projects. Networking meetings have allowed disseminating SAVING-E project. Moreover, have allowed obtaining new profitable opportunities of collaboration. For networking activities, a networking template with the most relevant information about the project has been created. • We have established a stable and regular contact with a local project from Ajuntament de Rubí named Rubí Brilla. The team of Rubí Brilla help us with the organization of the official inauguration day due to the participation of the Rubí’s Mayor. • On the other hand, we attended to a Workshop-Seminar from **LIFE InSiTrate (LIFE12 ENV/ES/000651)**.

	• We received the visit of Mr. Francesc Gambús, member of the European Parliament. He came to the UAB premises motivated by acquitting LIFE SAVING-E project. Moreover, on the same meeting, we could have contact with another LIFE project which has recently started on UAB called **LIFE reWINE (LIFE15 ENV/ES/000437)**. • Besides, **LIFE CELSIUS (LIFE14 EN/ES/00023)**, a project with a similar aim to our project, contacted us. After that, we had a face-to-face meeting with this project where we could exchange ideas and experiences. Moreover, they assisted to our Winter School on January 2018. • Finally, we established contact with another LIFE project called **LIFE DeNTreat (LIFE16 ENV/IT/00345)** which is a project related to our topic. We had a face-to-face meeting in UAB facilities.
Planning and problems encountered:	No problems encountered.
Progress indicators – deliverables:	<u>Progress indicators presented in the technical application form:</u> • *Begin data collection activity.* **Achieved** • *E-mailing list for making the first informal contacts.* **Achieved** • *Videoconferences with other LIFE projects handling similar themes to SAVING-E.* **We changed this communication channel by face-to-face meetings. Achieved** • *Participation of a small number of EU academic and practitioners in the summer school.* **Achieved** • *Related news uploaded in the blog.* **News section was uploaded according to the ongoing of the project.** • *Number of invitations for networking send and received.* **5 invitations sent and 7 received.** • *Number of meetings/brokerage events/others with SAVING-E presence.* **10 different events** • *Number of networking meetings, short and exchange collaborative visits.* **A total of 6** <u>Deliverables:</u> • **D3.1 Presentations of the project for networking** • **D3.2 Report on networking with other similar LIFE projects** <u>Milestones:</u> MD3.1 Informal contact list. **Achieved**

Table 11. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action D.4.

Action D.4	**Attendance and organization of specialized workshops, seminars, conferences, fairs and other events**
Responsible:	WssTP
Participants:	UAB, DAM and ACA
Objectives:	Attendance and organization of meetings, workshops, conferences and other similar activities to disseminate project's knowledge and to build networks.
Schedule	Foreseen start date: *October 2015* / Foreseen end date: *March 2019* Actual start date: *October 2015* / Actual end date: *March 2019*
Main outcomes:	This action deals with: (i) the organization dissemination event sby the SAVING-E team: Inauguration day, visits and hands-on sessions for students, Winter school, Workshop and Infoday and (iI) the attendance of SAVING-E team to scientific conferences, brokerage events and fairs organized by external parties. The events organized by SAVING-E team were: • The **Inauguration day** of the SAVING-E pilot plant was carried out on July 2016 with attendance of more than 100 people to the Rubí WWTP. The Mayor of Rubí, the Rector of the UAB and the Director of the ACA participated in the inauguration. This event was the first face-to-face opportunity for doing networking with public bodies, municipal authorities, research and general public, communication media, etc. News about the inauguration day and the SAVING-E project appeared in several media: Catalan TV (TV3), radio and newspapers. • The **Winter School** entitled: "Self-sufficient urban WWTP: Implementation of the autotrophic nitrogen removal in the main water-line" was successfully done on January 2018. 30 people (the total of places offered) attended to 2-days course from water industries, water agencies and technological centres and universities. During the course it was possible to deepen LIFE+ SAVING-E technology; both in the lectures gave by the project-leaders and in the practical sessions, as well as in the visit to the facilities of the Urban Wastewater Treatment Plant of Rubí where the SAVING-E Pilot Plant is located.

	• The **Workshop** was carried out on June 2018 in Valencia (Spain). 40 people from different stakeholders (water treatment companies, public administration and university) attended. In this event participated Dr. Tommaso Lotti from Technical University of Delft (The Netherlands). Dr Lotti is part of the team of Dr. Mark Van Loosdrecht, member of the Stakeholders Advisory Board (SHAB). Dr. Lotti participated in the event as member of the SHAB in substitution of Dr Van Loosdrecht and he made an oral presentation in the workshop and a working meeting with the SAVING-E team about the results and application of the technology. • The **Infoday** was carried out on March 2019 in Barcelona (Spain). 80 people (the total of places offered) from different stakeholders (water treatment companies, public administration and university) attended. During this event, the main outcomes of the project were presented by members of the SAVING-E team: Dr. Julio Pérez and Dr Julián Carrera (UAB), Dr. Javier Claros (DAM) and Dr. Jordi Robusté (ACA). • We also participate in the 2016-2017 (4 students) and 2017-2018 (6 students) editions of the UAB-Argó programme, in which we offer mentoring to high-school students performing their research works in a subject related to SAVING-E project. Two students from the 2016-2017 edition got the maximum qualification for their works and they were invited to present it in from of all the students from their respective high-schools (ca. 140 students). The SAVING-E pilot plant was visited by Institut Públic La Romànica (25 students), Argó programme 2016-2017 (25 persons) and Escola Emili Juncadella Primary School (twice, 50 students in total). The events organized by third-parties were the SAVING-E team presented the project were: • **LIFE14 Kick-off meeting** (November 2015, Lisbon, Portugal). Dr. Carrera, SAVING-E coordinator, presented the project and followed the instructions of EASME team for a correct development of the project. Attendees to the event: 50 people. • **XII Mesa Española del Agua (META) Conference** (June 2016, Madrid, Spain). Dr. Carrera, SAVING-E coordinator, presented the project in this event where Spanish stakeholders from companies and universities participate. Attendees to the event: 100 people.

	• **International Integrated Water Cycle Show (Iwater 2016)** (November 2016, Barcelona, Spain). Dra. Suárez-Ojeda, UAB team, participated presenting SAVING-E project with an oral presentation in this international fair. Attendees to the event: 4000 people. • **AEAS Technical conference** (May 2017, Tarragona, Spain). Dr. Claros, DAM team, presented the project in this event where Spanish stakeholders from companies and public administration participate. Attendees to the event: 200 people. • **I Water Section Innovation Technology Forum of Catalan Water Partnership** (April 2017, Terrassa, Spain). Dr. Carrera, SAVING-E coordinator, presented the project in this event. This event is a networking activity for promoting the transfer of knowledge about the most relevant technological and R&D innovations for the sustainable use of water in Catalonia. Attendees to the event: 100 people. • **7th European Bioremediation Conference & 11th ISEB Conference** (June 2018, Chania, Greece). Dr. Ramos, UAB team, done an oral presentation presenting the results of the start-up of the SAVING-E pilot plant in this international scientific conference. Attendees to the event: 150 people. • **International Integrated Water Cycle Show (Iwater 2018)** (November 2018, Barcelona, Spain). SAVING-E team participated in this international fair with an own stand and an oral presentation of the project. Attendees to the event: 4000 people. • **II Water Section Innovation Technology Forum of Catalan Water Partnership** (March 2018, Barcelona, Spain). Dra. Suárez-Ojeda, UAB team, presented the project in this event. This event is a networking activity for promoting the transfer of knowledge about the most relevant technological and R&D innovations for the sustainable use of water in Catalonia. Attendees to the event: 100 people.
Planning and problems encountered:	The SAVING-E school was initially scheduled for July 2017 as Summer School but it was finally done as Winter school on January 2018 in UAB, Barcelona (Spain). The reason for the change was to be able to have more data on the operation of the pilot plant at the time of doing the course. The change did not

	cause any major problems and finally the course was conducted with great success of attendance. The final event, Infoday, was finally done in Barcelona (Spain) instead of Brussels (Belgium) as previously scheduled. The reason for the change is that there was a clear interest of the Spanish stakeholders in seeing the results of the project. This interest was corroborated with the attendance of 80 people from different stakeholders (water treatment companies, public administration and university) to the event, the total expected capacity.
Progress indicators – deliverables:	<u>Progress indicators presented in the technical application form:</u> • *Number of the website visitors.* **The average of visits per month was 150. The average of pages seen per visit was 2.65.** • *Number of participants at summer school.* **The summer school was finally done as winter school 2018 and the course was filled with 30 people (full capacity).** • *Number of participants at workshop:* **40 people** • *Number of participants at Infoday:* **80 people (full capacity)** • *Number of visits performed by high-school and vocation training institutes:* **4 (100 people in total)** • *Number of papers/abstracts accepted for publication/presentation:* **4** • *Number of established contacts:* **10** <u>Deliverables:</u> • **D4.1 Press release following the inauguration day** • **D4.2 Report of SAVING-E team's attendance to vents** • **D4.3 Report of events organized by SAVING-E team** <u>Milestones:</u> • MD4.1 Announcement of selected participants for the winter school. **Achieved** • MD4.2 Announcement of participants for the workshop. **Achieved** • MD4.3 Announcement of selected participants for the Infoday. **Achieved**

Table 12. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action D.5.

Action D.5	**Notice boards, publications and press releases**

Responsible:	UAB
Participants:	DAM, ACA and WssTP
Objectives:	Dissemination of the project objectives, initiatives, events and services and relevant achievements.
Schedule	Foreseen start date: *October 2015* / Foreseen end date: *March 2019* Actual start date: *October 2015* / Actual end date: *March 2019*
Main outcomes:	The media coverage basically happened at three times: 1. Several press news was published regarding to the **start-up of the project** on TV news, webpages and Spanish and Catalan newspapers. Also, it appeared in online newspapers and journals. 2. Other press notices have been released after the **official inauguration day of the pilot plant** with a significant impact on national and local press media. 3. Finally, press notices have been released after the **final event of the project** with a significant impact on national and local press media. **Deliverable D5.1** contains the details of the **media coverage of SAVING-E** throughout the project. Considering the audience of the media that published news about the SAVING-E project, a total audience of between half a million and a million people can be estimated. Regarding the **on-site panel**, it has been located on main entrance of the Rubí WWTP, where the project is implemented. The panel shows the main objectives of the project to the visitors of the WWTP, such as the problem of the energy consumption in WWTPs and the technology that SAVING-E develops in order to transform WWTPs to energy-producers systems. Moreover, newsletters of the project were launched and summarize the main outcomes achieved in the project and the dissemination and networking activities. Newsletters are distributed to the audience by e-mail. The newsletters are also announced on the webpage and twitter. On the other hand, apart from the webpage, the most used communication channel was Twitter due to it allows disseminating the information in real time. All the notices regarding to the project were announced on the webpage and simultaneously by Twitter.

Planning and problems encountered:	Milestone MD5.1 was delayed 6 months respect to the original planning because it was decided that the on-site panel would have more impact if the installation was around the time scheduled for the official inauguration day. On June 2016, the panel was installed and the official inaugural day took place at the beginning of July 2016.
Progress indicators – deliverables:	Progress indicators presented in the technical application form: • *Installation of the first on-site panel.* **The installation of the on-site panel was done on June 2016.** • *Update of the on-site panel.* **Achieved** • *Publication of press releases every 4 months in the SAVING-E website.* **Publications of the website have been uploaded on the website according to the events and activities of the project.** • *Scientific article in high-impact journals.* **Not yet because the first publication is under review** Deliverables: • **D5.1 Report summarizing the press releases** • **D5.2 Publication of a scientific article** Milestones: • MD5.1 Installation of on-site panel. **Achieved** • MD5.2 Publication in the website of the summary and llink of the scientific article published. **Not yet because the first publication is under review**

Table 13. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action D.6.

Action D.6	**Layman's report**
Responsible:	WssTP
Participants:	DAM, ACA and WssTP
Objectives:	Development of Layman's report to non-specialist audiences
Schedule	Foreseen start date: *January 2019* / Foreseen end date: *March 2019*

	Actual start date: *January 2019* / Actual end date: *March 2019*
Main outcomes:	The SAVING-E project Layman's report is a 16-pages long report, from which 400 printed copies where distributed within the beneficiaries of the project. Each partner is responsible for their distribution along each one contacts. The electronic version (available in the SAVING-E webpage) was sent to the final list of contacts gathered during the events SAVING-partners organized (inauguration day, winter school, workshop, infoday, etc). This report, targeted at a non-specialist audience, including political decision-makers, outlines the main results of the project. The report provides a permanent record of the project that can be filed for future reference. It includes the following sections: i) The environmental problem targeted, ii) SAVING-E Project objectives, iii) overview of the pilot plant & installation, iv) SAVING-E Project: 3.5 years at a glance, v) Which are the SAVING-E Results?, vi) What does SAVING-E project mean for society at large? And vii) Dissemination Activities.
Planning and problems encountered:	No problems encountered.
Progress indicators – deliverables:	Deliverables: • **D6.1 Layman's report** Milestones: • MD6.1 Publication and distribution of Layman's report to general audiences. **Achieved**

6.1.4. Actions E. Project management and monitoring of the project progress

Table 14. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action E.1.

Action E.1	**Project Management by UAB**
Responsible:	UAB
Participants:	DAM, ACA and WssTP

Objectives:	General coordination and management of the project: (i) coordination of all the beneficiaries and (ii) reporting to the European Commission
Schedule	Foreseen start date: *October 2015* / Foreseen end date: *March 2019* Actual start date: *October 2015* / Actual end date: *March 2019*
Main outcomes:	UAB, as coordinator, has been the intermediary between the associated beneficiaries and the European Commission. The Partnership Agreements were successfully created, accepted and signed by the whole consortium of the project. Then, it was established the Project Management Manual which details the guidelines for the direction and the coordination of the project. At the same time, it was defined the Stakeholders Advisory Board. Moreover, SAVING-E project established the rules for the management of the technical and financial issues and the reporting system. Internal progress reports were planned every six months and they were arranged to provide the executive board with all the information necessary to be able to evaluate properly the progress of the project. This schedule was a suggestion that the coordinator and the associated beneficiaries adapted to the needs of the project and to its members' availability. The internal progress report included the following documents: Technical progress reports, financial statement of expenditure, timesheets, personnel costs, invoices and tickets related to all expenses and proof of payments and accounting records according to each associated expense. The "Projectplace" platform (supported by WssTP) was being used as a way to contact and to share documents between the beneficiaries throughout the SAVING-E project. Throughout the project, the communication between the partners was fluently and no significant problems were encountered on the management of the project. Regarding the interaction and communication with the **Stakeholders Advisory Board (SHAB)**: • A regular interaction with **Dr. Mark van Loosdrecht** from TU Delft (The Netherlands) has taken place. As explained in deliverable E1.2, Dr. Mark van Loosdrecht is a world-renowned researcher with large experience in wastewater treatments. Dr. Julio Pérez, from UAB team, traveled three times to Delft, once a year, to meet with Dr. van Loosdrecht.

	These visits were framed in various collaborative activities between the UAB team and Dr. van Loosdrecht's team and the travel costs were paid with funds external to this project. However, in each of his visits, Dr. Pérez presented Dr. van Loosdrecht the main advances of the project and took note of the comments and suggestions made by him. His comments and suggestions were related both with technical aspects of the SAVING-E project, and with the progress of other projects in the implementation of the autotrophic biological nitrogen removal at mainstream conditions. • Moreover, **Dr. Tommaso Lotti,** from Dr. van Loosdrecht's team, participated in the SAVING-E workshop (Valencia, 2018) as member of the SHAB in substitution of Dr Van Loosdrecht. Dr. Lotti made an oral presentation in the workshop and a working meeting with the SAVING-E team about the results and application of the technology. • Finally, Dra. Suárez-Ojeda, from UAB team, held a meeting in 2018 with **Dr. Nicolás de Arespacochaga** (Coordinator of the Department of Wastewater and Resource Recovery at CETAQUA), one of member of the SHAB. He came in representation of the Agrupació de Serveis d'Aigua de Catalunya (Water Services Group of Catalonia) (ASAC) (www.asac.es). In that meeting, Dra. Suárez-Ojeda present him the last advances of the project. Moreover, Dr. Arespacochaga gave the welcoming seminar to the cohort 2018-2019 of the Master degree in Biological and Environmental Engineering, where he explained the last tendencies of Wastewater and Resource Recovery sector, including SAVING-E project. Communication with the Monitoring team was completely satisfactory. Ms. Mariona Salvatella, from NEEMO, has followed our project. She visits one per year (four in total) our facilities in the UAB and Rubí WWTP where the pilot plant was located. During the monitoring visits all the technical and administrative issues of our project were successful presented and discussed. Regarding the communication with EASME, we sent the Mid Term Report on March 2017 and a Progress Report on March 2018. In both cases, the answer of EASME was positive (letters **Ares(2017)2681355** and **Ares(2018)2836151**) with some indications and recommendations that we followed during the rest of the project and during the preparation of this Final Report. Finally, Mr Solon Mias, from EASME, visited our facilities in UAB and Rubí WWTP on March 2019. During his visits, all the

	technical and some administrative issues of the project were presented and discussed. Regarding to amendments to the Grant Agreement, we received two letters from EASME (**Ares(2016)7353988** and **easme.b.3(2018)3793051**) with indication for amendments to Grant Agreement. All those indications have been followed. We want to highlight the change in **Article II.23.2 (d) – Certificate on the financial statements** because the initial requirement for our project to present a 'certificate on the financial statements', foreseen in Action E.3 of the project, changed and it was not mandatory for our project. Consequently, the Action E.3 was not carried out and the cost for the audit has been allocated to personnel costs.
Planning and problems encountered:	No problems have been found. The communication between the partners has been fluently. The establishment of the Partnership Agreement was in force with a delay of one month due a delay in the compilation of the signatures of the partners.
Progress indicators – deliverables:	Progress indicators presented in the technical application form: • *Milestones of the project.* **Achieved** • *Minutes of the project.* **Achieved** • *Gantt chart revision.* **Achieved** • *Mid-term report.* **Achieved** Deliverables: • **E1.1 Project Management Manual** • **E1.2 Constitution Stakeholders Advisory Board** Milestones: • ME1.1 Kick-off meeting. **Achieved**

Table 15. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action E.2.

Action E.2	**Audit**
Responsible:	UAB
Participants:	DAM, ACA and WssTP
Objectives:	A final audit certification will be obtained to guarantee that each partner Final Statement of Expenditure will achieve LIFE+ Programme Common Provisions

Schedule	Foreseen start date: *January 2019* / Foreseen end date: *March 2019*
Main outcomes:	Regarding to amendments to the Grant Agreement, we received two letters from EASME (**Ares(2016)7353988** and **easme.b.3(2018)3793051**) with indication for amendments to Grant Agreement. All those indications have been followed. We want to highlight the change in **Article II.23.2 (d) – Certificate on the financial statements** because the initial requirement for our project to present a 'certificate on the financial statements', foreseen in Action E.2 of the project, changed and it was not mandatory for our project. Consequently, the Action E.2 was not carried out and the cost for the audit has been allocated to personnel costs.
Planning and problems encountered:	No problems have been found.
Progress indicators – deliverables:	Not applicable

Table 16. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action E.3.

Action E.3	**After LIFE Plan**
Responsible:	UAB
Participants:	DAM, ACA and WssTP
Objectives:	Creation of an After LIFE Plan that will set out how the implementation and the dissemination of the SAVING.E technology will continue after the end of the project
Schedule	Foreseen start date: *January 2019* / Foreseen end date: *March 2019* Actual start date: *January 2019* / Actual end date: *March 2019*

Main outcomes:	SAVING-E consortium has developed an After LIFE Plan (see deliverable E3.1 for more detailed information). This After LIFE Plan is based on two main blocks: **1. FULL DEVELOPMENT AND EXPLOITATION OF SAVING-E TECHNOLOGY** The main objective of SAVING-E project was to demonstrate that a new technology is able to improve the energy balance of the urban WWTPs. According to the Technology Readiness Levels (TRL), LIFE+ SAVING-E project should increase the TRL of this technology from TRL 4 (Small scale prototype, built in a laboratory environment) to a TRL 6 (Prototype system, tested in intended environment close to expected performance). According to the results presented in this Final Report, this objective has been almost accomplished but some technical issues regarding a subsequent scale-up of the technology have not been completely solved. Consequently, this part of the After LIFE Plan has been planned to increase the TRL up to a pre-commercial level (TRL 8) within 4 or 5 years. The first step of the After LIFE Plan is to solve the technical issues for scaling-up the technology up to TRL 7. This step will be carried out with the same LIFE+ SAVING-E pilot plant. Three of the partners, ACA, DAM and UAB, have agreed to finance one more year of operation of the pilot plant in Rubí WWTP through a collaboration agreement. The agreement will be signed on May 2019. From April 2019 to April 2020, the operation of the SAVING-E pilot plant will allow to solve some technical problems that not allow scaling-up the technology to TLR 7. The main technical problem addressed will be the operation of the airlift reactor, specifically hydraulic issues explained in detail in Deliverable B4.1. During this year, DAM and UAB will work together to find the best way to scale-up the SAVING-E technology up to TRL 7 (operating in operational environment at pre-commercial scale), building a demonstration facility. This demonstration facility would have a total volume, at minimum, 10-fold higher than the total volume of the LIFE+ SAVING-E pilot plant. The construction and successful operation of this demonstration facility would allow to achieve the TRL 8 and it would serve to convince prospective clients of the application of SAVING-E technology at full-scale.

	We are currently working on finding the best way to finance the construction of the demonstration plant. A possibility is to apply to a Fast Track to Innovation (FTI) project from H2020 programme. In case of applying for a FTI project, we will need at least a consortium of three partners from three different EU countries. We are currently exploring the viability to present a proposal for a FTI project in the next two years. Also, we are evaluating which kind of partners would be the best to conform the consortium. **2. DISSEMINATION AND COMMUNICATION** The dissemination and communication activities of the After LIFE Plan can be divided in three types: • Maintenance and upgrading of the SAVING-E webpage during the next 5 years after the end of the project, that is, up to 2023. • As explained in the Final Report, the main scientific-technical results of the project were achieved in the last months and there was not enough time to publish them in scientific journals. The publication of a scientific paper is a long-time consuming process which can be extent for a year. In the next two years we are planning to publish four scientific articles. • The scientific-technical results achieved during the development of the SAVING-E LIFE project and the achievements in the future will be presented in scientific-technical conferences or congresses. As explained for the scientific articles, the late obtaining of technical results did not allow presenting all of them in these types of events during the validity of the project. The costs associated to the assistance and participation of these events will be assumed by SAVING-E consortium with own resources.
Planning and problems encountered:	No problems have been found.
Progress indicators – deliverables:	Deliverables: • **E3.1 After LIFE Plan** Milestones:

	• ME3.1 Strategy for implementing the After LIFE Plan. **Achieved**

Table 17. Description, schedule, main outcomes, problems encountered, progress indicators and deliverables of Action E.4.

Action *E.4*	***Compilation of information for indicator tables***
Responsible:	*UAB*
Participants:	*DAM, ACA and WssTP*
Objectives:	*Evaluation of the project according to the LIFE+ program indicators*
Schedule	Foreseen start date: October 2015 Actual start date: October 2015 Foreseen end date: end of the project Actual end date: end of the project
Main outcomes:	The indicators tables of the project were prepared according to the guidelines for compilation of the indicators. For each indicator evaluated, it is presented the beginning and final value and it has been included the actual values corresponding to the Final Report evaluation. The tables that have been prepared are the following: • Indicator 2.3.6 Point source pollution. • Indicator 4.1.1 Consumption. • Indicator 11.1 Website (mandatory). • Indicator 11.2 Other tools for reaching/raising awareness of the general public. • Indicator 12.1 Networking (mandatory). • Indicator 12.2 Professional training or education. • Indicator 13. Jobs • Indicator 14.1 Running cost/operating costs during the project and expected in case of continuation/replication/transfer after the project period For more details, see section 7 (Project Specific Indicators).

Planning and problems encountered:	This action is finalised. The Key Project-level Indicators (KPI) were compiled to make the evaluation of the LIFE+ program in the most accurate manner, although the nature and scale of the SAVING-E project made difficult to adapt them to the project. We present our KPI in this Final Report but we have had problems accessing to the KPI platform and we are trying to upload them to the webpage.
Progress indicators – deliverables:	Progress indicators presented in the technical application form: • *Submission of indicators tables at the beginning of the project:* **Achieved**. • *Submission of indicators tables with the Final Progress Report:* **Tables completed, but not possible to upload in the KPI web tool.** Deliverables: Action E4 was planned for being carried out among the whole project. Deliverables regarding to this action were scheduled for March 2017 (E4.1 was submitted with the Mid Term Report) and March 2019 (E4.2. Final Indicators Table). Milestones: ME4.1 (Indicators progress evaluation after D1). **Achieved.** ME4.2 (Indicators progress evaluation after D2-D6). **Achieved**.

6.2. Main deviations, problems and corrective actions implemented

The project was essentially carried out as it was scheduled and only some small deviations appeared. All these deviations were solved by implementing corrective actions. These small deviations and its corrective actions are explained below:

Action B.1 Design of the SAVING-E pilot plant: This action was finished with a delay of one month because Dr. Carlos Ramos was contracted by UAB on November 2015 instead of October 2015, as planned in the proposal, due to legal restrictions.

Action B.2 Construction of the SAVING-E pilot plant: This action started on January 2016 instead of December 2015 due to the delay of one month in Action B.1. However, the action finished at the beginning of June 2016 as previously planned.

Action B.3 Start-up of the SAVING-E pilot plant: The procedure of the start-up of the SAVING-E was modified regarding the originally proposed in the technical application form. In the previously proposed procedure, the three biological reactors were supposed to be simultaneously inoculated. This procedure assumed that the wastewater fed to the UAnSB reactor had to be supplemented with nitrite.

To solve the addition of external nitrite, it was decided to postpone the start-up of the UAnSB reactor until the start-up of the airlift reactor was almost complete. Consequently, the start-up of the HRAS and airlift reactors were initiated on July 2016, but the start-up of the UAnSB reactor was initiated on February 2017. Thus, the UAnSB could be fed with a wastewater containing ammonium and nitrite coming from the airlift reactor in the appropriate concentration and the external addition of nitrite was avoided.

Despite the change in the procedure of the start-up, the action finished at the beginning of March 2017, only one-week late from the originally planned.

Action B.4 Operation of the SAVING-E pilot plant: This action started on March 2017 and was finished on March 2019, four month more than initially planned. This extra month was needed to operate the pilot plant at low temperature taking advantage of the winter season. Some problems related to poor granulation of the nitrifying biomass in the airlift reactor have delayed the operation of the SAVING-E pilot plant at low temperature during the winter season of 2017. Part of these problems was related to the design of the separator of the airlift reactor and consequently, the separator was redesigned and improved.

The last part of the experimental part of this action, the operation at mainstream conditions and low temperature (15 ºC) was successful during almost two months. However, after this period, the formation of nitrate in the reactor and a decrease of the ammonium oxidation activity to nitrite were detected in the airlift reactor. Both negative results were a consequence of the following factors:

- On one hand, it was not possible to maintain a low DO concentration in the airlift reactor (1-2 mg O2 L-1) when temperature decreased. In fact, throughout the operational period at mainstream conditions, DO concentration was close to saturation (8 mg O2 L-1). Consequently, it was not possible to maintain the limitation by oxygen of the nitrite-oxidizing bacteria activity and finally, nitrate was formed. The impossibility of maintaining a low concentration was due to the configuration of the airlift reactor required, in order to keep the granules in suspension, an air flow higher than the air flow required for the biological activity.
- On the other hand, the decrease of the biological activity was due to the accumulation of a high amount of biomass in the bottom of the airlift reactor. Instead of the high air flow applied for maintaining the granules in suspension, a significant part of the biomass was accumulated in the bottom of the reactor due again to an ineffective design of this part of the reactor.
- Both problems could be solved with a better design of the bottom of the reactor and the aeration valves. Unfortunately, there was no time to make those modifications within the time limits of the project and it is a topic to improve in the scale-up of the technology.

Finally, the performance of the last reactor (UAnSB reactor) was totally influenced by the performance of the previous reactor (Partial nitritation airlift reactor). Specifically, the suitable control of the nitrite/ammonium ratio in the influent of the airlift reactor is basic for a good performance of the UAnSB reactor. This ratio depends on the online ammonium probe and the performance of this commercial probe has some limitations. In a future scale-up of the SAVING-E technology, the selection of the best online ammonium probe will be an important factor.

Action B.5 Technical and economical analysis for upgrading different types of urban WWTPs with SAVING-E process: This action started on July 2018 and finished on December 2018 due to some problems related to lack of information from European countries about their current situation related to wastewater treatment and nutrient removal. To solve this problem, other information sources than those planned were consulted (European Reports, websites from private and public institutions, others).

Action C.1 Technical and environmental impacts of SAVING-E technology: This action started on April 2017, but the first milestone (MC1.1 Compilation of all the experimental and theoretical data needed for the energy consumption assessment and LCA) was partially completed for Rubí WWTP in December 2017, 6 months more than the originally planned. These 6 extra-months were needed for allowing us to check and reconciliate the huge amount of data coming from different sources (ACA, DAM and the new enterprise operating Rubí WWTP since September 2016). Globally it was very difficult to collate the information coming from different sources and databases and to reconciliate them into useful units for performing LCI.

Similarly, data needed from SAVING-E pilot plant was not collected until December 2018 once deliverable B4.1 (Manual of operation of the integrated SAVING-E process at high and low temperatures) and milestones MB4.1 and MB4.2 were achieved.

Therefore, milestone MC2.2 (Quantification of the technical and environmental impacts of SAVING-E process) was completed 3 months later than the originally expected, while the deliverable C1.2 (Report containing Material Flow Analysis to study the potential use of the SAVING-E processes in a national scenario (Spain)) will be replaced by an energy flow analysis due to the fact that the date from SAVING-E pilot plant allows us to confirm that the flow of materials of the current operation of Rubí WWTP compared to the implementation of SAVING-E technology remains the same.

Action C.2 Socio-economic impacts at local, national and EU level for implementing SAVING-E technology: Some problems related with lack of information were identified. Other sources of information were consulted in order to obtain relevant information about indicators.

Action D.1 Definition and exploitation strategy. SAVING-E visibility, branding and deliverables preparation: This action was performed as initially planned, but it was finished on April 2016, one month later due to delay in the final designing of the roll-up, poster and photo-call. The creation of the SAVING-E logo and templates for a fast identification of the project were performed on November 2015. On May of 2016, the brochures, roll-up, poster and photo-call were printed. All the participants in the action were successfully implicated on them.

Action D.2 Website design, operation and back-office. Presence in social networking: No problems encountered. This action was performed as initially planned, and the SAVING-E webpage was launched on March 2016. At the same time, social networking profiles were created and linked to the webpage. SAVING-E consortium decided not to make use of Facebook, as the primary goal of our communications is to disseminate the project advances to a targeted audience and Facebook does not seem to offer an additional benefit, compared to the other two networks (Twitter and LinkedIn), towards this end.

Action D.4 Assistance and organization of specialized workshops, seminars, conferences, fairs and other events: The SAVING-E school was initially scheduled for July 2017 as Summer School but it was finally done as Winter school on January 2018 in UAB, Barcelona (Spain). The reason for the change was to be able to have more data on the operation of the pilot plant at the time of doing the course. The change did not cause any major problems and finally the course was conducted with great success of assistance.

The final event, Infoday, was finally done in Barcelona (Spain) instead of Brussels (Belgium) as previously scheduled. The reason for the change is that there was a clear interest of the Spanish stakeholders in seeing the results of the project. This interest was corroborated with the attendance of 80 people from different stakeholders (water treatment companies, public administration and university) to the event, the total expected capacity.

Action D.5 Notice boards, publications and press releases: The installation of the on-site panel was delayed 6 months respect to the original planning because it was decided that the on-site panel would have more impact if the installation was around the time scheduled for the official inauguration day. On June 2016, the panel was installed and the official inaugural day took place at the beginning of July 2016.

Action E.1 Project management by UAB: No problems have been found. The communication between the partners has been fluently. The establishment of the Partnership Agreement was in force with a delay of one month due a delay in the compilation of the signatures of the partners.

Action E.2 Audit: Regarding to amendments to the Grant Agreement, we received two letters from EASME with indication for amendments to Grant Agreement. All those indications have been followed. We want to highlight the change in Article II.23.2 (d) – Certificate on the financial statements because the initial requirement for our project to present a 'certificate on the financial statements', foreseen in Action E.2 of the project, changed and it was not mandatory for our project. Consequently, the Action E.2 was not carried out and the cost for the audit has been allocated to personnel costs.

Action E.4 Compilation of information for indicator tables:

The first problem we found was the fact that the indicators defined by the LIFE Programme were not suitable for the size (wastewater inflow rate to the pilot plant between 1 to 3 m^3/d) and the nature of our project (demonstration of a technology at pilot scale). We made an effort to select some of them which allows us to made the appropriate calculations for a flow rate of 1095 cubic meters per year, which the maximum flow-rate our pilot plant is able to treat. The KPI were presented in the mid-term and final reports.

6.3. Evaluation of Project Implementation

SAVING-E project had a correct implementation and the main objectives of the actions carried out were achieved successfully as summarized in the following pages:

Table 18. Summary of the main objectives and results of each action of the project.

Task or action/sub-action	Proposed	Achieved	Evaluation
Design of the SAVING-E pilot plant	*Design of the SAVING-E pilot plant using experimental data achieved by UAB in previous research studies at lab-scale.*	*Yes*	• *Design of the volume of each reactor carried out.* • *Connections between reactors, airflows and inflow defined.* • *Instrumentation and closed control loops defined and designed.*
Construction of the SAVING-E pilot plant	*Construction of the SAVING-E pilot plant, including all the material elements and the control algorithm following the design guide defined in the previous action*	*Yes*	• *Offers of every element of the pilot plant filled.* • *Orders and delivery requirements defined.* • *Delivery of materials and equipment done.* • *Pilot plant finished and installed.* • *Algorithm control implemented.* • *Operation manual finished.* • *Hydraulic and electrical tests done.*
Start-up of the SAVING-E pilot plant	*Inoculation and start-up of the SAVING-E pilot plant built in the previous action*	*Yes*	• *The complete start-up of the organic matter removal HRAS reactor with the design loading rate was achieved.* • *The complete start-up of the partial nitritation airlift reactor with the design loading rate was achieved.*

			• *A protocol for the start-up of the partial nitritation airlift reactor was established.* • *The complete start-up of the anammox UASB reactor with the design loading rate was achieved.*
Operation of SAVING-E pilot plant	*This action deals with the integrated operation of SAVING-E technology in the pilot plant. After the start-up carried out in the previous action, the three biological reactors of the SAVING-E technology will be connected and operated in an integrated manner for getting the process performance at long term treating a real urban wastewater*	*Yes*	• *The organic loading rate of design was achieved in the HRAS reactor.* • *The nitrogen loading rate of design was achieved in the partial nitritation airlift reactor.* • *The nitrogen loading rate of design was achieved in anammox UASB reactor.* • *The activity of the nitrite-oxidising bacteria in the airlift reactor was completely repressed.* • *A proper anammox bacterial population was achieved in the UAnSB reactor.* • *A suitable [nitrite formed]/[ammonium formed] ratio (between 1.2-1.3) in the effluent of the airlift reactor was achieved.* • *A suitable [nitrite consumed]/[ammonium consumed] ratio (between 1.2-1.3) in the UAnSB reactor was achieved.* • *A suitable [nitrate formed]/[ammonium consumed] ratio in the UAnSB reactor was achieved.* • *An anaerobic biodegradability of the secondary sludge from the HRAS reactor higher than 60% was achieved.*
Technical and economic analysis for	*Technical and economic analysis about*	*Yes*	• *A comprehensive analysis related to urban wastewater treatment and nutrient removal*

upgrading different types of urban WWTPs with SAVING-E process	*how the current WWTPs could be upgraded with the SAVING-E technology at Catalan, Spanish and European levels. Determination of the cost-efficient transferability of SAVING-E technology*		*at Spanish and European context was carried out.* • *A study of the retrofitting of the Rubí WWTP for implementing SAVING-E technology was carried out. The study was focused on technical and economical transferability analysis.* • *A study of the retrofitting of standard types of urban WWTPs for implementing SAVING-E technology was carried out. The study was focused on technical and economical transferability analysis.*
Technical and environmental impacts of SAVING-E technology	*To measure and document the effectiveness and the environmental benefit of the project actions as compared to the initial situation objectives and expected results*	*Yes*	• *A database including all the processes, energy and material inputs and outputs was carried out.* • *A set of global environmental indicators or environmental impacts categories for a conventional system based on Rubí WWTP and a WWTP based on SAVING-E technology was established.* • *An estimation of the CO_2 avoided emissions per each process and of the energy saving potentials was carried out.* • *A comparison of impact factors of the water and sludge lines of Rubí WWTP and a WWTP based on SAVING-E technology was carried out.* • *A quantification of the increase of the biogas production comparing Rubí WWTP and a WWTP based on SAVING-E technology was carried out.* • *A quantification of the reduction of the nitrogen*

			discharge comparing Rubí WWTP and a WWTP based on SAVING-E technology was carried out. • *A quantification of the energy saving in the global treatment comparing Rubí WWTP and a WWTP based on SAVING-E technology was carried out.* • *A quantification of the greenhouse gas emission comparing Rubí WWTP and a WWTP based on SAVING-E technology was carried out.*
Socio-economic impacts at local, national and EU level for implementing SAVING-E technology	*This action deals with the monitoring of the socio-economic impacts that the implementation of SAVING-E technology could represent at local and EU level.*	*Yes*	• *An economic evaluation of the implementation of SAVING-E technology in the urban WWTPs was carried out.* • *The social impact for the implementation of SAVING-E technology in the urban WWTPs was estimated.*
Definition of exploitation strategy, SAVING-E visibility, branding and deliverables preparation	*Definition of the templates following SAVING-E brand for being used in deliverables, presentations, minutes, etc. according to the target audience*	*Yes*	• *The exploitation strategy was defined.* • *The templates for each target group and dissemination events were created.* • *The SAVING-E corporate brand was created.* • *The SAVING-E brochure and roll-ups were created.*
Website design, operation and back-office. Presence in	*Creation several communication tools for the project's dissemination*	*Yes*	• *SAVING-E website was created and lunched.* • *SAVING-E website had 5394 visits throughout the project.* • *SAVING-E website had 3739 users throughout the project.*

social networks.			• *SAVING-E website had an average of 2.65 pages visited per session.* • *SAVING-E twitter account has 364 followers.* • *Each tweet of the SAVING-E project had an average of 5 retweets.*
Networking with other projects	*To establish networks with other relevant national and European projects, in particular LIFE projects. The principal aim will be to know other experiences on autotrophic nitrogen removal, energy savings measurements and upgrading of biogas production.*	*Yes*	• *Networking with 6 different projects, 4 of them LIFE projects, was done.* • *Face-to-face meetings were carried out with the most related projects: (i) LIFE CELSIUS (LIFE14 EN/ES/00023) devoted to the implementation of autotrophic nitrogen removal at mainstream conditions;(ii) LIFE DeNTreat (LIFE16 ENV/IT/00345) devoted to the implementation of autotrophic nitrogen removal; (iii) LIFE InSiTrate (LIFE12 ENV/ES/000651) devoted to biological nitrogen removal and (iv) RUbí Brilla, a local project from the Rubí council devoted to energy savings.* • *Two people from LIFE CELSIUS (LIFE14 EN/ES/00023) participated on the winter school of SAVING-E project.*
Assistance and organization of specialized workshops, seminars, conferences, fairs and other events	*This action deals with: (i) the attendance of SAVING-E team to scientific conferences, brokerage events and fairs organized by external parties;*	*Yes*	• *The Inauguration day of the SAVING-E pilot plant was carried out on July 2016 with assistance of more than 100 people to the Rubí WWTP. The Mayor of Rubí, the Rector of the UAB and the Director of the ACA participated in the inauguration. News about the inauguration day and the*

	(ii) the organization of the inauguration day, visits and hands-on sessions for students, winter school, workshop and Infoday by SAVING-E team.		*SAVING-E project appeared in several media: Catalan TV (TV3), radio and newspapers.* • *The summer school scheduled for July 2017 was finally done as winter school on January 2018 in UAB, Barcelona (Spain). 30 seats were offered that were filled with people from different stakeholders: water treatment companies, public administration and university.* • *The workshop was done on June 2018 in Valencia (Spain). 40 people from different stakeholders (water treatment companies, public administration and university) assisted.* • *The final event, Infoday, was finally done in Barcelona (Spain) instead of Brussels (Belgium) as previously scheduled. The reason for the change is that there was a clear interest of the Spanish stakeholders in seeing the results of the project. This interest was corroborated with the attendance of 80 people from different stakeholders (water treatment companies, public administration and university) to the event, the total expected capacity.* • *SAVING-E team presented the project on events organized by external parties:* • *LIFE14 Kick-off meeting (November 2015, Lisbon, Portugal). Attendees to the event: 50 people* • *XII META Conference (June 2016, Madrid, Spain).*

			Attendees to the event: 100 people • *AEAS Technical conference (May 2017, Tarragona, Spain). Attendees to the event: 200 people* • *Water Section Innovation Technology Forum of Catalan Water Partnership (April 2017, Terrassa, Spain). Attendees to the event: 100 people* • *7th European Bioremediation Conference & 11th ISEB Conference (June 2018, Chania, Greece). Attendees to the event: 150 people* • *International Integrated Water Cycle Show (Iwater) (November 2018, Barcelona, Spain). Attendees to the event: 4000 people*
Notice boards, publications and press releases	*Dissemination of the project objectives, initiatives, events and services and relevant achievements*	*Yes*	• *The on-site panel was located on main entrance of the Rubí WWTP on June 2016* • *The media coverage basically happened at three times: (i) Several press news was published regarding the start-up of the project on TV news, webpages and Spanish and Catalan journals; (ii) other press noticies were released after the Inauguration day on national and local press media; (iii) press notices were released after the final event, Infoday, on national and local press media.* • *Considering the audience of the media that published news about the SAVING-E project, a total audience of between half a million and a million people can be estimated.*

			• *The effectiveness of the dissemination can be qualified as positive based on the next parameters:* • *Full capacity in the four events organized by the project: Inauguration day, winter school, Workshop and Infoday. Total attendees to the events: 250 people.* • *Request for additional information on SAVING-E technology, through telephone calls or e-mail, by more than 10 companies in the water treatment sector.* • *Request for interviews with the project coordinator by different media: 2 TVs, 3 radios and 3 newspapers.*
Layman's report	*Development of Layman's report to non-specialist audiences*	*Yes*	• *The SAVING-E project Layman's report is a 16-pages long report, from which 400 printed copies where distributed within the beneficiaries of the project. The electronic version (available in the SAVING-E webpage) was sent to the final list of contacts gathered during the SAVING-E events* • *The report provides a permanent record of the project that can be filed for future reference. It includes the following sections: i) The environmental problem targeted, ii) SAVING-E Project objectives, iii) overview of the pilot plant & installation, iv) SAVING-E Project: 3.5 years at a glance, v) Which are the SAVING-E Results?, vi) What does SAVING-E project mean for society at large? And vii) Dissemination Activities.*
Project management and monitoring	*General coordination and management of*		• *The Partnership Agreements were successfully created, accepted and signed by the*

of the project progress	*the project: (i) coordination of all the beneficiaries and (ii) reporting to the European Commission*		*whole consortium of the project.* • *Project Management Manual was established to detail the guidelines for the direction and the coordination of the project. At the same time, it was defined the Stakeholders Advisory Board. Moreover, SAVING-E project established the rules for the management of the technical and financial issues and the reporting system.* • *The "Projectplace" platform was being used as a way to contact and to share documents between the beneficiaries throughout the SAVING-E project.* • *Throughout the project, the communication between the partners was fluently and no significant problems were encountered on the management of the project.* • *Communication with the Monitoring team was completely satisfactory. During the monitoring visits (once per year) all the technical and administrative issues of our project were successful presented and discussed.* • *Regarding the communication with EASME, we sent the Mid Term Report on March 2017 and a Progress Report on March 2018. In both cases, the answer of EASME was positive with some indications and recommendations that we followed during the rest of the project and during the preparation of this Final Report.*

			• *Finally, personnal from EASME, visited our facilities in UAB and Rubí WWTP on March 2019. During this visit, all the technical and some administrative issues of the project were presented and discussed.*
Audit	*A final audit certification will be obtained to guarantee that each partner Final Statement of Expenditure will achieve LIFE+ Programme Common Provisions*	*Not applicable*	• *According to the change in Article II.23.2 (d) – Certificate on the financial statements, the initial requirement for our project to present a 'certificate on the financial statements', foreseen in Action E.2, changed and it was not mandatory for our project. Consequently, the Action E.2 was not carried out.*
After-LIFE Plan	*Creation of an After LIFE Plan that will set out how the implementation and the dissemination of the SAVING.E technology will continue after the end of the project*	*Yes*	• *SAVING-E consortium has developed an After LIFE Plan based on two main blocks:* • *<u>Full development and exploitation of SAVING-E technology</u>: According to the Technology Readiness Levels (TRL), SAVING-E project should increase the TRL of this technology from TRL 4 to a TRL 6. According to the results presented in this Final Report, this objective has been almost accomplished but some technical issues regarding a subsequent scale-up of the technology have not been completely solved. Consequently, this part of the After LIFE Plan has been planned to increase the TRL up to a pre-commercial level (TRL 8) within 4 or 5 years.* • *<u>Dissemination and Communication:</u> The*

			dissemination and communication activities of the After LIFE Plan can be divided in three types: o *Maintenance and upgrading of the SAVING-E webpage during the next 5 years after the end of the project, that is, up to 2023.* o *Publication of results of SAVING-E project in four scientific articles in the next two years.* o *Presentation of results of SAVING-E project in several scientific-technical conferences in the next two years.*
Compilation of information for indicator tables	*Elaboration of LIFE programme indicators tables of the project, according to the guidelines for compilation of the indicators.*	*Yes*	*The tables that have been prepared are the following:* • *Indicator 2.3.6 Point source pollution.* • *Indicator 4.1.1 Consumption.* • *Indicator 8.1.1 Mitigation: Reduction of CO_2* • *Indicator 8.1.3 Mitigation: Renewable energy production* • *Indicator 11.1 Website (mandatory).* • *Indicator 11.2 Other tools for reaching/raising awareness of the general public.* • *Indicator 12.1 Networking (mandatory).* • *Indicator 12.2 Professional training or education.* • *Indicator 13. Jobs* • *Indicator 14.1 Running cost/operating costs during the project and expected in case of continuation/replication/transfer after the project period*

6.4. Analysis of benefits

SAVING-E project aims to evaluate whether is possible or not the conversion of current urban WWTPs from being net-energy consumers into self-sufficient or even net-energy producers by using all the organic matter for biogas production thanks to the implementation of a two-stage autotrophic BNR (nitritation + anammox) in the mainstream. This new process has not been applied or tested before neither at pilot scale nor at full scale. This process truly offers environmental, economic and social advantages compared to the current technologies applied in urban WWTPs.

SAVING-E project has demonstrated the stability of this new process at long term when working at low temperatures (15 ºC), which would allow SAVING-E to be subsequently applied at full scale in any European country no matter the season of the year. This project has increased the Technology Readiness Level (TRL) of SAVING-E technology from TRL-4 up to almost TRL-6. As explained in detail in deliverable E3.1 “After LIFE Plan”, some technical issues have to be solved during the next year to achieve TRL-6. Then, the consortium of the project has a plan to increase the TRL up to TRL-7 in the next two or three years, the last level before achieving a commercial application of the technology.

Technical and environmental results and impacts of the application of the SAVING-E technology versus conventional technologies for treating urban wastewaters can be summarized in:

- **Increase of 35% of the biogas production.**
- **35% of energy saving in the global biological treatment process.**

We have analyzed the potential energy flows of implementing the SAVING-E technology in the case study of Rubí WWTP (Spain). We have demonstrated that increased biogas production and a more energy efficiency technology (SAVING-E) in the process for removing nitrogen result in reduced energy demand in the WWTP. These results were assessed also in Catalan and Spanish scenarios.

Two scenarios (Table 19) were used to model the energy flows of implementing the SAVING-E technology. Scenario V0 treats 100% of the wastewater inflow using conventional activated sludge (CAS) and follows a self-sufficiency approach through biogas recovery. Scenario SE considers the implementation of the SAVING-E technology. Given the capacity of system, the experimental test and the results from Deliverable B5.2, we assumed that 50% of the wastewater inflow is treated through the SAVING-E technology, whereas the remaining 50% is treated by the CAS system. Overall, scenario SE models an increase in CH_4 content and biogas production.

The results of the energy consumption patter (Figure 2) denote the potential improvement of the SAVING-E technology can have over the Rubí WWTP treating only 50% of the total influent. The electrical energy consumption from grid is 0.22 kWh/m3 for the current configuration of Rubí WWTP, while with the application of SAVING-E technology is 0.06 kWh/m3, i.e. 73% decrease in the electrical energy demand from grid. This decrease is basically due to: i) improved biogas production (with SE scenario, 0.20 kWh/m^3 can be obtained from cogeneration compared to the 0.11 kWh/m^3 of V0 scenario), ii) 50% of the influent flow rate is treated by a technology with very low aeration needs (biological treatment in the SE scenario consumes 0.15 kWh/m^3 compared to 0.20 kWh/m^3 of the V0 scenario). Compared to the energy consumption (0.3 to 0.8 kWh/m^3) for Spanish WWTP larger than 100K PE, the total energy consumption (0.33 kWh/m^3 and 0.26 kWh/m^3 for V0 and SE scenarios, respectively) reported herein is in the low value of the reported range.

Table 19 Scenarios defined to model the effects of implementing the SAVING-E technology on the impacts of the WWTP.

Modeling scenarios	Treated wastewaster	Treatment scheme
V0	100%	Conventional activated sludge
SE	50%	High-rate activated sludge and aBNR process
	50%	Conventional activated sludge

In our assessment, energy self-sufficiency implies that the WWTP will reduce its dependence on conventional energy sources (e.g., local grid). An incremental widespread implementation of self-sufficiency approaches in this and other sectors could lead to a reduced demand for fossil energy and thus, improve the energy flows of the WWTPs. In other words, the environmental impacts of the WWTP might increase through the new technology, but it theoretically reduces the demand for conventional energy production and prevents this production from taking place.

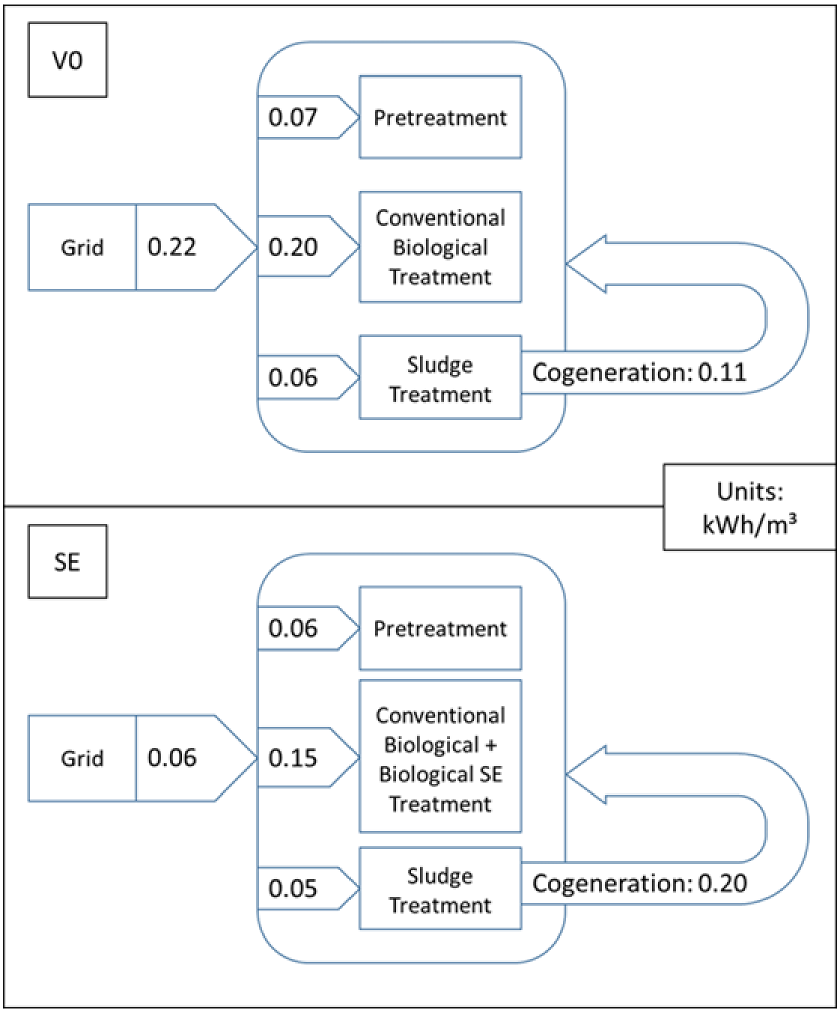

Figure 2. Energy consumption pattern of the Rubí WWTP (V0) and SAVING-E technology applied to the same WWTP (SE).

Digestion is one of the standard processes for sludge stabilization on middle- and large-sized WWTPs. In Catalonia, there are 16 WWTP (3%) with design capacity equal or over 10,000 PE, which is the breakpoint for anaerobic digestion implementation. All of them use the CAS technology to remove organic matter, but none of them have anaerobic digestion nor BNR implemented. As a whole, they sum an installed capacity of 874,141 PE, i.e. 146,356 m^3/d.

Considering the figures of electrical consumption from the grid shown in Figure 2 for SE scenario implemented in these 16 WWTP, this could potentially translate into 73%

electricity savings (8.8 MWh/d) compared to V0 scenario (32.2 MWh/d), if anaerobic digestion and SAVING-E technology is implemented at these 16 WWTP. Similar situation can be assured for Spanish WWTP (Table 20), where 41 WWTP only have organic matter removal with design capacity equal or over 10,000 PE. As a whole, they sum an installed capacity of 115,726,767 PE, i.e 23,145,353 m^3/d.

Table 20. Comparison of energy savings at local, regional and national level.

	Electrical consumption GWh/y for year 2013	Electrical consumption from grid for WWTPs with an installed capacity equal or over 10,000 PE (GWh/y)		Percentage of the electrical consumption of WWTP compared to local, regional and national electrical consumption (%)		Energy savings at local, regional and national context Percentage over total electrical consumption (%)
		V0 scenario	SE scenario	V0 scenario	SE scenario	
Rubí	430	2.2*	0.6*	0.50	0.12	0.38
Catalonia	41,559	11.8**	3.2**	0.03	0.01	0.02
Spain	232,008	1,858.6***	506.9***	0.80	0.22	0.58

*only Rubí WWTP. ** 16 WWTP at Catalonia that currently do not have implemented anaerobic digestion and BNR. ***41 WWTP at Spain (Catalonia excluded) that currently only have organic matter removal.

Wastewater treatment plants can substantially reduce grid electricity consumption, especially by utilizing treatment technologies with decreased aeration needs and with increased biogas production. With increasing population, stricter discharge requirements, and aging infrastructure, as well as rising energy prices and concerns about climate change, WWTP face many challenges that could significantly increase energy use and costs. For example, removal of emerging contaminants, such as pharmaceuticals and personal care products, might require significant increases in electricity consumption for wastewater treatment; therefore, new implementation of the traditional scheme for BNR should be avoided as much as possible in order as it is estimated that the electricity required for wastewater treatment will increase by 20% in the next 15 years in the developed countries to face the challenges like the one above mentioned.

Because of the potential energy savings, we strongly recommend the European Commission, but also member states and local governments to consider policy changes or incentives that can be implemented to help WWTP to widespread the use anaerobic digestion for waste sludge, but also treatment technologies with lowered energy consumption, as well as, energy efficient equipment to reduce energy costs and demand. These policy decisions might further encourage coupling energy recovery with adequate wastewater treatment.

The socio-economic benefits of the project can be divided in:

1. Effects produced during the 3.5 years of duration of the pilot project.
2. The possible effects that the transferability and application of the SAVING-E technology could have. Indeed, at medium and long term, DAM can transfer this technology by tenders at national and EU levels: Transferability at public entities of sanitation and private industrial sectors (Figure 3).

Figure 3. Boosting the development of a more advanced technology focused on energy and nutrient recovery in WWTPs.

The socio-economic effect during the duration of the project includes the generation of new jobs of specialised personnel. Indirectly, some providers were involved in the construction and O&M activities along project. Also, the socio-economic effect includes the social awareness about wastewater treatment into the general public and the training of professionals (head of WWTP and operators) in new technologies of energy self-sufficient urban wastewater treatments. To complete the analysis, in the economic impact and estimation of CAPEX & OPEX in three studies cases was performed.

Some social and economic impacts that may be relevant were identified during the implementation of this project. As mentioned before, SAVING-E project raised as an alternative to improve wastewater treatment in term of reaching energy self-sufficient in current WWTPs. Positive social effects that would be generated as a consequence of SAVING-E project incorporates the effect under Job creation and employment opportunities for those who will be employed by the project, either in the design, construction, transport or implementation. Also, the increases economic activities during the project that benefit the communities around the project. Generally, there is the employment of skilled, semi-skilled and unskilled persons in the building and construction of the plant. Provision of clean and conservative energy is also another positive output due to biogas production. Important social effects were identified according to working quality, opportunity, new knowledge and security in the job.

Tables 21 and 22 show the general indicators defined to evaluate the socioeconomic impact of the SAVING-E development and implementation. This analysis is performed taking into account information obtained in the B and C actions. Table 23 includes qualitative and quantitative information about social indicators identified (employment, education, etc.) and their impact in term of classification (positive or negative) and analysis. Table 24 includes qualitative and quantitative information about economic indicators identified and their impact in term of classification (positive or negative) and analysis. This analysis is carried out taking into account the comparison between baseline Rubi WWTP and SAVING-E implemented. More information is included in Deliverable B5.2. Also, tables 25 and 26 show information about economic indicator in Case 1 (CAS-Conventional Activated Sludge) and Case 2 (EA-Extended Aeration).

Table 21. Indicators to evaluate social impact

INDICATORS	Description:
1. Boosting employment in the water and industrial sectors. *Nº of new jobs.*	Technical and specialized profiles (engineers, technicians, operators) in granular sludge, N removal via nitrite, self-sufficient energy WWTP, etc
2. Training programs in advanced solutions in the water sector. *Nº workshops and training courses developed.*	- Winter school UAB BCN; Workshop DAM VLC; Internal workshops ACA and DAM; Conferences and courses in the UAB; Others courses and conference participation.
3. Increase in social awareness about wastewater treatment represents. Children and young educational programs. *Nº of assistants, Nº programs,*	- Cátedra DAM www.catedradam.com (primary school program call “La maleta del agua”). - UAB educational programs in primary and secondary schools. - Professional training centres (scholarships).
4. Innovation activities. *Nº activities, Nº of thesis awarded, Nº ideas, …*	Open Innovation, Hackathon (challenges in water sector), best thesis award, …

Table 22. Indicators to evaluate economic impact

INDICATORS	Description:
CAPEX.	
<u>Sceneries:</u> 1. Building and retrofitting of the existing WWTPs *(Rubi WWTP case : Conventional Activated sludge, 20.000 m3/d, Anaerobic digestion, …)* 2. Building new WWTPs.	Total costs (€); capacity and size: m3/d; PE (population equivalent); existing technology reemplacement (pumps, reactors, thickeners, anaerobic digestion, etc).
OPEX	
Operation and maintenance. Energy, chemical reagents, preventive and corrective maintaincance…	kWh/m3; €/m3; m3CH4/kg sludge; equipments failures, **Cost savings by SAVING-E implementation (€/m3).**
INVESTMENT	
1. Public sector. Public service contracts. Green procurement. 2. Private sector (agri-food sector, …).	- Number of public tenders including SAVING-E or similar processes for organic matter valorization and N removal. - Number of tenders where SAVING-E could be implemented.

Table 23. Classification and analyses of the social project´s impacts.

Indicator	Impact	Classification and analysis
1. Boosting employment in the water and industrial sectors.	**Employment** opportunities to the population of the area during SAVING-E project execution. *Nº of new jobs.*	Positive, short-term. • **2 technical** profiles full time • **1 administrative** profile medium time. • **n administrative and technical profiles** involved in project activities. Partial time.
	Employment opportunities to the population of the area. Technical and specialized profiles involved in activities of construction and O&M of both new and retrofitting facilities. *Nº of new jobs.*	Positive, important long-term. • An estimation of at least **1 technical profile per each WWTP specialized** in granular biomass, N removal via nitrite, self-sufficient energy. Medium or full time. • An estimation of at least **1 technical profile (operator) for O&M activities.** Full time.
	Provider's development. Direct impact in local economy and indirect impact in the water sector. *Nº of providers involved.*	Positive, important long-term. • **Administrative and technical profiles** involved in project activities. Partial time.
	Increase the income of the population working on the site. *Employment rate.*	Positive, important short-term and long-term.
2. Training programs in advanced solutions in the water sector.	**Increase in the number of technical and specialized profiles.** *Nº workshops and training courses developed.* *Nº attendees.*	Positive, important short-term and long-term. • At least **10 training courses** were performed along project. (courses and specialized workshops in some WWTP, ACA and DAM offices and UAB). • More than **100 operators, head of WWTP, personnel of water utilities attended.**
3. Social awareness about wastewater treatment represents.	**Increase in social awareness.** Increase of knowledge about pollution, climate change, eutrophication, wastewater treatment, SAVING-E process Children and young educational programs. *Nº attendees, Nº programs.*	Positive, important short-term and long-term. • At least **20 actions were carried out along project execution**. Most of these actions were performed by UAB (degree and Master´s programmes) as well as primary and secondary educational programmes (5^{th} june world environmental day). • Around **10 educational actions** carried out by ACA in the framework of Educational Programmes. • CATEDRA DAM-UVEG. At least 3 actions of environment educational programs in primary schools. • More than 200 attenders for all activities.
4. Innovation activities	**Increase in social awareness** *Nº activities, Nº of thesis awarded, Nº idea*	Positive, important short-term and long-term

Table 24. Economic project´s impacts. Baseline Rubi WWTP for an average flow of 20.000 m^3/d

Economic impact	Rubi WWTP CAS Baseline	Rubi WWTP+SAVING-E implementation
Total energy consumption (kWh/day)	7.197	5.120
Energy production (kWh/day)	3.500	4.060
Net energy consumption (kWh/day)	3.697	1.060
Costs per day (€/day)	407	117
Costs per year (€/year)	148.435	42.559
Cost savings (€/year)	0	105.876
Building and retrofitting of the existing WWTP to remove nitrogen (€)	2.000.000 (N removal)	4.112.000
Payback (years). Considering sanitation taxes of 0.412 €/m^3.	< 1	< 2

Table 25. Economic project´s impacts. Case 1 WWTP CAS (Conventional Activated Sludge) for a an average flowrate of 30.000 m^3/d

Economic impact	Case 1 WWTP CAS Baseline	Case 1 WWTP + SAVING-E implementation
Total energy consumption (kWh/day)	7.926	6.832
Energy production (kWh/day)	4.347	5.347
Net energy consumption (kWh/day)	3.579	1.486
Costs per day (€/day)	394	163
Costs per year (€/year)	143.702	59.644
Cost savings (€/year)	0	87.059

Building and retrofitting of the existing WWTP to remove nitrogen (€)	0	3.912.060
Payback (years). Considering sanitation taxes of 0.412 €/m^3.	0	< 1

Table 26. Economic project´s impacts. Case 2 WWTP EA (Extended Aeration) for an average flowrate of 9.000 m^3/d

Economic impact	Case 2 WWTP EA Baseline	SAVING-E implementation
Total energy consumption (kWh/day)	2.414	1.932
Energy production (kWh/day)	0	1.798
Net energy consumption (kWh/day)	2.414	134
Costs per day (€/day)	266	15
Costs per year (€/year)	96.925	5.391
Cost savings (€/year)	0	91.534
Building and retrofitting of the existing WWTP to remove nitrogen (€)	1.500.000 (Anaerobic digester)	4.112.000
Payback (years). Considering sanitation taxes of 0.412 €/m^3.	< 2	< 3

7. Key Project-level Indicators

In the following section are presented the indicators tables of the project according to the guidelines for the compilation of the indicators. As explained before, we were not able to upload the tables in the KPI web tool.

Table 27. Indicator 2.3.6 Point source pollution

Specific Context	Choose the River Basin Specific Pollutant(s) (December 2015).	At the beginning	MTR	At the end	5 Years beyond	Units	Comments	Choose the Type of point source pollution.	Choose the point source related Key Type(s) of Measure(s) (KTM) related to point source pollution.
RIERA DE RUBÍ	CAS_14798-03-9 Ammonium	54.4	Not possible to be quantified	9.9	9.9	kg/year	The calculation of this parameter (ammonium) has been done with the inflow of the SAVING-E pilot plant (1095 cubic meter per year). The value of this parameter at the beginning has been calculated with the average value in the effluent of the Rubí WWTP during 2014 and the expected flow of the SAVING-E pilot plant.	Urban waste water	Urban or industrial (including farms) waste water plants
RIERA DE RUBÍ	EEA_3133-03-7 - CODCr	78.0	Not possible to be quantified	54.8	54.8	kg/year	The calculation of the parameter (CODCr) has been done with the inflow of the SAVING-E pilot plant (1095 cubic meter per year). The value of this parameter at the beginning has been calculated with the average value in the effluent of the Rubí WWTP during 2014 and the expected flow of the SAVING-E pilot plant.	Urban waste water	Urban or industrial (including farms) waste water plants

Table 28. Indicator 3.1.1 Consumption

Specific Context	Choose the Energy sources.	At the beginning	MTR	At the end	5 Years beyond	Units	Comments
Rubí	Electric	315	Not possible to be quantified	186	186	kwh/year	The calculation of the parameter has been done with the inflow of the SAVING-E pilot plant (1095 cubic meter per year). The value of this parameter at the beginning has been calculated with the average consumption value in the Rubí WWTP during 2014 and the expected inflow treated by the SAVING-E pilot plant.

Table 29. Indicator 8.1.1 Mitigation: Reduction of CO_2

Specific Context	Choose of greenhouse gas	At the beginning	MTR	At the end	5 Years beyond	Units	Comments
Local	CO_2	2.7	2.2	2.2	559	tons CO_2/year	The calculation of the parameter for "MTR" and "At the end" has been done with the inflow of the SAVING-E pilot plant (1095 cubic meter per year). The value of this parameter at the beginning was taken from the average value for the Rubí WWTP during 2014 as reported by operator. The value "5 years beyond" was calculated taking into account replication potential as reported in Deliverable C1.1, C1.2 and C 1.3, i.e. the energy credits were accounted for in the environmental balance of SAVING-E implemented at Rubí WWTP.
Catalonia	CO_2	4169	4169	4169	3032		The calculation of the parameter for "at the beginning", "MTR" and "At the end" has been done with the generated load of WWTPs only removing COD where anaerobic digestion could be implemented in the stated specific context. The value "5 years beyond" was calculated taking into account replication potential as reported in Deliverable C1.1, C1.2 and C 1.3
Spain	CO_2	53966	53966	53966	39248		
EU28	CO_2	237041	237041	237041	172393		

Table 30. Indicator 8.1.3 Mitigation: Renewable energy production

Specific Context	Choose renewable energy source	At the beginning	MTR	At the end	5 Years beyond	Units	Comments
Local	Biogas from anaerobic digestion	1,586,655	N/A	N/A	1,951,655	kwh/year	Production of methane with the secondary sludge of the SAVING-E process can be up to 75% higher than the produced with the secondary sludge of the Rubí WWTP. However, the surplus biomass produced from SAVING-E pilot plant was not used for anaerobic digestion. This is why “N/A” appears for “MTR” and “At the end” columns. The value of this parameter at the beginning was taken from the average value for the Rubí WWTP during 2014. The value “5 years beyond” was calculated taking into account replication potential as reported in Deliverable B5.3.

Table 31. Indicator 11.1 Website (mandatory)

Specific Context	Website (mandatory)	At the beginning	MTR	At the end	5 Years beyond	Units	Comments	Reaching and/or awareness raising of the general public through the project website	Choose the Indicators for raising the awareness of Individuals.
Spain	No. of individuals	0	850	1020	750		Other indicator for raising the awareness of individuals will be the number of followers in the SAVING-E twitter account and the average number of retweets and/or likes of each our tweets.	Awareness raising	Following websites (likes, subscribers...)., Asking project related questions., Other (specify in comment box).
Rest of Europe (including Russia)	No. of individuals	0	425	510	375		Other indicator for raising the awareness of individuals will be the number of followers in the SAVING-E twitter account and the average number of	Awareness raising	Following websites (likes, subscribers...)., Asking project related questions., Other (specify in comment box).

							retweets and/or likes of each our tweets.		
America	No. of individuals	0	144	245	180		Other indicator for raising the awareness of individuals will be the number of followers in the SAVING-E twitter account and the average number of retweets and/or likes of each our tweets.	Awareness raising	Following websites (likes, subscribers...)., Asking project related questions., Other (specify in comment box).
Asia	No. of individuals	0	136	163	120		Other indicator for raising the awareness of individuals will be the number of followers in the SAVING-E twitter account and the average number of retweets and/or likes of each our tweets.	Awareness raising	Following websites (likes, subscribers...)., Asking project related questions., Other (specify in comment box).

Others	No. of individuals	0	75	102	75		Other indicator for raising the awareness of individuals will be the number of followers in the SAVING-E twitter account and the average number of retweets and/or likes of each our tweets.	Awareness raising	Following websites (likes, subscribers...)., Asking project related questions., Other (specify in comment box).

Table 32. Indicator 11.2 Other tools for reaching/raising awareness of the general public

Specific Context	Other tools for reaching/raising	At the beginning	MTR	At the end	5 Years beyond	Units	Comments	Reaching and/or awareness raising of the general public.
Spain	Print media	0	40000	40000	40000		First, a video about the project was broadcasted on the public television of Catalunya (TV3). TV3 audience in Catalunya is about 3 million people and the average audience of TV3 is 15%, which is to reach a general audience of 450,000 people. Secondly, a radio program about the project was also broadcasted on several local radio stations, which could mean to reach a general audience of 50000 people. Finally, several press realses about the project were printed on important daily newspapers of Catalunya, that means to reach a general audience of 40000 people	
Spain	Other media (video/broadcast)	0	500000	500000	500000		First, a video about the project was broadcasted on the public television of Catalunya (TV3). TV3 audience in Catalunya is about 3 million people and the average audience of TV3 is 15%, which is to reach a general audience of 450,000 people. Secondly, a radio program about the project was also broadcasted on several local radio stations, which could mean to reach a general audience of 50000 people. Finally, several press realses about the project were printed on important daily newspapers of Catalunya, that means to reach a general audience of 40000 people	

Table 33. Indicator 12.1 Networking (mandatory)

Specific Context	Choose the Target audience.	At the beginning	MTR	At the end	5 Years beyond	Units	Comments	Choose the Networking tools used.
Spain	Members of interest groups	0	400	1700	1700	No. of individuals	Firstly, the official inaugural of the SAVING-E pilot plant will be carried out in July 2016. This event represented the first face-to-face opportunity for doing networking activities with public bodies, municipal authorities, general public, communication media, etc. Secondly, personnel of the different beneficiaries of SAVING-E project assisted to networking meetings, workshops, conferences and platform meetings to present SAVING-E project with an estimated participation of 100 stakeholders per meeting. Finally, an Infoday about the SAVING-E project was carried out in UAB during the first months of 2019. The audience of this event were mainly Spanish stakeholders identified through the dissemination actions of the project.	Workshops, Networking (mandatory), Other training or educational events, Conferences
Spain	Layman	0	0	750	375	No. of individuals	A Layman's report of 16 page targeted at non-specialist audience, including political decision-makers, outlining the main results of the project was carried out and distributed at the end of the project.	Other training or educational events
Rest of Europe	Layman	0	0	250	125	No. of individuals	A Layman's report of 16 page targeted at non-specialist audience, including political decision-makers, outlining the main results of the project was carried out and distributed at the end of the project.	Other training or educational events

Table 34. Indicator 12.2 Professional training or education

Specific Context	Choose the Target audience.	At the beginning	MTR	At the end	5 Years beyond	Units	Comments	Choose the Training/education tools used.
Spain	Professionals	0	0	80	80	No. of individuals	A workshop was carried out in Valencia (Spain). It was mainly oriented towards the involvement of public bodies, water professional's staff, water professionals-decision makers, water utilities and public administration professionals.	Workshops
Spain	Pupils (of school age)	0	40	500	300	No. of individuals	Visits to the SAVING-E pilot plant for high school and vocational training students and their teachers was carried out along the project. Participation in the Argó UAB program and in report made by UAB journalisms students contributed to this indicator.	Field trips Mentoring
Spain	Students (in higher education)	0	0	50	50	No. of individuals	A winter training school was in Barcelona (Spain). This course was mainly oriented towards future professionals in charge of managing SAVING-E like facilities.	Classes/courses

Table 35. Indicator 13. Jobs

Specific Context	At the beginning	MTR	At the end	5 Years beyond	Units	Comments	Choose the Sex of the employee (s)	Choose the Specificities of the employees.	Choose the Age group.	Choose the Level of education.	Other specifiers:
Spain	0	2	4.5	0	No. of FTE	Two PhD professionals were contracted using the budget of the SAVING-E project to carry out technical and management tasks. One of them was a full time employee and the other one a part-time employee.		Skilled	25-54	Tertiary (ISCED levels 5-8)	

Table 36. Indicator 14.1 Running cost/operating costs during the project and expected in case of continuation/replication/transfer after the project period

Specific Context	At the beginning	MTR	At the end	5 Years beyond	Units	Comments
Europe	0	389,368.16	1,169,068	166,496.32	€	The value “at the end” is the total SAVING-E project budget. The value “5 years beyond” correspond to the collaboration agreement explained in the After Life Plan.