LIFE Project Number
LIFE13 ENV/ES/000160

FINAL Report
Covering the project activities from 01/07/2014 to 30/06/2017

Reporting Date
30/09/2017

LIFE+ PROJECT NAME or Acronym
Advanced control MBR for wastewater reclamation
BRAINYMEM

Project Data

Project location	Spain
Project start date:	01/07/2014
Project end date:	30/06/2017
Total Project duration (in months)	36 months
Total budget	506,367€
Total eligible budget	506,367€
EU contribution:	253,183€
(%) of total costs	50.00
(%) of eligible costs	50.00

Beneficiary Data

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2. Executive Summary

The main objective of this project was to demonstrate that Membrane Biological Reactor (MBR) technology with an advanced control system is the best available technology for wastewater treatment, in terms of environmental impact and effluent quality. For this purpose, a pilot plant (60 m^3, 5 m^3/h) located in Almuñécar (Granada) was used as a demonstration plant. To achieve the energy reduction objective, two control strategies were implemented: a control system for the biological process and another for the filtration process.

Firstly, the demonstration plant, which was already installed, was modified to be adapted to the new project by the installation of different controllers, actuators and other accessories. After that, some modifications were performed in the SCADA system in February and May 2015. Since then, the demonstration plant operated with the novel control system. Along the project, different modifications of the control system were performed in order to optimise the energy reduction without compromising the effluent quality. The deliverable of the description of the control system was updated to include the last control logic of the optimized system.

Regarding to the biological aeration, based on online analysis of nitrification intermediate products, the data showed that the ammonium in the effluent reached higher values than desired when the control system was active. For this reason, the control was optimised to find a compromise between biological aeration reduction and adequate nutrient removal. A modification of the initial control was performed to include the concentration of NH_4-N in the effluent as a parameter. This modification was made by the Automation department of ACCIONA Agua, and it did not affect the demonstration of the control, since the operation was not stopped and it was considered as an optimisation of the control system. After some months of operation, an idea for a further improvement of the control system came out and it was implemented: instead of controlling the air flow rate, the dissolved oxygen in the aeration tank was controlled with a setpoint which was fixed based on the nitrification products. This achieved more reduction in the aeration energy of the biological process. The energy consumption by the biological aeration went from 0.55 to an average on 0.45 kWh/m^3 treated water which represented a 18% of the reduction (with values ranged from 0.55 kWh/m^3 to 0.40 kWh/m^3) compared with a plant without biological aeration control. As many plants have nowadays a control system implemented, a comparison was made with the most implemented control system, based in a fixed dissolved oxygen setpoint. The plant was operated with this control system during four months. The reduction of biological aeration energy compared to the energy consumption using the fixed dissolved oxygen setpoint control system was 8%.

Regarding to the filtration process control, it involved the installation of the dosage pump for flux-enhancers and a modification in the SCADA (supervisory control and data acquisition) system. The aeration rate did not affect the characteristics of effluent and a stable permeate quality was observed during most of the experimental period. The results showed that MBR pilot-plant could operate with the control system while ensuring a high treatment performance for organic matter removal. The membrane control was operative for 23 months, without any significant faults. The membrane scouring associated energy costs went from 0.21 to 0.13 kW/m^3 of treated water, meaning a 38% reduction. Taking both control systems, the aeration energy consumption decreased by approximately 22% with the filtration control.

In order to enhance trace organic pollutant removal and to increase sludge filterability (when needed) a flux-enhancer dosing pump was installed, which is controlled by the advanced control system. To select the flux enhancer to be used in the demonstration plant, a state-of–the-art review was performed in order to identify the best additive. The selection was finally determined by making a compromise between filterability improvement and micropollutant removal. Before implementing the flux-enhancers dosage in the plant, some additives were evaluated with jar tests in the laboratory. The activated sludge with additives showed a better performance in terms of filterability compared to the control sludge without additives. After six months of operation of the plant, the flux enhancer dosage started in order to improve the filterability when needed. However, the improvement expected by the addition was not reached, and the option of adding flux-enhancers to improve process operation was discarded for future plants.

Once the control of the demonstration plant was in operation, the phase of analytical campaign started. This occurred earlier (September 2015) and finished later than initially scheduled (May 2017). However, the number of planned samples was kept approximately the same as planned. Experience in previous projects showed that approximately half of the influent samples analyzed will have micropollutant concentrations under the detection limit, meaning that these data will not be used and therefore it was decided to start before in order to analyze a number of samples high enough to obtain data from which we can extract representative conclusions. The results of the flux-enhancer addition related to the removal of micropollutants were not satisfactory and no improvement in the removal of the selected compounds was shown after adding the flux-enhancer. For this reason, an alternative technology was evaluated at lab-scale as a tertiary treatment to eliminate organic micropollutants in treated water. This technology is based in the application of a plastic foam carrier with activated carbon on its surface (LEVAPOR). Biofilm was developed on the surface of the carriers, and after that they were used for treating an effluent spiked with 10 µg/L of diclofenac, estradiol and 17-α-ethinylestradiol. From all studied contaminants, estradiol and 17-α-ethinylestradiol showed high removal in short-term tests, whereas diclofenac, a compound biologically persistent in conventional processes, showed moderate removal up to 30%. However, the concentrations of micropollutants decreased over time indicating the relevance of biological activity for the removal process. For long term tests, the removal increased up to 90% in all cases. The results showed that it can be an interesting post treatment for emerging micropollutant removal since adsorption achieved around 50% removal for most compounds in the first 45 min and after 48 hours it was reached almost 100% removal for all tested compounds.

Taking all these into account, the objectives of the BRAINYMEM have been fulfilled. The described objectives as in the proposal were as follows:

1) To control the air scouring of the plant based on fouling rate plant data registered and processed by the SCADA of the demonstration plant.
2) To control the biological aeration based on online analysis of nitrification by-products, which are reliable indicators of nitrification performance.
3) To enhance trace organic pollutant removal and to increase sludge filterability (when needed) by means of including flux-enhancer dosing, controlled by the advanced control system, to the activated sludge of the plant.
4) To transfer the acquired knowledge to stakeholders by means of specific education and dissemination strategies and platforms as well as recommendations to policy makers.

The aeration control (objectives 1 and 2) was already achieved via the implementation of the expert control system in the first period of the project, which was already reported in the Inception Report. Reduction of 22% of total energy consumption has been achieved with the implementation of the control systems.

Regarding to objective 3, the results showed that the addition of flux-enhancers did not improved the micropollutant removal. However, a highly promising technology for micropollutant removal was tested as an alternative technology, the LEVAPOR carriers, and the removal rates achieved for the studied micropollutants was almost 100% removal for all tested compounds after 48 h and 50% after 45 min contact time.

Considering objective 4, this objective was fulfilled along the project by implementing the actions described in the communication plan. At this point, several dissemination actions have already taken place in order to raise interest in the project. Apart from the press note released until the date of the Inception Report submission (covered by 12 different press media), 3 more press notes have been released which were covered by numerous media. The project has been also explained in a video and an infographic document explaining both the ACCIONA's R&D projects on waste water, as well as in a video specifically produced for the project. The web site reached more than 6.917 visits, 400 brochures were printed, and the project was presented in different conferences, where the main national water stakeholders and decision makers were present.

It can be concluded that all objectives of the project were achieved. The results were satisfactory and they are already being implemented in a real plant in the Basque Country, where a new MBR is being built with the BRAINYMEM control system.

3. Introduction

Due to the increased concern on global warming, there is more awareness about emissions of greenhouse gases (GHGs) worldwide. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These three major GHGs can be produced during wastewater treatment (Hofman et al., 2011). Indeed, N_2O emissions from wastewater is an emerging problem, as wastewater is nowadays the sixth largest contributor to N_2O emissions, accounting for approximately 3% of N_2O emissions from all sources (Gupta and Singh, 2012). Moreover, it has been evidenced that WWTP are not able to remove efficiently some substances in the water, the so-called emerging pollutants or micropollutants, a broad group of substances that includes from pharmaceutical products to personal care products and nanomaterials. Such substances have been found by numerous studies to accumulate in the aquatic medium, potentially endangering water ecosystems.

The aim of the BRAINYMEM project was the reduction of the environmental impact of membrane bioreactors (MBR), both in water and the atmosphere. This was achieved by implementing a novel control system that will reduce energy consumption and by the addition of optimal chemical additives that would reduce emerging micropollutant concentration in the effluent. For this purpose, a pilot plant (60 m^3, 5 m^3/h) located in Almuñécar (Granada) served as a demonstration plant. To achieve the energy reduction objective, two control strategies were implemented: a control system for the biological process and another for the filtration process. For the objective of reducing the micropollutant concentration, a flux-enhancers dosage was installed (Figure 1).

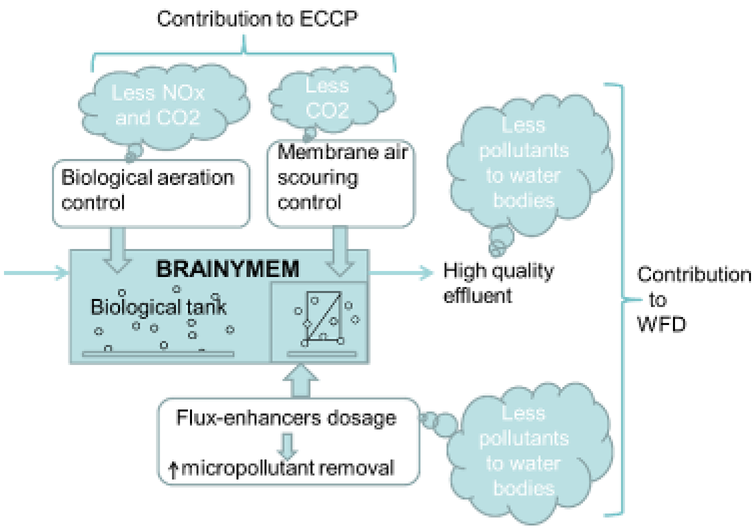

Figure 1. Brainymem project scheme.

Specific objectives as in the proposal were as follows:

1. To control the air scouring of the plant based on fouling rate plant data registered and processed by the SCADA of the demonstration plant.
2. To control the biological aeration based on online analysis of nitrification by-products, which are reliable indicators of nitrification performance.

3. To enhance trace organic pollutant removal and to increase sludge filterability (when needed) by means of including flux-enhancer dosing, controlled by the advanced control system, to the activated sludge of the plant.
4. To transfer the acquired knowledge to stakeholders by means of specific education and dissemination strategies and platforms as well as recommendations to policy makers.

4. Administrative part

4.1 Description of the management system

The project management includes all the tasks concerning the relationship between the participants of the project, the operating procedures, administrative, financial and technical management and the schedule of the consortium meetings. The management structure of the project consists on a Project Coordinator, a Project technical Committee and an Advisory Board as shown in Figure 2.

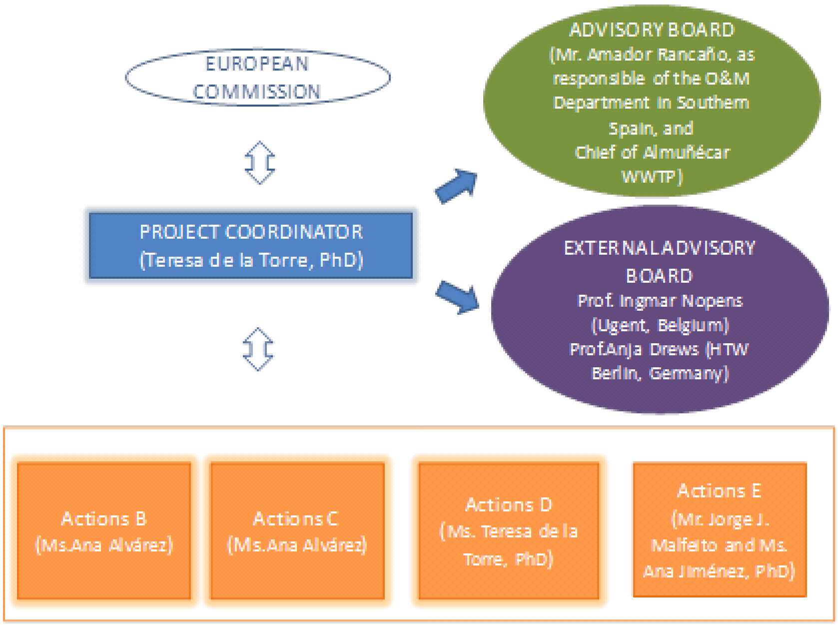

Figure 2. Structure of the project management of the project.

The function that each one has had into the project is described below:

Project Coordinator (Dr. Teresa de la Torre from ACCIONA Agua):

- Day to day communication with the European Commission and with the External Monitoring Team
- Formal revision and submission to the EC of progress reports, related cost statements, and any other document or communication pertaining to the project.
- Calling on participants and/or members of the Committees to attend the Project Coordination meetings, as well as setting up and circulating the meeting agendas.
- Supervising and informing all participants about the project progress (i.e. sending interim reports, meeting minutes, etc.).
- Day to day assistance to the overall Project Management (including both technical and administrative issues).

Technical Committee (TC) (Dr. Teresa de la Torre, Ana Álvarez and Jorge Juan Malfeito, all from ACCIONA Agua): The Project Technical Committee is led by Dr. Teresa de la Torre. The role of the TC involved the following tasks:

- To ensure that each member meets the Annual WorkPlan concerning results and defined deliverables and milestones.
- To establish a schedule for monitoring the technical aspects of the project. After each meeting, the coordinator shall prepare the minutes for the session.
- To provide the coordinator with all the necessary information for the preparation of monitoring reports sent to the Commission.
- To meet every six months to monitor the actions carried out and, based on the results, to schedule the work plan for the next 6 months.

It has to be mentioned that Teresa de la Torre took a maternity leave from January to Mid June 2016. In this period Ana Jiménez and Ana Álvarez were responsible for her tasks.

Advisory Board (AB): The project has also had a panel of experts that have assisted the project coordinator and technical responsible in their technical decisions. The advisory board is formed by Mr. Rancaño, from ACCIONA Agua, who is the responsible of the O&M Department in southern Spain. Moreover, two external experts in MBR technology have been asked for participation to assess the Technical Committee: Prof. Ingmar Nopens from UGent (Belgium) and Prof. Anja Drews from HTW Berlin (Germany). Periodic meetings with them have been held to discuss technical issues (see below).

Through the project several **Technical Committee meetings** have been organized in order to review the technical progress and monitor the actions carried out and to plan the following months:

- (Weekly) Technical Committee meetings to review the technical progress of the project, monitor the actions carried out and plan the following week.
- September 2014 Kick-off meeting LIFE projects
- September 2014: Meeting with Advisory board member (Prof. Ingmar Nopens, UGent, Belgium)
- October 2014: Head of Automation Dpt. ACCIONA (Alejandro Beivide)
- November 2014: Organization of the pilot plant and lab actions between the Team in Barcelona and Almuñécar
- November 2014: Meeting about the administrative and financial issues of the project
- January 2015: Programming company (control logic to SCADA)
- March 2015: Monitoring Visit
- April 2015: Meeting with Head of Automation Department of ACCIONA (Alejandro Beivide) for optimization of the control systems
- October 2015: Meeting with Head of Automation Department of ACCIONA (Alejandro Beivide) for optimization of the control systems

- December 2015: Meeting with Advisory board member (Prof. Ingmar Nopens, UGent, Belgium)
- June 2016: Monitoring visit
- July 2016: Meeting with Advisory board member (Prof. Anja Drews, HTW Berlin)
- September 2016: Meeting with Advisory board member (Amador Rancaño O&M Area Responsible ACCIONA Agua)
- November 2016: Meeting with Advisory board member (Amador Rancaño O&M Area Responsible ACCIONA Agua)
- April 2017: Monitoring visit
- May 2017: Meeting in Acciona Agua Madrid with the O&M Department of Acciona Agua to present the results of Brainymem
- June 2017: Conclusion meeting – Review of Final Report

The deliverables related to the action E1. Project management monitoring have been submitted with the following reports:

- E1.1: Project Management Handbook - 30/09/2014
- E1.2: Inception Report - 31/03/2015
- E1.4: Mid-Term Report - 30/06/2016
- E1.6: Final Report – 30/09/2017

The progress indicators of this action are the following:

	Method of calculation (Consortium)	Inception Report Jul.14-Mar.15	Midterm Report Jul.2014-Jun.16	Final Report Jul.14-Sep.17[1]
Budget Execution	% of justified costs vs approved costs (506,367 €)	17% (85,950€)	51% (259,932 €)	95% (482.714,26 €)
Tasks Performance	% of Tasks completed vs total number of Tasks (25)	24% (6/25)	40% (10/25)	100% (25/25)
Objectives achieved	% of specific objectives achieved vs total number of specific objectives (4)	0% (0/4)	50% (2/4)	100% (4/4)
Fulfilment of the planning	% of deliverables submitted vs total deliverables number (22)	36% (8/22)	41% (10/22)	100%[1] (22/22)
Successful relationship between partners	Number of problems between partners.	0	0	0

Table 1. Progress indicators through the milestones of the BRAINYMEM Project.

[1] Including deliverables to be delivered by 30/12/2016

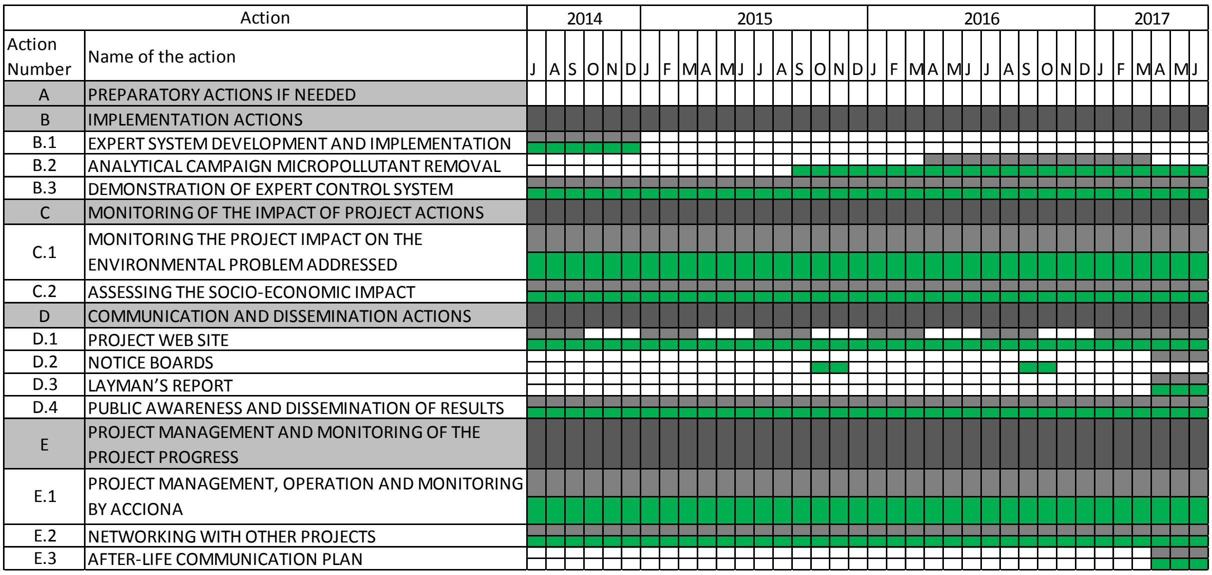

Figure 3. Original (grey) and final (green) chronogram of the project.

4.2 Evaluation of the management system

The monitoring of the actions performed in the project, as well as the reports related to the action performance and those delivered to the European Commission, media and external organization have been elaborated by technicians of ACCIONA Agua. The economical and administrative management has been done by an external company (ZABALA) specialized in the management of European and LIFE+ projects.

The project management process has been based on a constant communication by means of phone calls and e-mails. Moreover, periodic meetings have taken place to guarantee the accomplishment of both technical and economic aspects of the project.

The person in charge of the communication with the Commission and the External Monitoring team has been Dr. Teresa de la Torre (ACCIONA Agua). Every month, Dr. Teresa de la Torre has sent an update email to the Monitor of the External Monitoring Team who has been in charge of the OFREA project, briefing the main advances in the project.

5. Technical part

5.1. Technical progress, per task

5.1.1. Action B.1. Expert system development and implementation

This action included some modifications in the pilot plant in order to implement the control system. The control system was designed to control both the aeration (membrane and biological) and the flux-enhancer dosage. In relation with this task, more details can be found in the deliverable "B1_ Deliverable B1. Logic of control system as implemented" which was included in the inception report. The different controllers, actuators and other accessories were installed in the demonstration plant already constructed (Figure 4), and was exclusively used for the development of the Brainymem project. This task is subdivided into three subtastks:

Figure 4. General overview of the demonstration plant.

Task B.1.1. Development of the logic of the aeration control

The logic of the control system was developed by Acciona and implemented in the SCADA of the plant. This control varies the air flow in the biological tanks based on ammonium and N_2O data measured on line. In the case of the membrane aeration control system, these modifications were performed basically to relate the membrane aeration flow, supplied by the blower, to the fouling rate data measured online in the plant.

Task B.1.2. Development of the logic of the flux-enhancer dosage.

The logic of the control system was developed by Acciona and implemented in the SCADA of the plant. In the case of the flux-enhancers dosage, the control distinguishes two operational modes for the dosage of flux-enhancers: a sequence for the emergency mode and a sequence for continuous mode. In the first case, the control system has been designed to act when the aeration has reached a maximum value for a certain time and the fouling rate is still higher than desired. In the second case (continuous mode), the pump is activated by the operator and will stay activated at a specified speed until the continuous mode is deactivated.

Task B.1.3. Implementation of the control.

Once the expert system was developed, an external Automation company implemented it at the demonstration plant in Almuñécar (Granada, Spain) (Figure 6). Two ammonium sensors (Figure 5a, influent and effluent) from Hach Lange (Germany) and a N_2O sensor (Figure 5b) from Unisense (Denmark) were required by this control system and they were installed in the demonstration plant. The N_2O sensor has a duration time of approximately 1 year and it was replaced twice along the project (March 2015 and December 2016) but it was envisaged initially and any delay in the operation of the plant was registered. The N_2O sensor is the world's only sensor to directly measure dissolved nitrous oxide. The flux enhancer dosage control required a dosage pump which was acquired and installed in the plant (Figure 7).

Figure 5. a) Ammonium sensor to control the influent concentration. b) Probe to measure N2O emissions.

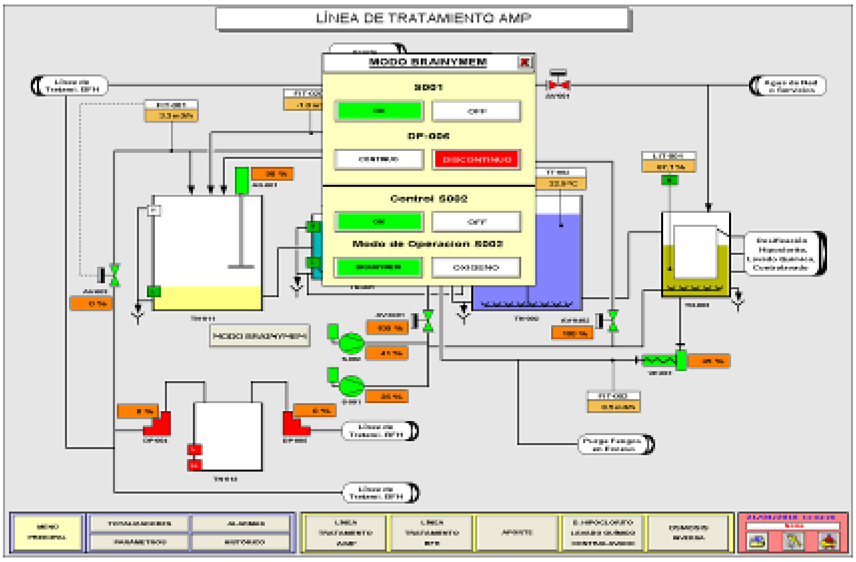

Figure 6. Implementation of the control in the SCADA system of the plant.


Figure 7. Pump for flux enhancer addition.

This action concluded on time. As an indicator, the description report for the Automation Company written which can be found in Deliverable B1, the programming of this logic on the SCADA and the installation of the different accessories for control acquired and installed (Figure 3, Figure 4, Figure 5).

- Participants of this task:
  - Marina Arnaldos, Teresa de La Torre, Ignasi Jordana, Jorge Juan Malfeito, María del Mar Micó, Adolfo Molina, Carlos Rodríguez (Acciona Agua): development of the logic of the aeration and flux enhancer dosage control:
- Outputs achieved: Sensors and accessories for air scouring control acquired and installed in the plant. Logic implemented. Deliverable done.
- Finished on schedule:

	Proposed date	Actual date
Start	Jul. 2014	Jul. 2014
End	Jan. 2015	Jan. 2015

Table 2. Action B.1 timetable

5.1.2. Action B.2. Analytical campaign micropollutant removal

Due to the presence of trace organics pollutants and the ineffective conventional treatment to eliminate them, this action is focused on the analytical campaign for trace organics pollutants removal achieved by the pilot plant after flux enhancers dosing compared to the removal efficiency without additive dosage. This action was divided into two different tasks: evaluation of micropollutant removal and toxicity tests. Both of them have been done by two outsourced entities and Acciona Agua was responsible for processing the data obtained by the external laboratory. Furthermore, it was carried out a series of lab experiments to complete the above mentioned tasks and give an alternative to flux enhancers: the use of a biocarrier called LEVAPOR as post-treatment. This analytical campaign was planned to start in April 2016, but was started in September 2015. Experience in previous projects showed that approximately half of the influent samples analyzed will have micropollutant concentrations under the detection limit, meaning that these data will not be used. Moreover, Almuñécar is a highly touristic area, the wastewater load, temperature and composition will differ significantly from winter and summer, and therefore it was decided to start before and analyze a number of samples high enough to obtain data from which we can extract representative conclusions.

Task B.2.1. Evaluation of micropollutant removal

The compounds analyzed during the analytical campaign study are listed in Table 3 and Table 4. The analytical campaign was divided into three parts: a) evaluation of micropollutant removal without flux enhancer addition, b) jar tests and c) the evaluation of micropollutant removal after flux enhancer addition.

Antibiotics	Anti-inflammatory drugs	Anticonvulsant	Estrogens
Sulfamethoxazole	Diclofenac	Carbamazepine	17β-estradiol
	Ibuprofen		17α-ethyilestradiol
			Estriol
			Estrone

Table 3. Pharmaceutically active compounds

Compound	Abbreviation
Di(2-ethylhexyl)phthalate	DEHP
nonylphenol	NP
4-nonylphenol monoethoxylate	NP1EO
4-nonylphenol diethoxylate	NP2EO

Table 4. Phthalate and nonylphenols.

a) Task B.2.1.1 Removal of micropollutants without flux enhancer addition

The samples from the influent and effluent of the demonstration plant without additive dosing were evaluated during five months: in winter period from September 2015 to January

2016 and in August 2016 employing high performance liquid chromatography-high resolution mass spectrometry (HPLC-HRMS) method.

The obtained results for the BRAINYMEM water samples during the whole reference campaign are summarized in the following table.

Compounds	Influent wastewater			Effluent wastewater		
	Mean / $\mu g.L^{-1}$	Max / $\mu g.L^{-1}$	SD / $\mu g.L^{-1}$	Mean / $\mu g.L^{-1}$	Max / $\mu g.L^{-1}$	SD / $\mu g.L^{-1}$
Diclofenac	0.32	0.44	0.19	0.08	0.092	0.01
Carbamazepine	0.18	0.22	0.03	0.18	0.181	0.00
Sulfamethoxazole	1.42	1.75	0.54	0.18	0.204	0.02
Ibuprofen	11.17	15.8	4.04	0.04	0.072	0.03
Nonylphenol	2.82	4.76	2.75	0.70	1.23	0,62
NP1EO	<LOD	<LOD	-	<LOD	<LOD	-
NP2EO	<LOD	<LOD	-	<LOD	<LOD	-
DEHP	5.20	5.4	3.01	1.10	1.2	0.64
17β-estradiol	<LOD	<LOD	-	<LOD	<LOD	-
17- α-Ethinylestradiol	<LOD	<LOD	-	<LOD	<LOD	-
Estrone	<LOD	<LOD	-	<LOD	<LOD	-
Estriol	<LOD	<LOD	-	<LOD	<LOD	-

Table 5. Parameters analyzed in the wastewater treatment plant influent and effluent, reference phase.

LOD.: Limit of detection

As it can be seen inTable 5, the concentration of most of the compounds analyzed was under the detection limit. However, it was observed that the effluent of the membrane bioreactor (MBR) of Almuñécar (Granada) showed the presence of diclofenac, one of the substances included in the list of priority substances of the Water Framework Directive (WFD). The average removal and the standard deviation of the analyzed substances by an MBR without additional treatment was shown in Figure 8. The majority of the compounds detected were removed by more than 80% except diclofenac and carbamazepine. Diclofenac showed a moderate removal up to 56% while, as reported in literature (Rattier *et al.*, 2014), the carbamazepine is highly persistent showing poor removal after MBR treatment (<10%). The highest removal was found for ibuprofen with an average of 98%, followed by nonylphenol, sulfametoxazole and DEHP with a 87%, 85% and 83% of removal respectively, meaning that the process was not able to completely eliminate them. Given these results, a flux enhancer among several additives was selected in order to assure an effluent without the presence of these substances. An increase of micropollutant removal efficiency was expected when flux enhancer addition started.

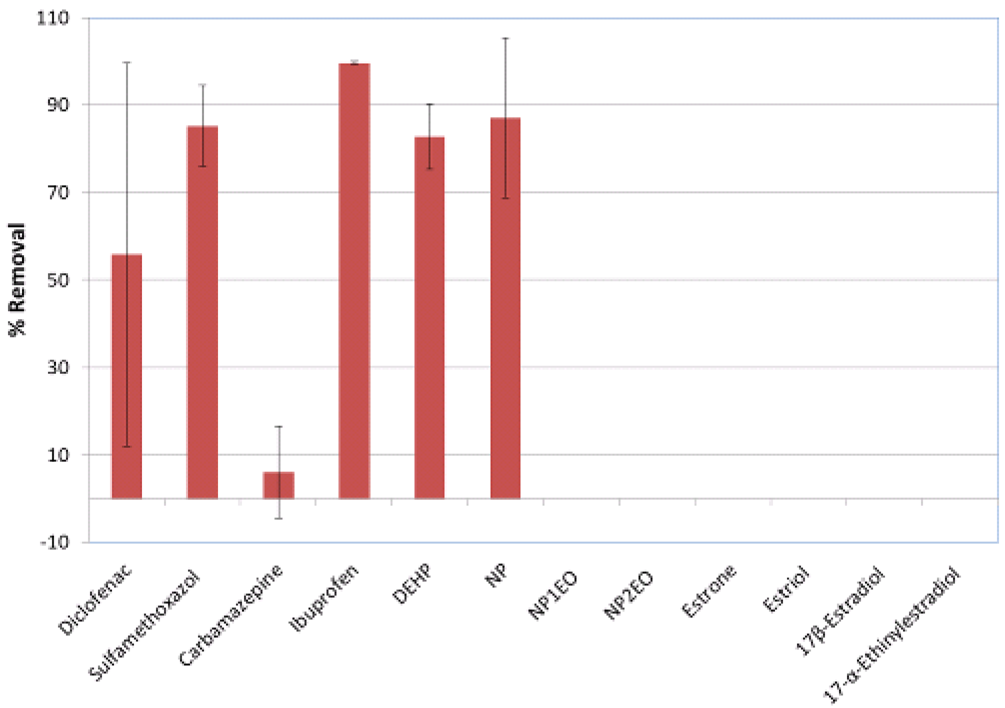

Figure 8. % Removal of micropollutants without additive dosing (Reference phase).

b) *Task B.2.1.2 Jar tests*

In order to find the optimum dosage of flux enhancer to remove micropollutants, jar tests were carried out in the laboratory of the pilot plant. Based on a review of the literature, two cationic polymers were selected: MPE50 of Nalco Chemical Company and Magnafloc LT35 commercialized by BASF Chemical Company. Samples were spiked with 10 µg/L of diclofenac, estradiol and 17-α-ethinylestradiol to study the removal efficiency. More details of these tests can be found in the deliverable "D.B.2.1 Effect of flux-enhancer dosing in an MBR system on trace organic removal and toxicity". As it is depicted in Figure 9 and Figure 10, the results showed a removal of the selected substances at the concentration of 150, 300, 500 and 700 mg.L^{-1}, for MEP50 and Magnafloc LT35 respectively.

The different results obtained for each concentration and compound made difficult the task to select the optimum dosage, since apparently the optimum concentration depended on each substance. Furthermore, additional jar tests were performed to determine the optimum dosage for filterability improvement (see Action B.3.2) where the concentration obtained was 300 mg L^{-1}. For that reason, it was decided to start with low concentration (300 mg L^{-1}) and in the case to be required, increase that concentration.

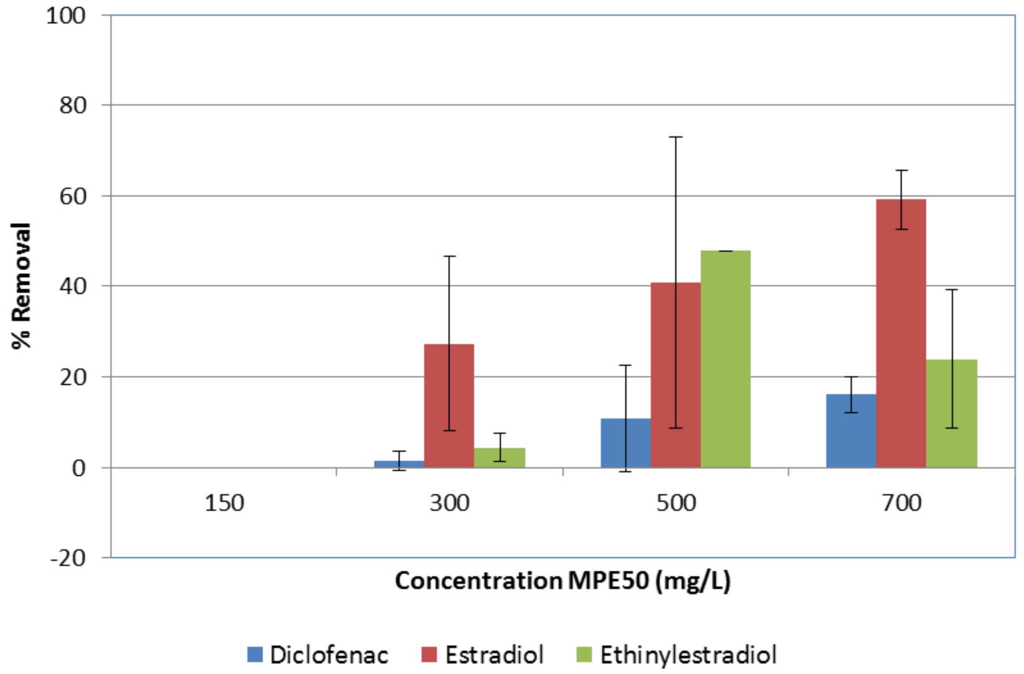

Figure 9. % Removal of selected substances by MPE50 dosage.

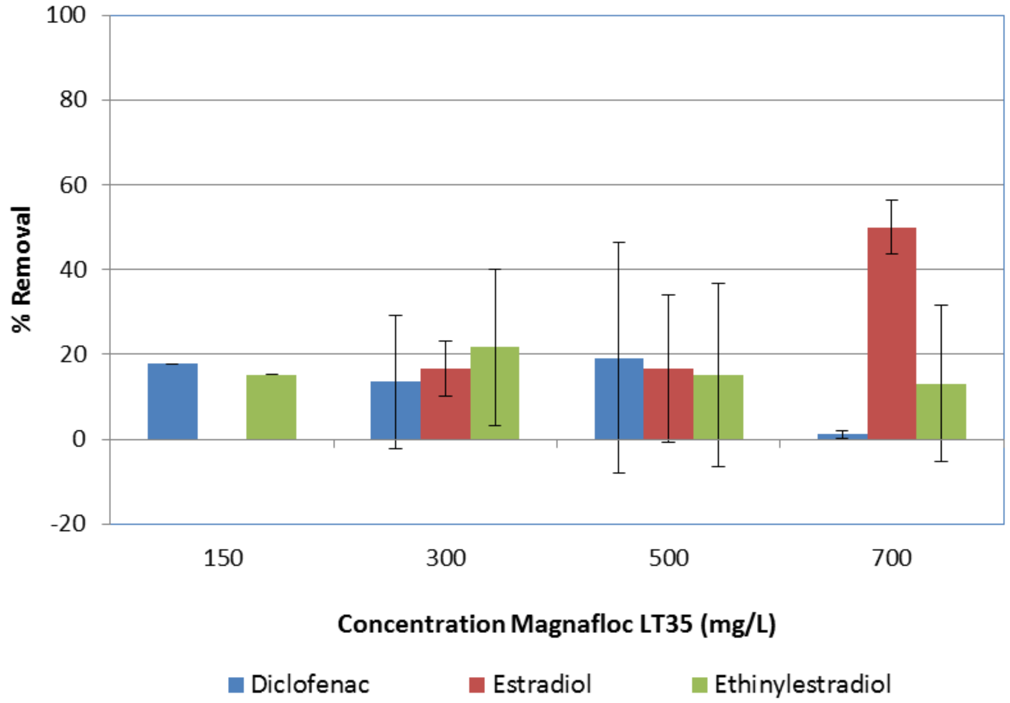

Figure 10. % Removal of selected substances by Magnafloc LT35 dosage.

c) *Task B.2.1.3 Removal of micropollutants after flux-enhancer addition*

After dosing the optimum concentration of the flux enhancer in the demonstration pilot plant, the samples from the influent and effluent were evaluated during five months: from November 2016 to April 2017. The concentration of micropollutants was measured and the results were compared with those without using a flux enhancer. In Figure 11 has been represented a comparison between the removal of compounds with and without flux enhancer dosage. As it can be seen, removal rates from flux enhancer addition were in some cases even lower than the removal achieved without treatment. For some compounds as carbamazepine, NP and NP2EO were found higher concentration after flux enhancer dosage. In the case of nonylphenols, NPEO can degrade partially to NP, which is a compound more persistent. Due to this fact, NP could be found in the effluent of wastewater treament plants at higher concentracion than in influent samples. In the case of carbamazepine, the concentration is so close to the detection limit that the results could be provoked by an error in the quantification method (**Table 6**).

	Influent wastewater			Effluent wastewater		
Compounds	Mean / µg.L^{-1}	Max / µg.L^{-1}	SD / µg.L^{-1}	Mean / µg.L^{-1}	Max / µg.L^{-1}	SD / µg.L^{-1}
Diclofenac	0.71	0.848	0.14	0.49	0.602	0.09
Carbamazepine	0.05	0.065	0.01	0.09	0.107	0.02
Sulfamethoxazole	0.46	0.576	0.12	0.25	0.313	0.05
Ibuprofen	7.88	10.56	1.38	0.02	0.080	0.03
Nonylphenol	0	0.171	0.03	0.36	0.416	0.03
NP1EO	<LOD	<LOD	-	<LOD	<LOD	-
NP2EO	0.015	0.171	0.00	0.02	0.041	0.01
DEHP	<LOD	<LOD	-	<LOD	<LOD	-
17β-estradiol	<LOD	<LOD	-	<LOD	<LOD	-
17- α-Ethinylestradiol	<LOD	<LOD	-	<LOD	<LOD	-
Estrone	<LOD	<LOD	-	<LOD	<LOD	-
Estriol	<LOD	<LOD	-	<LOD	<LOD	-

LOD.: Limit of detection

Table 6. Parameters analyzed in the wastewater treatment plant influent and effluent, after flux enhancer treatment.

The low efficiency of the product could be found in the main removal mechanisms of micropollutants in wastewater treatment where biodegradation and adsorption are the process through trace organics are removed. Altough some authors had been reported coagulation/flocculation was a good option to remove micropollutants, the results showed no improvement and this practice was not considered for real scale applications.

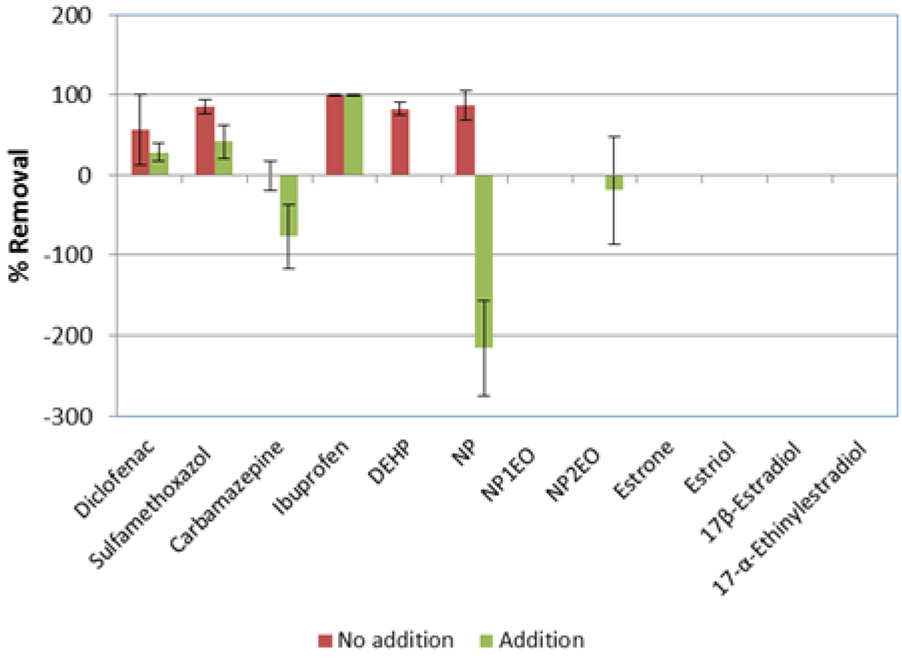

Figure 11. Comparison between micropollutants removal with and without flux enhancer addition.

Task B.2.2. Toxicity tests

Micropollutant analysis was combined with toxicity tests to provide information on the androgenic activity of the pollutants discharged. To determine the androgenic activity of wastewater and treated water samples, it was used AR-EcoScreen cell (Otsuka Pharmaceutical cells) that contains the human androgen receptor and luciferase as reporter gene. Samples were collected over the course of one year. They were maintained in DMEM/F-12 medium, supplemented with 10% fetal bobbin serum (FBS), penicillin (100 U/ml), streptomycin (100U/ml), hygromycin (25 mg/ml), and zeocin (50 mg/ml) at 37 Cº in an atmosphere containing 5% CO_2. The androgenic activity is presented as dihydrotestosterone (DHT) hormone equivalents from each sample.

In Figure 12 were represented the toxicity results, namely the DHT equivalents/ml found in effluent and influent samples of the MBR without flux-enhancer addition; for each sample (A) and the average of these results (B). Influent samples showed significant androgenic activity, which a maximum in sample 5 where the concentration was 0.8 DHT-Eq ng/ml influent. On the other hand, androgenic activity was not always detected in effluent samples with an average of 0.01 ± 0.01 ng DHT eq/ml. An average hormone removal efficiency of 100% for androgens (corresponding to an average residual concentration of 0.4±0.12 ng DHT eq/ml) from the daily wastewater was achieved. So, these results showed the effluent contains low or none androgenic activity.

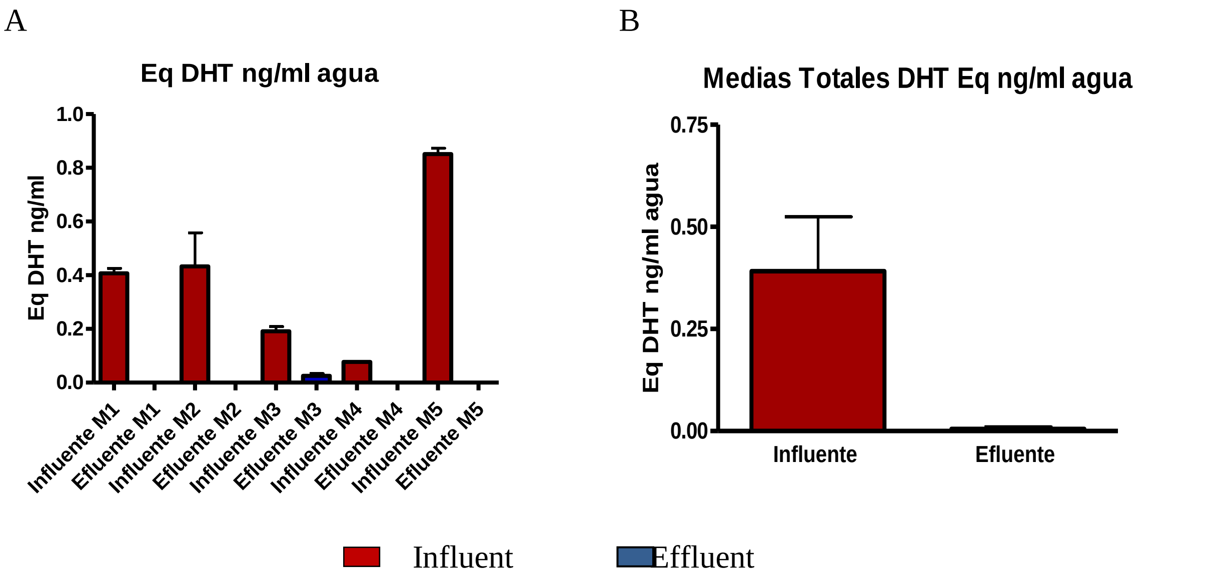

Figure 12. DHT Equivalents (ng/ml) in effluent and influent samples (A) and the average of them (B).

After evaluating the presence of androgenic substances without additive dosing, a new campaign started. Samples from the influent and effluent of the demonstration plant with flux enhancer were taken during five months: from November 2016 to April 2017. The optimum dosage obtained in jar tests was applied in the pilot plant. In Figure 13 has been represented the DHT equivalents/ml found in effluent and influent samples; for each sample (A) and the average of these results (B) after flux enhancer treatment. Androgenic activity was always detected in incoming wastewater during this period study. The highest level of androgenic activity was detected in February at 0.10 DHT-Eq ng/ml. MBR treatment <u>with flux enhancer</u>

addition decreased the DHT-Eq in the water from an average of 0.07 ± 0.01 DHT-Eq ng/ml influent to 0.00±0.00 DHT-Eq ng/ml in the effluent. The removal achieved was up to 100% and no androgenic activity was detected in any of the effluent samples, proving the effectiveness of the treatment.

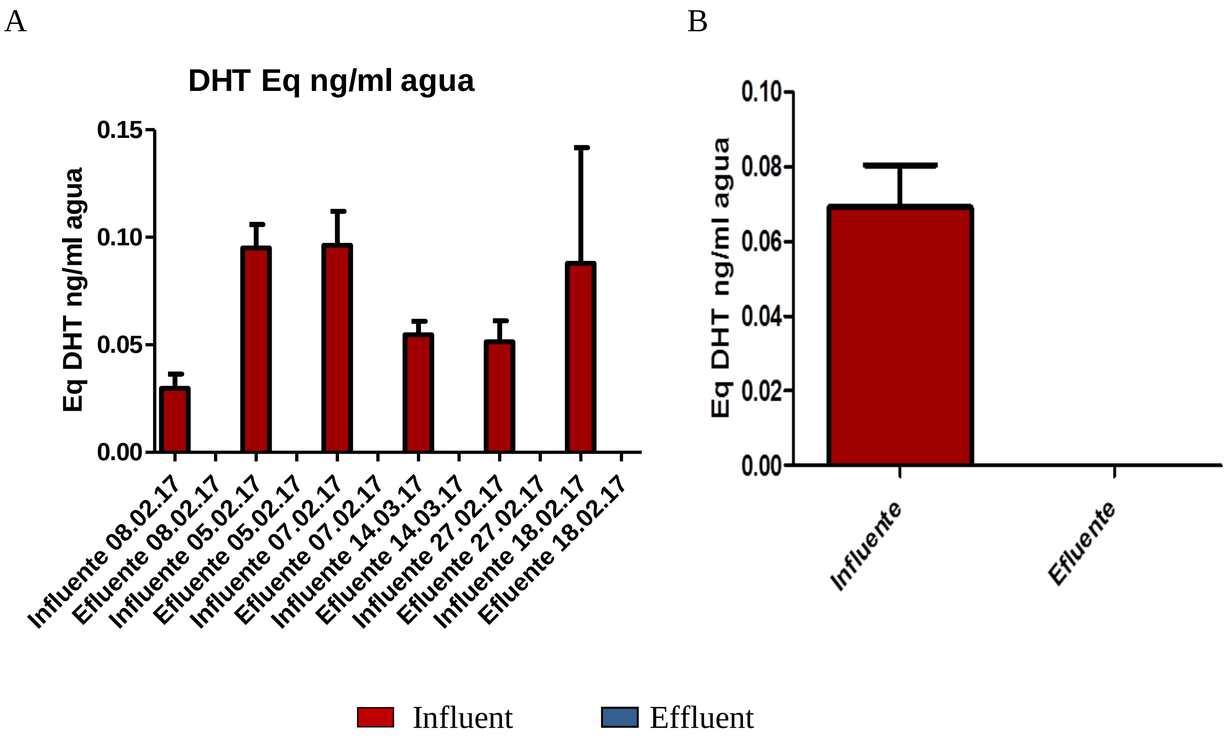

Figure 13. DHT Equivalents (ng/ml) in effluent and influent samples (A) and the average of them (B) after flux enhancer addition.

Task B.2.3. Cost/benefit analysis

The results showed that the flux enhancer used in this action, a cationic polymer, did not achieve the improvement expected after addition. Furthermore, toxicity tests showed the MBR treatment without additives is able to remove efficiently the androgenic activity in wastewater. So the application of flux enhancer at full scale was disregarded.

Task B.2.4. Additional treatments: LEVAPOR

Additionally, tests with a plastic foam carrier called LEVAPOR were performed. The objective of this experiment was to determine the extent to which some micropollutants can be removed using sponge carriers with biofilm and activated carbon on its surface. LEVAPOR biocarrier coated with surface active was used for treating an effluent spiked with 10 µg/L of diclofenac, estradiol and 17-α-ethinylestradiol.
The results showed initial removal by adsorption in LEVAPOR biocarrier of all micropollutants was demonstrated. Among the contaminants, estradiol and 17-α-ethinylestradiol showed high removal in short-term tests, whereas diclofenac, a compound biologically persistent in conventional processes, showed moderate removal up to 30%. More details of these tests can be found in the deliverable "D.B.2.1 Effect of flux-enhancer dosing in an MBR system on trace organic removal and toxicity" attached to this report in Annex 5.3.

Figure 14. LEVAPOR Biocarrier

The action B.2 was completed on time: it started before planned, in September 2015, in order to have representative data and was extended until 2017. The analytical campaign was divided into two: with and without flux enhancer addition.

- Participants of this task:
  - José Luis Santos (Fundación ProDTI): evaluation of traces organics micropollutants
  - Ana Valdehita (INIA): toxicity tests.
  - Teresa de la Torre, Ana Mª Clemente, Enrique Ferrero, Lidia Jiménez, Jorge Juan Malfeito, Adolfo Molina, Susana Navea, Carlos Rodríguez, Carmen Romero (Acciona Agua): processing the data obtained by the external laboratory.

- Outputs achieved: Samples sent to the external laboratory. Two analytical campaigns performed: without and after additive dosing. Evaluation of presence of micropollutant and toxicity. Deliverable "B.2.1 Effect of flux-enhancer dosing in an MBR system on trace organic removal and toxicity" concerning this task done and attached to this report in Annex 5.3.

- Finished on schedule:

	Proposed date	Actual date
Start	Apr. 2016	Sept. 2015
End	Apr. 2017	Apr. 2017

Table 7. Action B.2 timetable

5.1.3. Action B.3. Demonstration of expert control system

This action included the control system demonstration in the demonstration plant placed in Almuñécar (Granada, Spain) (144 m^3/d, 60 m^3) for water reclamation. The pilot plant was already built before the start of the LIFE Brainymem project (Figure 4).

This action lasted the whole period of the project and the demonstration plant has been working for more than one year. The demonstration of the novel system has been split into three parts: biological aeration control, air scouring control and flux enhancer dosage control.

Task B.3.1.1. Biological aeration control

The biological process control has been optimised during the whole period of study. In Table 8, the different biological control modifications and tested since the beginning of the project are shown.

Control	Description	Validation time
No control (Reference)	Air flow constant: (Blower frequency at 55%)	1 year
Control 1	NH_4-N influent & N_2O aerated tank changing blower frequency between 45-55%	2 months
Control 2	Same as control 1 including NH_4-N effluent feedback.	7 months
Control 3 (DO control)	DO control in aerated reactor. Constant set point. Different periods varing DO setpoint between 1-2 mg DO/L	4 months
Control 4 (BRAINYMEM)	Based on NH_4-N & N_2O measurements in aerated tank changing DO setpoint between 0-2 mg DO/L.	3 months

Table 8. Control strategies tested in Brainymem demonstration plant.

First, before the implementation of the control, a reference phase was performed with the aeration rate pre-set to a fixed value. As nitrifiers are known to be able to nitrify at lower dissolved oxygen concentration in many operational circumstances, the maximal energy saving potential was not achieved.

The first control (control 1) implemented used the variables N_2O concentration in the aerobic tanks and NH_4-N in the influent to modify the air supplied by the blower. However, it was observed that the biological aeration control system had a high impact on dissolved oxygen (DO) in aerobic tanks, which had immediately a negative effect on nitrification and consequently high NH_4 in the effluent was found. In order to find a solution for this situation, the biological control was modified to include the NH_4-N in the effluent as a parameter (Control 2). This way, if high NH_4-N concentration in the effluent was detected, the aeration would be increased and it would prevent a nitrification failure. The results are shown in Figure 15. During the control time, N_2O concentration was slightly increased; the reason for that could be that bacteria needed more time to adapt. These values are highly dependent on the operating conditions (SRT, aeration rate) and it was expected the N_2O concentration will be reduced with long time operation. Although the control showed good performance, still some NH_4-N peaks were detected in the effluent. To avoid peaks in the effluent, a new modification of the biological control was made.

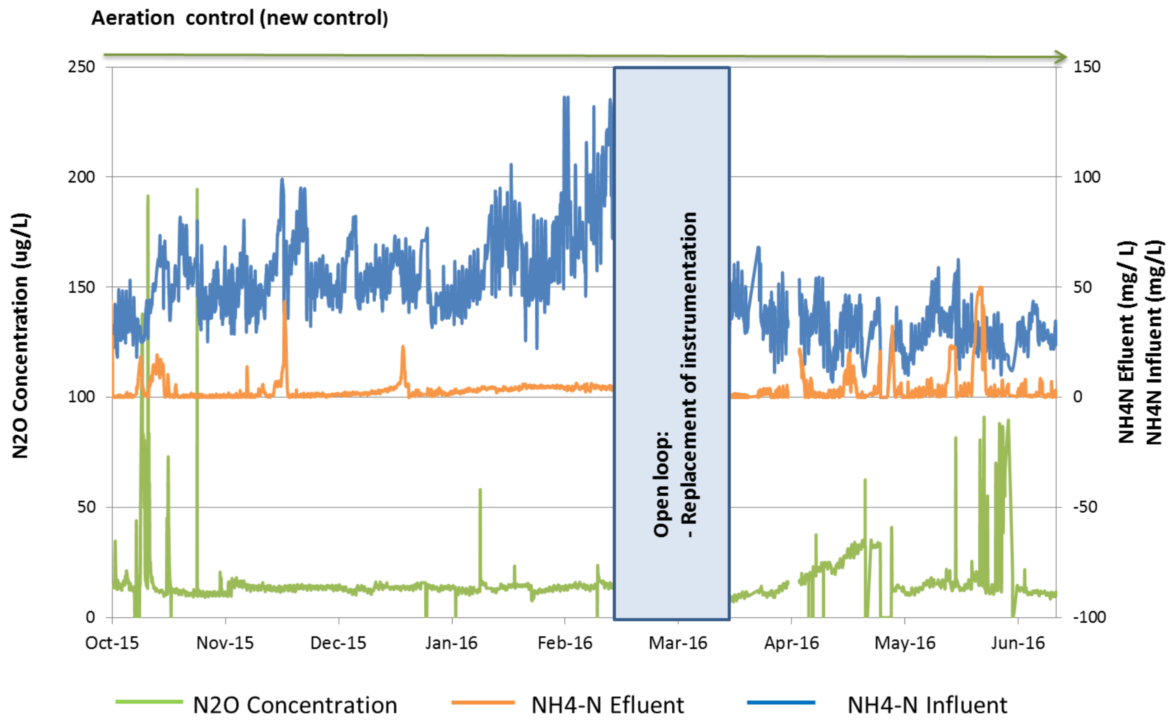

Figure 15. Performance of the biological control. Evolution of N2O concentration, NH4-N influent and NH4-N effluent concentrations during operating the biological control. NH4-N influent and NH4-N effluent is represented in secondary y-axis.

Additionally, the control implemented was compared with the most common control applied in wastewater treatment plant, which modifies the aeration flow to reach a constant dissolved oxygen set-point (control 3). Several set-points values were tested (1 mgl^{-1} and 1.5 mgl^{-1}).

In **¡Error! No se encuentra el origen de la referencia.**, it has been represented the measured concentration of the effluent ammonia, N_2O concentration and DO concentration in the aerobic reactor.

The results showed that the BRAINYMEM control was able to regulate the instantaneous N_2O production at the aerated reactor to a low value, avoiding the occasional N_2O high peaks produced with the previous control.

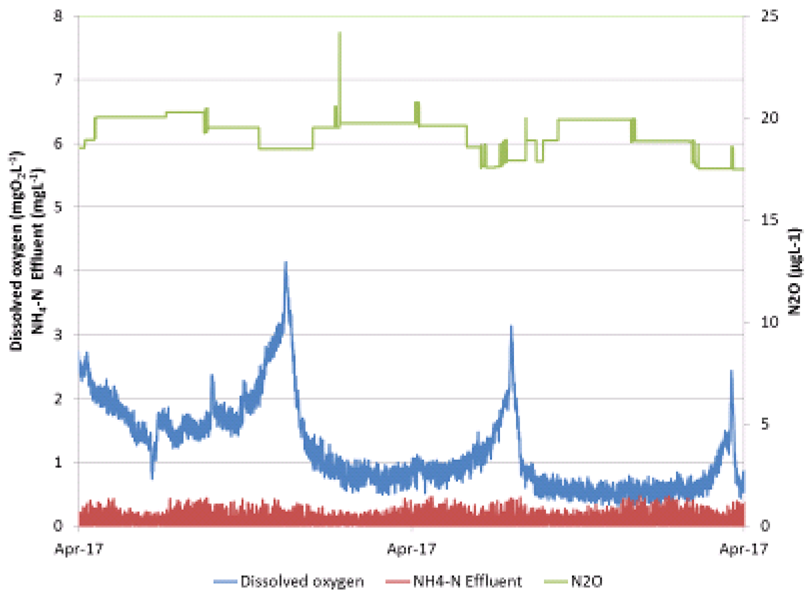

Figure 16. Performance of the optimized biological control (Control 4). Evolution of N2O and DO concentration in aerated tank and NH4-N effluent concentrations during operating the biological control.

Some of the modifications of the control was made by the Automation department of Acciona Agua, and it did not affect the demonstration of the control, since the operation was not stopped and it was considered as an optimization of the novel control. The operation of the plant was kept until the end of the project.

Task B.3.1.2. Air scouring control demonstration

The filtration process control involved the installation of the dosage pump for flux-enhancers (Figure 7) and a modification in the SCADA (supervisory control and data acquisition) system. The overall effect of the control logic implementation which varies aeration in the membrane reactor was investigated by comparing the results with the reference period (**¡Error! No se encuentra el origen de la referencia.**). To evaluate possible effects on the membrane performance, the TMP (Transmembrane pressure) evolution was observed and compared to earlier investigated periods where the pilot plant was operated with constant parameters (Figure 17). The variability of the wastewater and environmental conditions could have an effect on TMP. The changes in the aeration rate were represented as the % frequency of the blower. Filtration performance, expressed as TMP development over time, showed a high variability during filtration, due to the membrane operated at constant J instead of constant pressure. TMP increase over time as a result of membrane fouling. When the value reached 500 mbar a recovery cleaning is carried out. The control fixed the time between the recovery cleanings in four months, however, in some cases as summer periods, it was not found a TMP increase after five months operation which was presumably due to the good performance of BRAINYMEM control.

The differences between summer and winter periods could be caused by changes in the ambient conditions as temperature increases. The temperature could have a remarkable effect on the efficiency of MBRs. Low temperatures can impact on the formation of foulants by increasing carbohydrate concentration and affect the settleability and filterabitlity of the sludge. TMP were normalized to the reference temperature of 20ºC in order to take into account the influence of temperature on the process by applying the following equation:

$$TMP_{20} = TMP_T \cdot e^{\theta (T-20)}$$

Where TMP_{20} was the transmembrane pressure at 20ºC, while TMP_T was the previously parameters measured at the experimental temperature (T). The value for the temperature coefficient (θ) was calculated taking into account the water viscosity. TMP was represented normalized to the reference temperature with the changes in the aeration rate before and after the control operation (Figure 18). In this study, TMP normalization to 20ºC the values normalized to the temperature showed a similar trend to these shown in Figure 18. As a result, the conclusion obtained from these results were the same: the control system was very effective in fouling control.

	Period
Reference	July 2014 – May 2015
Filtration control	May 2015 – January 2017

Table 9. Timeline of filtration control in Brainymem demonstration plant.

At last, filtration performance (as permeability) was also evaluated during the period reference where the pilot plant was operated with constant membrane aeration and compared to the values with the control system (Figure 19). For the membrane used in this study and for the given flux of operation, the permeability values on average were practically constant: 50 LMH bar^{-1} when the pilot plant was operated at fixed aeration rate, whereas during the novel control operation permeability values were more variable, with values which ranged from 40 $L.bar^{-1}.m^{-3}.h^{-1}$ and 100 $L.bar^{-1}.m^{-3}.h^{-1}$. The lower values were caused by the modification of MBR air scouring, however, the system was able to manage the fouling in the time set (four months) and to achieve an energy reduction without compromising the nutrient removal.

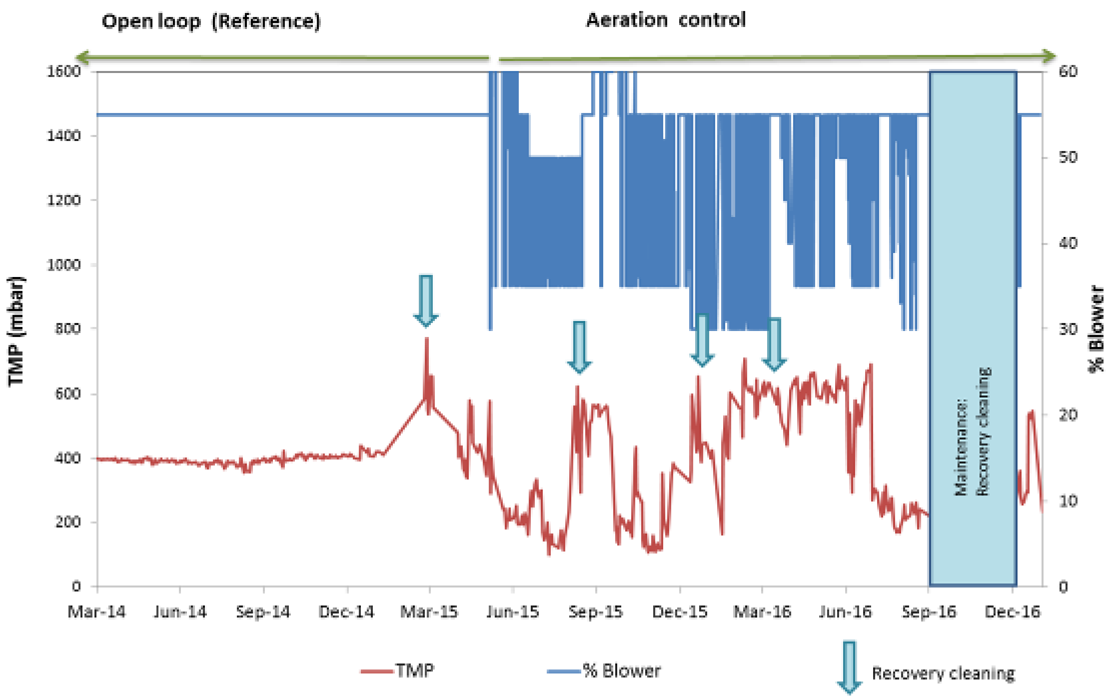

Figure 17. Evolution of the TMP (mbar) operating the BRAINYMEM membrane aeration control.

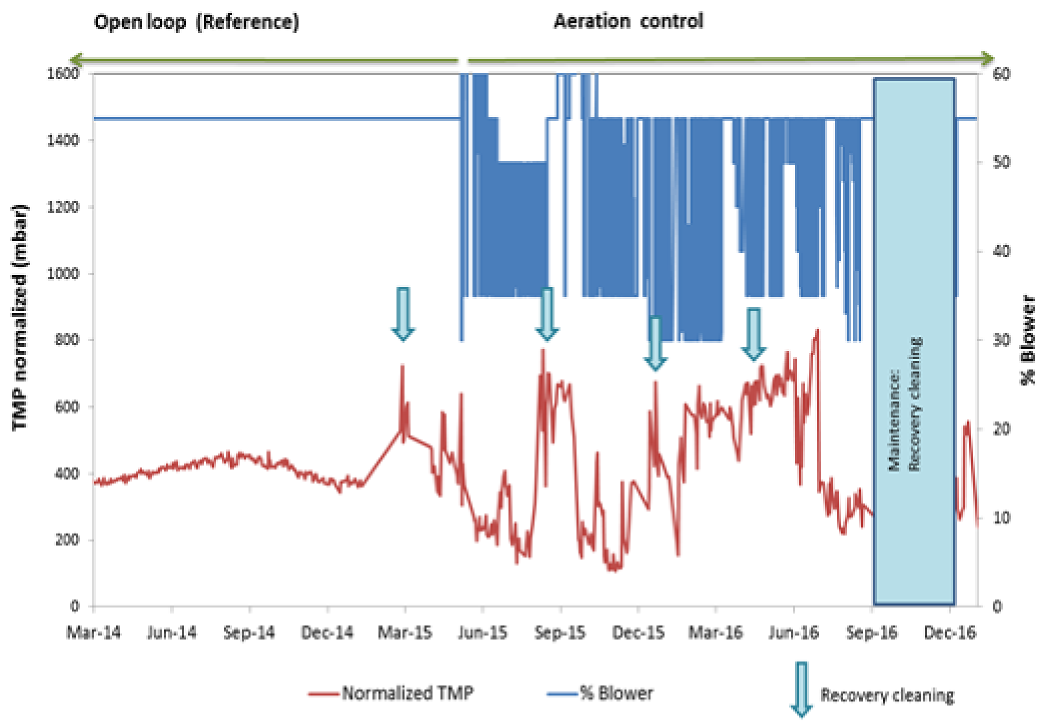

Figure 18. Evolution of the TMP normalized (bar m2 h)-1 and the % frequency of the blower in the reference period operating at fixed aeration rate and operating the novel control.

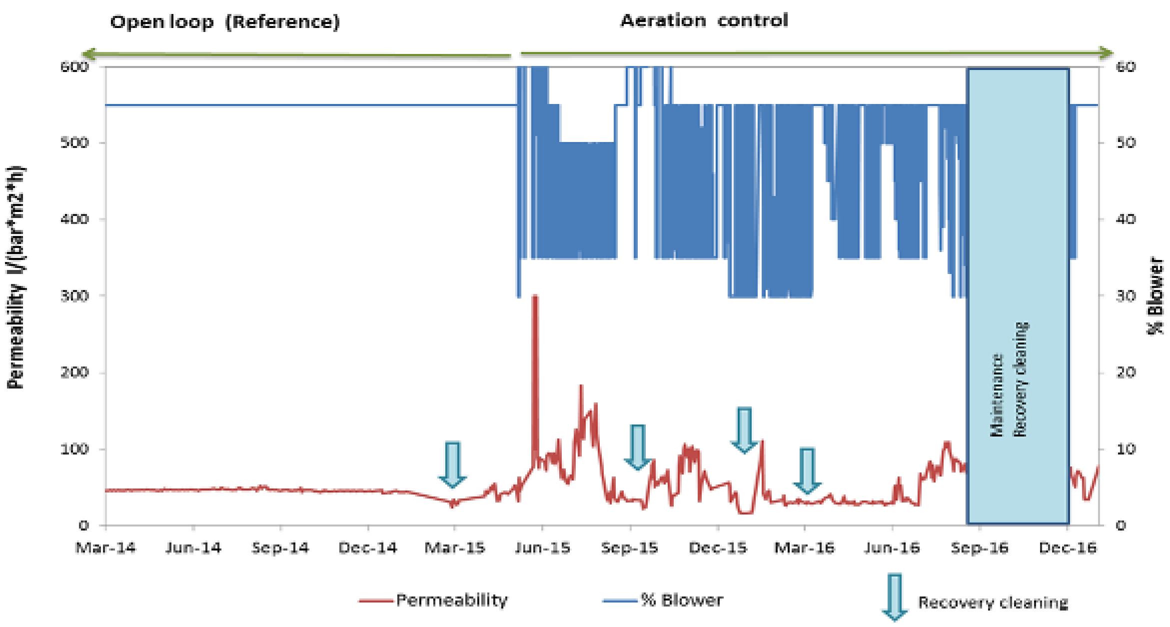

Figure 19. Evolution of the permeability l (bar m2 h)-1 and the % frequency of the blower in the reference period operating at fixed aeration rate and operating the novel control.

Regarding to effluent quality, when less DO is recycled to the anoxic zones, better maintenance of anoxic conditions is allowed and then better denitrification. A detailed characterization of the influent and effluent was carried out. The effluent quality has been evaluated in this project by comparing the biological nutrient, COD and TSS removal efficiencies prior and during the validation of the membrane and biological control (Table 10). The results presented were divided into two periods: when just the filtration control system was in operation and when both (aeration and filtration) controls were active in order to distinguish the influence of each control in nutrient removal. The results were compared with the reference phase.

EFFLUENT						
	TSS	**COD**	**NH_4-N**	**TN**	**TP**	**pH**
	mg/L	**mg O_2/L**	**mg/L**	**mg/L**	**mg/L**	**-**
Reference	1946	147	31	37	10	7.3
Brainymem membrane aeration control	1627	103	31	35	15	7.2
DO control (Control 3)	1473	133	32	35	8	7.3
Brainymem Biological aeration control	811	70	20	25	11	7.3
EFFLUENT						
	SS	**COD**	**NH_4-N**	**TN**	**TP**	**pH**
	mg/L	**mg O_2/L**	**mg/L**	**mg/L**	**mg/L**	**-**
Reference	0	19.7	0.22	7	4	7.2
Brainymem membrane aeration control	0	20.5	0.7	6	4	7.3
DO Control (Control 3)	0	21	0.15	9	4	7.3
Brainymem Biological aeration control	0	16	0.19	7	3	7.3

Table 10. Loading rates and characteristic of influent and effluent from MBR

During the operation of both controls, the removal efficiency values were similar to the removal efficiency during the reference. The parameters measured in the effluent showed that the average concentration of chemical oxygen demand (COD) and total nitrogen (TN) were similar to the reference period. Total suspended solids (TSS) were removed completely. The average NH_4^+-N concentration in the effluent is higher during the filtration control operation, possibly because there was a period of instability in this phase due to adjustment of the initial biological control. In fact, with operation with the optimized control, the average has decreased to 0.19 mgL^{-1}.

The most relevant conclusions were that the control which modify the aeration rate did not affect the characteristics of effluent due to fact that stable permeate quality was observed during the experimental period. The results showed that MBR pilot-plant could operate with the control ensuring good treatment performance for organic matter removal. The filtration control has been operative for 15 months, without any significant faults.

Task B.3.1.3. Demonstration of flux enhancers dosage

This action included a series of jar tests prior to the filtration performance experiments on the pilot-scale MBR plant in order to select the most effective chemicals with regard to the removal of fouling causing compounds and the improvement of the sludge filterability and the use of flux enhancer in emergencies mode.

Task B.3.1. 3.1 Jar Tests experiments for filterability improvement

In order to evaluate the effectiveness of the additives, the following parameters were determined in the flasks: modified fouling index (MFI), time to filter (TTF), transparent exopolymer particles (TEP), UV absorbance and COD.

According to the literature, it is generally assumed that the cationic polymer entraps fouling compounds into the sludge flocs, increases the size of the sludge flocs and leads to a more porous filtration cake, thus enhancing the filterability (Figure 20).

Figure 20. Comparison of the sludge flocculation before and after flux-enhancer addition with activated sludge from the demonstration plant.

Task B.3.1.3.2 FE dosing in emergencies

Once the air scouring control had demonstrated that was able to keep a good filtration performance and to control the fouling, it was started the flux enhancer dosage in emergencies. The flux enhancer dosage control in emergencies trials were divided in two phases: a calibration of the flux enhancer control system and a second phase with optimized control parameters.

- Phase 1: Calibration of flux enhancer control system.

The flux enhancer control system was designed to act when the aeration had reached a maximum value for a certain time, since with a stable operation the fouling rate could be controlled by the aeration. The daily permeability was registered to calibrate the flux enhancer control system parameters. The results can be seen in Figure 21. The dosage control became active in November 2015 and until March 2016, the concentration dosed was 300 mgL^{-1}.

However, the effectiveness of the flux-enhancer validated in several studies was not found in those trials, since flux enhancer did not retard the recovery cleaning and did not improve the permeability trend. After these results, the additive supplier was consulted and their recommendations were implemented in the plant. Firstly, it was decided to increase the dosage up to 350 mg L^{-1} and slow down the velocity of the dosing pump in order to improve mixing. At last, flux enhancer control became active after the recovery cleaning of the membrane to start dosing at preliminary stages of fouling.

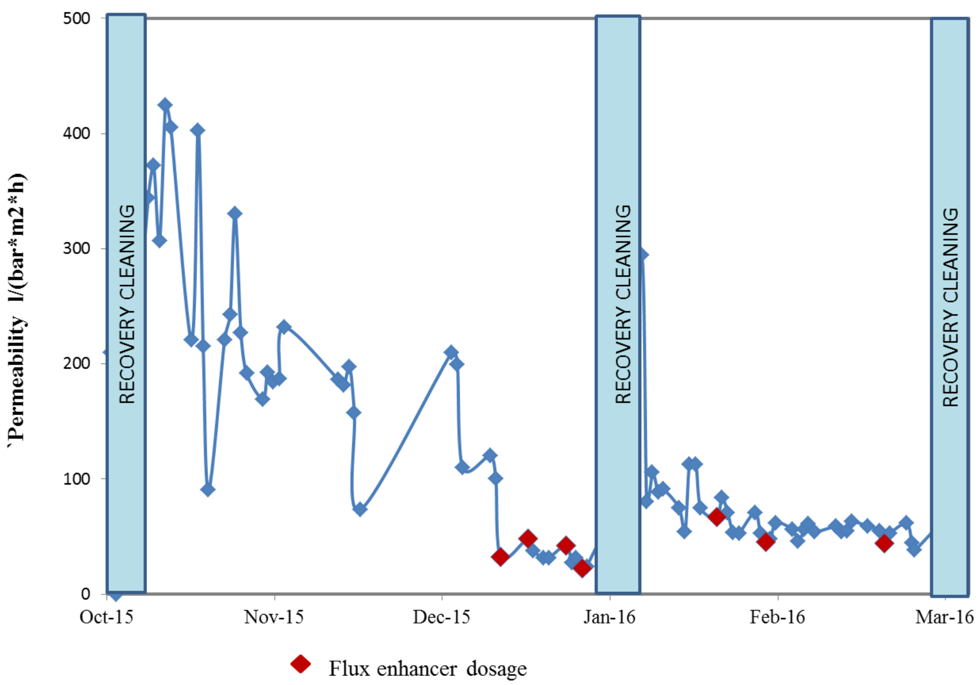

Figure 21. Evolution of the permeability l (bar m2 h)-1 with addition of flux enhancer in emergencies.

- Phase 2: Validation of the control parameters.

In the calibration phase, it was verified that the control was correctly acting and the parameters were modified to get the maximum efficiency of the product. In general, MPE50 increases the critical flux for an MBR and decreases the fouling rate, leading to a reduction of membrane cleaning frequency. Since in those trials the MBR operational parameters has not being modified in order to have the same conditions in all experiments, it was expected a permeability rise and longer operation time before the next recovery cleaning. In this respect, an increase of the permeability was not observed in comparison to the untreated reference after flux enhancer addition. In Figure 22, the permeability showed a slow decrease in the first days due to a failure in the electric power. The control activated the chemical addition, but it was not returned to the initial permeability and the values were maintained. After several weeks without a significant change in permeability values with flux enhancer addition, at the beginning of June, the permeability increased, allowing the plant to continue operating. However, it could not be determined the effect on permeability of the flux enhancer due to the increase was before the addition. Related to the time between recovery cleanings, the results showed that the cleaning interval has been extended up to five months (from march 2016 to

November 2016). But, as it was seen in the previous year without additive, the permeability and the operation time increased in summer period. So, based upon the obtained results, flux enhancer addition had not effect on filtration performance, since the permeability increase was produced before flux enhancer addition and it could be as a consequence of several factors such aeration rate or temperature increase. So, in these trials, the effectiveness of flux enhancer dosage in emergencies could not be demonstrated and this practice was disregarded for real implementation.

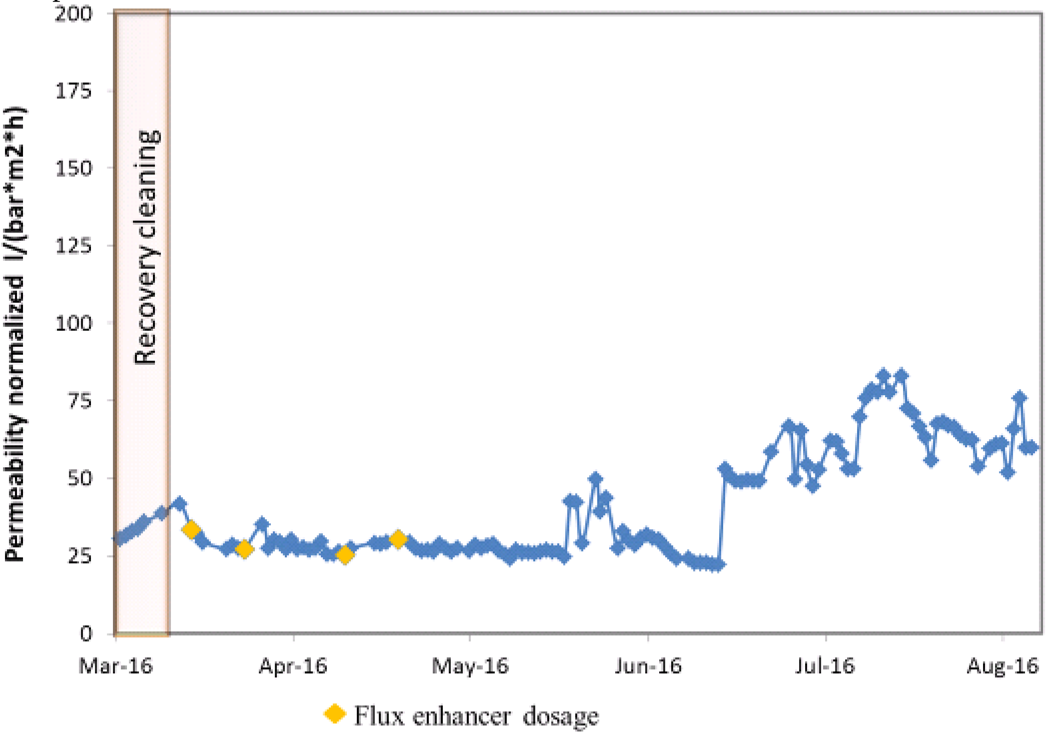

Figure 22. Permeability evolution with flux enhancer dosage (Validation phase).

<u>Task B.3.1.4. Results evaluation BRAINYMEM expert control system</u>

After operation and data gathering and processing, the results were analysed. One of the most important factor for evaluating the technology in terms of economic feasibility is the energy consumption. The evaluation of the MBR operation in previous studies indicated that MBR energy costs are one of the main drawbacks of this technology, mainly due to blowers, so the focus was on optimizing the aeration. In Figure 23 has been represented the energy consumption per m^3 of treated water by aeration (biological and membrane) in the reference phase and after the implementation of the novel control. The energy consumption by the biological aeration went from 0.55 to an average on 0.45 kWh/m^3 treated water which represented a 18% of the reduction (with values ranged from 0.55 kWh/m^3 to 0.40 kWh/m^3). On the other hand, modifications in air scouring have led to reduce the energy costs, since the membrane aeration consumption went from 0.21 to 0.13 kWh/m3 of treated water (Figure 23). The aeration energy consumption decreased by approximately 22% with the filtration control.

Although including sensors and control strategies adds complexity and capital costs to the system, with the implementation of the Brainymem control strategies, significant energy and GHG savings have been achieved, making the MBR technology a more economically and environmental friendly option for wastewater treatment and reuse.

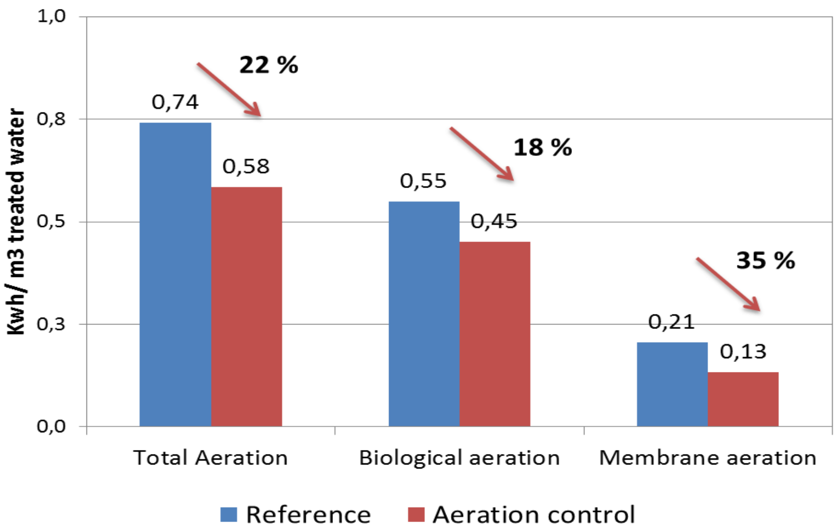

Figure 23. Energy consumption by biological and membrane aeration in reference period and after the implementation of the control.

The main conclusion of this action was that the process demonstrated the capability of producing the same product quality with less energy consumption. The filtration control achieved improvements on the permeability and reductions on the membrane aeration energy consumption (35%) without affecting sludge properties or the filtration performance, verifying the effectiveness of the control. The energy saving in the process increases the competitiveness of this technology. Related to biological control, several problems were initially encountered which were solved with a modification of the control logic.

The results showed the conventional control system for the period studied based on a dissolved oxygen set-point was able to achieved similar results as Brainymem system in terms of energy consumption, but this control produced more N_2O peaks and a mean higher N_2O concentration than the Brainymem control. which was only slightly lower for the last one. Flux enhancer dosage control did not show influence on membrane permeability values during fouling events. The improvement expected by the addition was not achieved and this practice was disregarded for the real implementation.

- Participants of this task (all from ACCIONA Agua):
  - Ana María Álvarez, Adolfo Molina, Teresa de la Torre, José Antonio López, Marina Arnaldos, María Auset, Lidia Jiménez, Ignasi Jordana, Jorge Juan Malfeito, María del Mar Mico, Jessica Ruiz, Enrique Ferrero, Susana Navea, Carme Repolles (Acciona Agua): Operation of the demonstration plant and Characterization of influent and effluent samples.

- The action finished following the initial Gantt Chart.

	Proposed date	**Actual date**
Start	Jul. 2014	Jul. 2014
End	Jun. 2017	Jun. 2017

Table 11. Action B.3 timetable

- Outputs achieved: Demonstration plant in operation for two years.

5.1.4. Action C.1. Monitoring the project impact on the environmental problem addressed

Task C.1.1. Analysis of the initial situation

In order to evaluate the impact of the project in the water use in the Region and the overall environmental impact, an assessment of the initial situation regarding wastewater reuse was performed. A deliverable attached in Annex 2 of the Inception Report ("C.1 Report on the initial situation"), and in the annex 5.1 of this report, has been compiled for this purpose, reflecting a review performed about wastewater reuse at regional, national (Spain) and EU-level. Additionally, it was analysed the MBR technology development in Spain and its potential to be employed in water reclamation.

The main conclusion of the deliverable was that wastewater reuse is highly needed in the Region of Andalusia but the practice is under expansion. MBR technology like the one demonstrated along this project would contribute to reduce water scarcity and would have a clear impact on the water resource services as well as to reduce the operational costs to make it more competitive.

Task C.1.2. Final report on environmental indicators

Once Actions B2 and B3 had concluded, the obtained data were processed and the initial situation was updated with the expected environmental impact of the project. A series of appropriate indicators was defined for the monitoring of the environmental impact of the project:

- Energetic costs of the plant per m^3 of treated water

The membrane bioreactor (MBR) has become widespread as an advanced treatment for municipal wastewater. However, the main drawback for its application is the relatively high energy consumption compared to a conventional treatment (CAS) (Table 12). However, it should be noted that although membranes and energy costs are higher than systems used in conventional treatment, total water costs can be competitive due to the lower footprint and installation costs. Moreover, there has been a steady downward trend in membrane prices, which is still continuing.

Treatment Option	Energy Use ($kWhm^{-3}$)
CAS	0.15
CAS – BAF*	0.25
CAS – MF/UF**	0.35 – 0.5
MBR	0.75 – 1.2***

* CAS – BAF: Conventional Treatment with Biological Aerated Filter
** CAS – MF/UF: Conventional Treatment with Microfiltration or Ultrafiltration membranes
*** Power consumption range from small to large-scale plants.
(Source: Hai et al 2013)

Table 12. Energy use of conventional treatment versus MBR treatment.

The advanced control system BRAINYMEM, developed to reduce the energy consumption and consequently the greenhouse gas emissions, has shown a decrease in energetic costs in relation to reference MBR system. In Table 13 can be found an analysis of the energy consumption of the MBR system with BRAINYMEM control. The BRAINYMEM control has shown to give a 3% reduction in overall energy usage compared to a reference MBR system including biological aeration. In the foreseen proposal 0,14 kWh per m3 treated water reduction was estimated due to the implementation of the air scouring control. After the operation of the plant, 0,08 kWh per m3 reduction was achieved, representing a 35% reduction compared to a reference MBR system. However, it should be noted that this energy reduction had taken place at pilot scale and there is a great potential that this energy reduction will be higher at a greater scale.

	Membrane Aeration		Biological Aeration		Total Energy	Reagents	Total
	(kWh/m3)	(€/m3)	(kWh/m3)	(€/m3)	(€/m3)	(€/m3)	(€/m3)
Reference MBR	0,20	0,021	0,55	0,057	0,132	0,0025	0,1345
MBR with BRAINYMEM Control	0,13	0,014	0,44	0,045	0,128	0,0032	0,1313

* Euros per kWh = 0,103 €/kWh

Table 13. Reference MBR vs BRAINYMEM CONTROL MBR

- Overall GHG emissions, separated as CO_2 and N_2O.

Furthermore, the results with the BRAINYMEM control were analyzed in terms of N_2O and CO_2 emissions. In Table 14 was presented the N_2O concentrations in the reference, with the BRAINYMEM control and with a control based on a dissolved oxygen setpoint. The concentration of N_2O with the application of the both control strategies increased. However, if we transform the concentration of N_2O into $TnCO_2$ equivalent, the associated contamination produced is low. The control working with a fixed set-point of 1.0mgL-1 was appropriate to reduce energy consumption (more information can be found in deliverable D.B.3.3), however the control does not capture information about the performance of biochemical reactions leading to occasional uncontrollably N2O production.The reduction estimated in the proposal was calculated based on N_2O emissions found in literature that could be potentially diminished. According to Kampschreur *et al*. (2009), emission data from full scale plants showed N_2O values ranging from 0 to 14.6% of the nitrogen load. With an average nitrogen load of 60 mgN/L (Henze, 2008), N_2O emissions could go up to 0.014 kgN2O/m3 treated water or the equivalent 4.130 kgCO2/m3. However, the concentration of N2O in the pilot plant was up to 1% of the nitrogen load. As a result, GHG reduction compared to our reference was lower than projected in the proposal.

When taking into account the reduction of $TnCO_2/m^3$ associated to the reduction in energy consumption, we can see that the environmental impact of the increased N_2O due to the application of the control can be disregarded. Taking this into account, Table 15 below gives a summary of the average TnCO2 eq. with and without the BRAINYMEM control. As the Table 15 shows, there is a 22.5% TnCO2 Equivalent saving through the introduction of the BRAINYMEM control system.

GHG Emission	Average N_2Oµg/L
GHG emissions w/out project	7,3
GHG emissions with project (Brainymem control)	13,3
GHG emissions with control based on DO setpoint	37,6

Table 14. N2O concentration in reference MBR vs BRAINYMEM CONTROL MBR

GHG Emission	Average TnCO_2 eq.
GHG emissions w/out project	21,0
GHG emissions with project (Brainymem control)	16,3
GHG emissions with control based on DO setpoint	17,3
GHG emissions savings	4,7

Table 15. GHG Emissions Comparison in Tn CO2 Equivalent

- Reactivity of micropollutants discharged in terms of toxicity and estrogenic activity.

Current WWTP are not specifically designed to eliminate micropollutants. Thus, many micropollutants are able to pass through wastewater treatment processes due to their persistency or/and the continuous introduction. In Spain the most abundant micropollutants detected in the influent is ibuprofen, with the concentration levels ranging from 3.73 to 603 ug/L (Santos et al., 2009).. In contrast, steroid hormones were found in wastewater at much lower levels (<100 ng/L). However, their occurrence even at low concentrations is a concern because of their high estrogenic effect. MBR processes and conventional activated sludge are effective in removing some compounds but in the case of pharmaceuticals, MBR has shown better results.

In order to remove the emerging micro pollutants to a higher degree, one additive was selected to be applied in the demonstration pilot plant. The results showed that the emerging micropollutants can be removed by up to 50% with the MBR technology. In the case of toxicity tests, the removal achieved for androgenic activity without additive was up to 100%, proving the effectiveness of the treatment. However, when evaluating the additives in the demonstration plant, the removal rates where similar or even lower than without the additives. For this reason, the application of theses additives was discarded. As an alternative, the application of Levapor as post-treatment was evaluated. These results and those corresponding to the additives can be found in the report B.2. Effect of flux-enhancer dosing in an MBR system on trace organic removal and toxicity.

- The main conclusion of the action was:
  - Wastewater reuse is highly needed in the Region of Andalusia but the practice is under expansion.
  - MBR technology like the one demonstrated along this project would contribute to reduce water scarcity and would have a clear impact on the water resource services.
  - The development of the technology would lead to reduce the operational costs to make it more competitive.

- Participants of this task:
  - ACCIONA Agua: Marina Arnaldos, Ana Álvarez, Teresa de la Torre
- Outputs achieved: Environmental impact of the project quantified.

- Finished task.

	Proposed date	Actual date
Start	Jul. 2014	Jul. 2014
End	Jun. 2017	Jun. 2017

Table 16. Action C.1 timetable

Action C.2. Monitoring the project impact on socio-economic problem addressed

Task C.2.1. Analysis of the initial situation (completed)

In this action, the socio-economic situation before the implementation of the project was analyzed for Spain and particularly for Andalusia. Some of the indicators selected for the assessment of the socio-economic impact of the project were the total volume of reused treated wastewater, the different uses for the reclaimed wastewater in Spain and in Andalusia and its impact on economic activities, or the potential job creation. Furthermore, the number of MBR plants operating nowadays and its evolution along the years was presented and all this was summarized in deliverable D.C.2.1., "Report of the initial situation", attached in Annex 5.1. Some values presented were a little bit outdated (values from 2006-2007) and they were mainly percentages, so the selected indicators have been improved and quantified with more updated figures.

When analyzing the situation in wastewater reuse in Spain, the data indicate that the volume of reclaimed water in Spain was about 530 Hm^3/year (2013), accounting for 10.6 % of the total treated wastewater volume, according to the National Statistics Institute. Table 17 summarizes the volume of wastewater treated in Spain and particularly in Andalusia and its uses by the different pathways in 2013. Although water reclamation has mainly agricultural use, it is expected it would shift to more advanced purposes (industrial, urban) in the near future. Focusing on the Region of Andalusia, where the BRAINYMEM project is located (Almuñécar, province of Granada) is regulated by the Mediterranean District Authority (D.H. Mediterráneo). The use of water for **agricultural purposes is by far the most frequent use** although the percentage for environmental or urban uses is increasing.

	Unit	Andalusia	Spain
Volume of wastewater treated	Hm^3/year	756.7	4998
Reclaimed water	Hm^3 (%)	62.9 (8.3)	531 (10.6)
Discharge to the sea/riverbed	Hm^3 (%)	675.7 (89.3)	4423.4 (88.5)
Infiltration	Hm^3 (%)	0.0	20 (0.4)
Others	Hm^3 (%)	18.2 (2.4)	25 (0.5)

Table 17. Volume of wastewater treated in Spain and Andalusia and its uses by the different pathways in 2013.

There is a considerable ecological benefit in having available water instead of using freshwater sources. Moreover, the availability of reclaimed water would improve the water scarcity problem in the area due to the imbalance between extraction and natural recharge.

Task C.2.2. Analysis of technology implementation

This task comprises the analysis of the cost and benefits of the technology in real plants. Considering the installed MBR technology and the reuse water price, a cost-benefit analysis was performed assuming that the expert system is implemented. More details can be found in the deliverable “D.C.2.1 Final report containing socioeconomic impact of the project” attached in Annex 5.3.

A cost-benefit analysis has been undertaken to estimate in monetary terms the changes in plant design and operation coming from the **novel advanced control system**. To this end, the net present value (NPV = Present Value of Benefits – Present Value of Costs) of upgrading the treatment plant with the new control system has been calculated. The NPV integrates the investment costs (fixed and variable operating costs) and the benefits (in terms of reduced energy consumption and, if deemed possible, improved water quality) of the novel advanced control system over the plant lifetime.

The benefits quantified are those associated with the reduced energy consumption and the reduction of CO_2 emissions linked to the novel advanced control system. The benefit associated with energy savings has been estimated using a price of energy of 0.1032 €/kWh. For the estimation of benefits associated to the CO_2 reduction, a social cost of carbon equal to 120€/Tm of CO_2 has been considered. It was analysed over a 15 years’ period. The analysis of costs-benefits for Brainymem project is negative since because the costs of installing the control system (fixed + variable) are much higher than the benefits obtained with the system in terms of energy savings and emissions avoided. However, this will change as we increase the size of the plant in which the system is installed. As the costs and benefits may be specific to each specific case, depending on factors such as the size of the treatment plant in which the system is incorporated, three full scale MBR installations with different sizes has been considered to study the benefits of implementing the BRAINYMEM project. Table 18 the net present value of the novel advanced control system when the energy consumption of real scale plants of different sizes are considered. It can be observed that the benefits increase in all cases. The net present value for the 15 years’ period come to be €130,643, €630,998, and €861,762 for a small, a medium and a large-scale plant, respectively. It can be observed that the advanced control system is now feasible when taking into account real scale application.

Plant size	NPV (€) - including benefits associated with CO2 emissions	
	15 years lifetime	**30 years lifetime**
Pilot plant (Almuñecar)	-44,891	-58,872
Small scale plant	77,185	130,989
Medium scale plant	577,540	909,173
Large scale plant	808,304	1,268,072

Table 18. Net present value (NPV): Cost-benefit analysis considering the size of the plant.

Task C.2.3. Data extrapolation: estimation of the socio-economic impact

The socio-economic impacts for BRAINYMEM include economic and environmental effects related to the installation of an MBR. As this technology has the potential to improve the water quality of the water effluent, it would have a significant positive impact on its use, potentially creating a more efficient and productive use of water. In the region, sectors that are benefiting from water reuse are the agricultural and recreational sector (gardening and golf areas). Moreover, due to more potential water availability, the area will attract more tourists and hence will allow for further employment opportunities. In agriculture, there will be possibilities for emerging job opportunities and an improvement on the irrigation systems. Since the system reduce the energy requirements there is a positive impact in energy costs.

Furthermore, MBR produces an effluent with high quality, its availability in the region could lead to an increase of agriculture productivity. Due to water reclamation, it can relieve water stress in the area and avoid overexploitation of aquifers. On the other hand, water availability has social benefits such as the development of more recreational and green areas, increasing the tourism in the area.

EFFECT S	IMPACT	SOCIOECONOMIC INDICATOR
OVERALL ECONOMIC IMPACT	+	WTTP operational costs Reductions in energy costs
WATER QUALITY IMPROVEMENT	+	Water Quality
ENERGY COST SAVINGS	++	Reductions in energy costs
EMPLOYMENT CREATION IN THE WTTP DUE TO THE MBR UNIT INSTALLATION	+	Employment rate in the WTTP
CREATING EMPLOYMENT	+	Increased employment rates in related sectors (agriculture, tourism)
RECREATIONAL AND GREEN AREAS	+	Increased access to green areas irrigated by the reused water, increase in number of parks available
IMPROVE COMMUNITY ACCESS	+	Access to water-related services
REDUCE ENVIRONMENTAL DEGRADATION	0	Increase of people's living standard
AGRICULTURAL PRODUCTIVITY	++	Increase in sustainable water supply for farmers, how many litres of water used per crop Creation of wealth by increasing the possibilities for agricultural production
++ Significant impact	--Significant negative impact	0 No relevant impact
+ Mid positive impact	- Mid negative impact	

Table 19. Socio-economic impact of BRAINYMEM implementation

The main conclusions of the action were that projects such as BRAINYMEM can:

- Improve water quality of the local water bodies as well as preserve the potable water resources and the local aquifers.

- Boost local and regional economies, since by increasing water availability, industrial and service sector activities will show an impact on the employment rate since industrial and service sector activities such as tourism development will be benefited.

- Participants of this task:

    - ACCIONA Agua: Marina Arnaldos, Ana Mª Jiménez, Ana Álvarez, Teresa de la Torre.
- Outputs achieved: Socioeconomic impact of the project quantified.
- Finished task.

	Proposed date	Actual date
Start	Jul. 2014	Jul. 2014
End	Jun. 2017	Jun. 2017

Table 20. Action C.2 timetable

5.2 Dissemination actions

5.2.1 Objectives

The main objective of the dissemination action, as specified in the proposal, was to transfer the acquired knowledge to stakeholders by means of specific dissemination activities and platforms as well as recommendations to policy makers. The key stakeholders were identified and involved in the development of the project. However, not only the stakeholders were the objective of the communication, as the goal was to reach the broadest target audience possible. Different dissemination strategies were designed depending on the type of audience.

5.2.2 Dissemination: overview per activity

In the framework of this action significant progress has been done. First, a specific communication plan was developed by month 3. The corresponding deliverable is attached in the Annex 5.2. as "D.D.4.1 Communication Plan (updated)". It contains and describes the main objectives of the dissemination activities, the key tailored messages to communicate to the identified stakeholders and the dissemination materials needed. A set of indicators to assess the effectiveness of this Communication Plan were included, with the aim of identifying corrective measures if dissemination objectives were not accomplished.

Secondly, considering a potential list of agents that would probably be interested on the project results, a database was created concerning all the contact details of the different organizations detected that could be interested in the project. The final database table, attached in Annex 4 as "Mailing List Brainymem" contains contact details of 203 water stakeholders representing the main actors in the water sector.

5.2.2.1. Action. D.1 Project Web site

The project website (www.life-brainymem.com) was launched on the 26th of December 2014 (Month 6). It is being updated in a (bi)monthly basis with news, publications, pictures and projects selected for networking. The language in which the website is written (both English and Spanish) is comprehensive for the general public. The website exceeded the number of 5000 visits (6,917), well above from the 2000 set as target in the initial proposal. 5,984 users were registered, from more than 10 countries. This data have been highlighted in aguasresiduales.info (http://www.aguasresiduales.info/revista/noticias/proyectos-de-reutilizacion-y-eficiencia-en-edar-life-ofrea-y-life-brainymem-objetivos-ie36o) as well as in the twitter and website of ACCIONA AGUA (http://www.acciona-agua.com/pressroom/in-depth/2016/june/life-ofrea-y-life-brainymem-mission-accomplished/).

Responsible: Teresa de la Torre (ACCIONA Agua).

- Participants of this task (from ACCIONA Agua): Elena Reyna, Gonzalo Zamacois

5.2.2.2. Action D.2. Notice Boards

Notice Boards are printed and installed since September-October 2015. One billboard was located in the demonstration plant facilities (Figure 24) and other two, in poster format, are shown at the ACCIONA Agua's R&D facilities in Barcelona and headquarters in Madrid. In September 2016, an additional notice board was located in the 'Mancomunidad Costa Tropical', a public busier place where it can generate more impact.

Figure 24. Detail of the billboard at the pilot plant

Figure 25. Detail of the billboard at the Mancomunidad de la Costa Tropical

Responsible: Teresa de la Torre (ACCIONA Agua).

5.2.2.3. Action Layman's report

A brief report of 8 pages summarizing the results of the project was elaborated. The language selected for this report was simple and the audience was the general public. The report was done in both English and Spanish. The electronic version can be downloaded in the website of the project. It has been attached both in paper (Annex 3) and digitally (Annex 5.3) to the Final Report.

Responsible: Teresa de la Torre (ACCIONA Agua).

- Participants of this task (from ACCIONA Agua):
  - Jorge Malfeito.
- Outputs achieved: Layman's report performed in two languages and published on the website. 5 copies were printed.
- Finished task

	Proposed date	Actual date
Start	April 2017	June 2017
End	April 2017	June 2017

Table 21. Action D.3 timetable

5.2.2.2. Action D.4. Public awareness and dissemination of results

In the framework of this action, several activities have been done. First, a specific communication plan was developed by December 2014. This deliverable has been updated and is attached in Annex 5.3. It contains and describes the main objectives of the dissemination activities, the key tailored messages to communicate to the identified stakeholders and the dissemination materials needed. A set of indicators to assess the effectiveness of this Communication Plan is included, with the aim of identifying corrective measures if dissemination objectives were not accomplished.

Three press notes have been released in this period, covered by national and international media.

Three technical publications have been published. The first one was published the 2015 January-February number of the Spanish technical magazine RETEMA. Secondly, The FuturEnviro technical magazine published a short article about the project in the 2015 September issue. The third publication summarizes the final results of the project in the magazine RETEMA of June 2017. All publications can be downloaded from the project website. Additionally to that, an internet article about the project was published at the website www.sostenibilidad.com.

In order to widen the audience, the LIFE BRAINYMEM project is explained in two videos: one video specific of the project (https://www.youtube.com/watch?v=H_Mgd3XTrzY), launched in June 2017, and a video recorded by ACCIONA in which the most significant R&D project on wastewater and reuse are described. This video was distributed internally through ACCIONA's newsletter, shared by corporative social media and it is accessible in YouTube (https://www.youtube.com/watch?v=2fpAvk_SfqM). Also, the same information was "translated" into an infographic chart, published in relevant media and accessible in interactive way through ACCIONA Agua website (http://www.acciona-agua.com/depuradora-es/index.html).

On the occasion of the World Water Day 2017, a special action for the LIFE projects coordinated by ACCIONA Agua was performed. An installation was built in Bilbao (Basque Country, Spain), people were interviewed about water usage, and a landing page was created that gave information about the LIFE projects.

Regarding participation in conferences and workshops, the first presentation of the project in a conference was done at the Jornadas AEAS in 2015 and the final results were presented at the Jornadas AEAS 2017. This is a biannual event of the Spanish Association for Water Supply and Sanitation that took place in Burgos (Spain) from the 28th to the 30th of April 2015 and from the 24th to the 26th of May 2017. The project was also presented in three water events taking place in Barcelona: in the final SANITAS Workshop in September 2015, in the Conference of the Amics del Aigua Association in March 2017 and in the Jornada BRM2017 in June 2017, where a poster was also presented. Two more posters were printed and presented at the CONAMA in November 2016 in Madrid and in the Jornada LIFE OFREA in September 2016.

Table 22. Oral presentation at the BRM2017.

Table 23. Poster presentation at CONAMA 2016.

Finally, two set of project brochures were published in February 2015 (200 copies) and May 2017 (200 copies). They can be downloaded from the website and hard copies can be found in ACCIONA R&D facilities and headquarters. Some copies have been distributed in the main events attended by project participants: IDA Conference 2015 (San Diego, CA, USA), OZWater 2015 Conference (Adelaide, Australia); CTM LIFE Networking event 2016 (Manresa, Spain); SIGA 2017 (Madrid, Spain); Workshop about "Innovative Water Saving Solutions" 2017 (Munich, Germany); Porto Water Week 2017 (Porto, Portugal). The brochures were also distributed at the demonstration plant visit during the 25 years LIFE Anniversary on the 18th of May 2017.

Internal dissemination was also tackled. The results of the project were presented in a technical meeting with Department of O&M of ACCIONA Agua Spain so that they know the technology and be able to apply it in their WWTP in operation and future plants.

A special workshop of the project was organized within the framework of the SIGA event, a Water Fair that took place in Madrid in March 2017. An oral presentation of the BRAINYMEM project showed the most relevant results obtained, followed by a networking session. The Workshop included the presentation of two LIFE projects coordinated by ACCIONA Agua, the BRAINYMEM project and the CELSIUS project.

Table 24. Picture at the BRAINYMEM Workshop at the SIGA fair in Madrid.

In 2017, the LIFE Programme celebrated its 25 years with numerous events from the different LIFE projects. BRAINYMEM joined the celebration with a special visit to the plant, were 20 high-school students visited the demonstration plant and attended a class about the LIFE Programme, wastewater treatment and the BRAINYMEM technology.

Table 25. Students visiting the plant during the 25-years of the LIFE Programme celebration.

The dissemination materials are annexed to this document in Annex 4, showing a collection of printed dissemination materials generated along the project.

- Outputs achieved: Communication plan done and updated. 8 conferences attended where the project was presented. Dissemination material: 400 brochures printed, 3 press notes, 3 articles in technical publications (2 in RETEMA and 1 in Futurenviro). 1 video dedicated to the project and another video presenting the project. 3 Posters and 2 articles in proceedings and 5 power points that were presented in some of the main water events.

5.3 Evaluation of Project Implementation

As the plant was already built and in operation, there was much work already done when the project started. For the implementation of the technologies developed along the project, only partial modifications were needed like the installation of new sensors and a dosing pump. Moreover, the project based on wide knowledge already gained in previous projects about the relationship between the aeration needs and the variables that influence the biological process. For this reason, the development of the control system started from a solid base. In the first expert control system, several points of improvement were identified and new versions of the control system were developed and evaluated until the final optimized version was found. Regarding the removal of micropollutants, the application of the technology which was planned initially did not show the desired results and therefore an alternative technology (LEVAPOR) was evaluated, which showed very interesting results. It can be concluded that the approach was correct and the project has obtained valuable results.

Objectives achieved in the project as compared to the initial proposal can be seen here:

Task	Foreseen in the revised proposal	Achieved	Evaluation
B1. Expert system development and implementation	Deliverable B.1.1, B1.2 and B1.3 Description of the control system	Yes	Logic of control developed and implemented. Demonstration plant adapted for the expert control system (sensors installed, SCADA modified etc.). The logic of control was optimized along the project based on the obtained results. One deliverable containing the three deliverables (B.1.1., B.1.2. and B.1.3.) done and updated periodically with the corresponding optimizations.
B2. Analytical campaign micropollutant removal	Deliverable B.2.1. describing the results of the concentration of micropollutants and toxicity	Yes	Analysis of composite samples from influent and effluent from the periods with and without flux-enhancer dosing. Analysis of samples from the jar tests. Analysis of samples from the LEVAPOR studies. Deliverable including all these results done.
B3. Demonstration of expert control system	Deliverable B.3.1, B.3.2. and B.3.3. will describe the operation of the plant along the project.	Yes	Operation of the plant in different phases: without control system, with conventional control system, and with different versions of the BRAINYMEM control system. Deliverable done.
C1. Monitoring the project impact on the environmental problem addressed	Deliverable C.1.1. Analysis of the initial situation and C.1.2. Final report containing the environmental cost-benefit analysis.	Yes	Initial situation analysed and indicators defined in Deliverable C.1.1. Environmental impact of the project evaluated in and summarized in D.C.1.2. and D.C.2.2. (joint deliverable)
C2. Assessing the socio-economic impact	Deliverable C.2.1. and C.2.2. Analysis of the initial situation and definition of indicators and final evaluation of impact.	Yes	Initial situation analysed and indicators defined (Deliverable C.2.1.). Socioeconomic impact of the project in the Region evaluated and described in D.C.2.3. Analysis of technology implementation performed and described in D.C.1.2. and D.C.2.2. (joint deliverable)
D1. Project website	Deliverable D.3.1. Project web site. Expected 2000 visits.	Yes	Project website working since December 2014 (Month 6). 6,917 visits to the website and 17,650 pages views and 5,948 users. Website updated periodically (every 1-2 months)

D2. Notice Boards	To be printed at the end of the project.	Yes	Notice Boards printed in September 2015 (before schedule) and located in 4 different locations around Spain (1 in Madrid, 1 in Barcelona and 2 in Granada).
D3. Layman's Report	D.3.1. Layman's report.	Yes	Deliverable D.4.1. Layman's report done and published on the website of the project.
D4. Public awareness and dissemination of results	D.4.1 Communication plan, D.4.2. Reports on the workshops/conferences attended, D.4.3. Dissemination material.	Yes	Communication plan done and updated. Nine conferences and events attended. 3 oral presentations about the project, 3 oral presentations including the project (1 slide) and 3 posters. Dissemination material: 400 brochures printed, 2 press releases, 2 articles in proceedings, 7 articles in magazines, 2 internet articles, 1 video of the project, 1 internet action during the world water day, numerous LinkedIn messages and Twitter mentions by influencers (Revista Retema: 9,275 followers; Acciona: 97,838 followers; Iagua: 58.000 followers; LIFE Program: 12,000 followers; Elena Reyna: 707 followers).
E1. Project management monitoring	Periodic technical meetings, both internal and with the Advisory Board.	Yes	Weekly technical meetings to follow-up the project results. 1 meeting with Prof. Anja Drews (HTW Berlin), 2 meetings with Prof. Ingmar Nopens (UGent) and 1 meeting with Amador Rancaño, Responsible of Area of O&M of WWTP of Acciona Agua. 3 meetings with the Department of Automation and Control of Acciona Agua.
E2. Networking with other projects	Deliverable E.2.1. Report on networking with other projects.	Yes	Database with 203 contacts completed. Several events attended with networking sessions. LIFE Projects contacted per email or at events: 7. Deliverable E.2. Report on networking with other projects performed.
E3. After-LIFE communication plan	Deliverable E.3.1.After-LIFE communication plan.	Yes	Deliverable E.3. After-LIFE communication plan performed and published on the website.

As already mentioned in the dissemination chapter, the results of the dissemination have been highly satisfactory. The technology developed in the project is directly applicable to any WWTP and giving the energy reduction showed in the results, the interest that raised among the water stakeholders was high. Many contacts were done during the several networking opportunities that took place in the conferences and other networking events.

5.4 Analysis of long-term benefits

1. Environmental benefits

a. Direct / quantitative environmental benefits:

The main direct environmental benefit associated to the implementation of the project in WWTP is the energy savings, reduction of the carbon footprint and its associated GHG emissions. As concluded from previous chapters, a global aeration energy reduction of 22% is achieved with the implementation of the expert control system developed in the BRAINYMEM project.

b. Relevance for environmentally significant issues or policy areas (e.g. industries/sectors with significant environmental impact, consistency with 6th or 7th (as applicable) EU Environment Action Programme and/or important environmental principles, relevance to the EU legislative framework (directives, policy development, etc.)

Indirect environmental benefits could be the information gathered in this project about N2O concentration in the liquid phase of the bioreactor. When the project started, it was the first time that N2O was monitored in the liquid of activated sludge. Previously, N2O could only be measured in the gas phase as no sensors were available for measuring N2O in the liquid phase. For this reason, the N2O data gathered in this project represent a valuable database for N2O concentrations that can help evaluation of N2O impact and production of N2O in WWTP, and can be used as support database when evaluating future potential policies on N2O emissions.

Moreover, the results of micropollutant removal shown by the LEVAPOR biocarrier are promising and it can be considered a valuable tool for reducing toxicity of the WWTP effluents. Efficient technologies like this are necessary to avoid the impact that these contaminants may induce in the aquatic media.

2. Long-term benefits and sustainability

a. Long-term / qualitative environmental benefits
    i. LIFE+ Environment Policy and Governance: e.g. long term sustainable technology, from product to functional focus, from end-of-pipe to prevention; high visibility for environmental problems and/or solutions; spin-off effect in other environmental areas etc.

b. Long-term / qualitative economic benefits (e.g. long-term cost savings and/or business opportunities with new technology etc., regional development, cost reductions or revenues in other sectors)

c. Long-term / qualitative social benefits (e.g. positive effects on employment, health, ethnic integration, equality and other socio-economic impact etc.)

d. Continuation of the project actions by the beneficiary or by other stakeholders.

In terms of long-term environmental benefits, reduction in GHG emissions associated to the 22% reduction of energy used in the aeration of the biodegradation of contaminants in the treatment of wastewater is a great goal achieved from the environmental point of view, which will last along the years and can be applied to any WWTP. In the case of the membrane aeration a greater reduction in energy and correspondingly GHG emissions was achieved, however this will be benefitial only for the plants operating with MBR technology. On the other side, the fact that the BRAINYMEM technology will reduce significantly the operation costs of the MBR plants will make this technology more competitive and will boost the implementation of this technology worldwide. This is also benefitial for the environment because the MBR technology produces a much cleaner effluent, free from pathogens and solids, which can be directly reused. This will therefore increase the availability of water and reduce water scarcity, contributing to the application of the principles of the circular economy in the industry.

Moreover, the application of the LEVAPOR technology for the reduction of emerging micropollutants represents a promising advance in combating this pollution of increasing concern. The results obtained in this project presented 90% removal rates for these compounds, and if this technology is applied in the future and existing WWTPs, the impact on the aquatic environment in the long-term will be remarkable, as it has been demonstrated that concentrations of even ng/L have an impact in terms of endocrine disruption in the aquatic fauna.

From the positive data of the future water reuse and MBR technology market data evaluated in action C2, it can be concluded that the BRAINYMEM MBR control has a promising induced and indirect socioeconomic impact at different levels. For instance it can improve governance schemes on water reuse and increase the related level of public awaraness. Moreover, with the implementation of the BRAINYMEM technology, the MBR systems will be improved in both operating costs and effluent quality. This will have a direct influence in the widespread implementation of these kind of systems for wastewater reclamation and will improve reclaimed wastewater in both quality and price. The introduction of the BRAINYMEM control of MBR systems at full scale would have numerous postive socioeconomic impacts according to the water expert from the Almuñecar city council which was interviewed during the project. From water security, job creation, improved urban asethetics, research, water security to increased farm yeilds are all seen as postive socioecnomic benefits of introducing this technology at full scale.

Potential positive benefits of the BRAINYMEM project were evaluated in action C2, and they are reflected in the following table:

POSITIVE POTENTIAL IMPACTS OF THE BRAINYMEM PROJECT

- ✓ Increasing the quality and availability of freshwater resources, allowing communities a security of supply gaining a sustainable water resource.
- ✓ Boosting the local and regional economies, allowing demographic growth, also industrial and public service sector activities and fostering other activities such as tourism development. Improving the Urban aesthetics through the creation of an artificial lake with treated wastewater (desirable).
- ✓ Freshwater at a lower cost and at a lower environmental impact, in comparison with other available technologies
- ✓ An improved water quality of the local water bodies.
- ✓ Educating and making citizens aware of water reuse, derived from the dissemination of BRAINYMEM results, which will raise awareness about water reuse.
- ✓ Creating opportunities for further research and for advancing knowledge of water reuse in the region.

3. Replicability, demonstration, transferability, cooperation:

The replicability of the project is clear in the case of the BRAINYMEM project, and it has started already. The first full-scale plant that will be constructed with the BRAINYMEM technology is the Kobaron plant, which is a small MBR plant that will be constructed in Basque Country (Spain). Construction and operation and maintenance of the plant will be done by ACCIONA Agua. From the cost-benefit analysis performed in Actions C, for medium-size plants, the results of the cost-benefit analysis came out with benefits of more than 600,000 € in 15 years that could be achieved when implementing the BRAINYMEM technology. In the present scenario, where the energy costs are increasing rapidly, any reduction of the energy consumption (22% with the BRAINYMEM technology) is highly attractive for any operator, and new plants with the BRAINYMEM technology are expected soon. Application of the BRAINYMEM technology is however not restricted to new plants, but it can also be used to retrofit an existing plant, starting from the plants that ACCIONA Agua nowadays.

The technology can also be transferred from the municipal wastewater sector to other sectors where other types of wastewater must be treated. Food and beverage industry, canning industry or Aquiculture are examples of industries producing biodegradable wastewaters that can be treated with the BRAINYMEM technology.

4. Best Practice lessons: briefly describe the best practice measures used and if any changes in the followed strategy could lead to possible adjustment of the best practices

The best practice measures used are part of the actives of our organization. In Acciona Agua several of the procedures that have been applied in the operation of the pilot plant are standardized. There exist templates for the checklists for the operation of the plant, for the bulletin of analytics, for the elaboration of reports, and everything is located in the server of the department. All these tools help minimizing the mistakes in the follow-up of the operation, the interpretation of results, the team work and avoid repetition of work. The transfer of technology within the organization is as well standardized and this promotes that all valuable results obtained in the projects are transferred to the corresponding departments in Acciona Agua, where they will be applied in real plants.

As lessons learned, it is worthly mention that the use of flux-enhancers is not recommended to be used in real plants to control permeability and/or remove micropollutants. Best practice learned as a result of this project for the control of permeability is the use of the BRAINYMEM control system. For the elimination of micropollutants, the best practice would be to use a post-treatment like the use of activated carbon or the use of LEVAPOR.

5. Innovation and demonstration value:

A demonstration plant (5 m3/h) was operated for almost 3 years along this project. The demonstration value is in this sense clear, as the dimensions of the plant are representative to those of a full-scale plant, and the long-term operation without significant failures assures that the technology can cope with any event that can occur in a real plant.

The innovation value refers to the use of a novel sensor, the N2O liquid sensor from Aquisense which, as previously mentioned is the first sensor in the market capable of measuring N2O in activated sludge. Moreover, the use of this parameter (N2O in the activated sludge) in an aeration strategy is also novel and a patent related to this innovation has been registered by Acciona Agua within this project. As the aeration energy is a critical point in the O&M costs of a WWTP, the development of new control strategies that may reduce its energy consumption is an active field of research nowadays.

Besides, the use of the LEVAPOR biocarriers for the elimination of micropollutants, a topic of increasing concern, is a valuable innovation performed in this project. The first drafts for the proposal of establishing minimal requirements for water reuse at European level already contained limits for emerging micropollutant concentration in reclaimed water. In this scenario, new technologies that can deal with these contaminants are necessary at an affordable cost for the operator.

6. Long term indicators of the project success

The number of plants where the BRAINYMEM technology is implemented is the best indicator of success of the project, along with the energy consumption reduction achieved along the years. Energy consumption (as kWh per m3 of water treated) is an easy parameter to estimate CO2 footprint of the plant and evaluate economically benefits of the technology, However, more indicators are necessary to understand the success of the project. In the evaluation of the environmental and socioeconomic impact (Actions C1 and C2), a cost-benefit analysis taking into account the purchasing of the new sensors was performed in these actions, which concluded that the net present value was positive for a middle-size plant, but for a small plant (similar size than the demonstration plant), and taking into account the whole life-cycle of the plant, it was not worthwhile to implement the BRAINYMEM technology. This means that the energy consumption reduction as a unique indicator for project success is not a reliable indicator of project success, as the whole life-cycle of the plant must be assessed, and CAPEX cost due to the sensors must be taken into account.

6. Comments on the financial report

6.1 - Costs incurred

As showed in the table below, the total budget spent by ACCIONA in the project BRAINYMEM from the start date to 30th June 2017 is 482.714€.

PROJECT COSTS INCURRED			
Cost category	Budget according to the grant agreement*	Costs incurred within the project duration	%**
1. Personnel	278.434	283.080	102%
2. Travel	23.929	11.612	49%
3. External assistance	107.588	78.114	73%
4. Durables: total non-depreciated cost	0,00	0	-
- *Infrastructure sub-tot.*	0,00	0	-
- *Equipment sub-tot.*	0,00	0	-
- *Prototypes sub-tot.*	0,00	0	-
5. Consumables	54.690	65.554	120%
6. Other costs	8.600	12.774	149%
7. Overheads	33.127	31.579	95%
TOTAL COST	**506.368**	**482.714**	**95%**

*) This is the budget approved by the EC in the original Grant Agreement
**) Percentage expressed as the ratio between each budget line and the actual total cost incurred within the project

Action number and name	Foreseen Total costs (excluding overheads)	Spent so far (total costs excluding overheads)	Remaining / Exceed (-)
Action B1- Expert system development and implementation.	71.992	42.340	29.652
Action B2- Analytical campaign micropollutant removal.	51.631	46.751	4.880
Action B3- Demonstration of expert control system	251.427	256.748	-5.321
Action C1- Monitoring the project impact on the environmental problem addressed	5.633	9.601	-3.968
Action C2- Assessing the socio-economic impact	5.633	17.033	-11.400
Action D1- Project Web site	10.680	16.593	-5.913
Action D2- Notice boards	500	579	-79
Action D3- Layman's report	3.852	0	3.852
Action D4- public awareness and dissemination of results	32.460	23.616	8.844
Action E1- Project management, operation and monitoring	37.966	34.790	3.176
Action E2- Networking with other projects	1.467	3.084	-1.617
Action E3- After-life communication plan	0	0	0
TOTAL	473.241	451.135	22.106

Table 26. Budget discrepancies by Action without overheads.

7. Annexes

The following table summarizes the documentation presented in this report both in paper and in digital format (CD), which has been sent both to the Commission and to the external monitoring team. Please, note that due to requested material in each format, annexes in CD and Paper format are not corresponding by numerical classification, instead two different lists of annexes are presented.

Paper
▪ Final Report Annexes: ▪ Annex 1. Financial report ACCIONA Agua SAU: o Financial report o Financial statement of individual beneficiary o Consolidated cost statement (Common) o Standard Payment request ▪ Annex 2. After LIFE communication plan (Deliverable D.E.3). ▪ Annex 3. Layman Report (Deliverable D.D.4) ▪ Annex 4. Dissemination material
CD

- Final Report
- Annexes:
  - Annex 1. Financial report ACCIONA Agua SAU (PDF and Excel):
    - Financial report
    - Financial statement of individual beneficiary
    - Consolidated cost statement (Common)
    - Standard Payment request
  - Annex 2. Final outcomes indicators
  - Annex 3. Commission Letter on Midterm Report Answered and Support material.
  - Annex 4. Pictures and dissemination material generated along the project
  - Annex 5. Deliverables
    - Annex 5.1 Inception Report deliverables:
      - D.B.1.1, D.B.1.2 & D.B.1.3 Logic of control system as implemented. UPDATED
      - D.C.1.1 Report of the initial situation
      - D.C.2.1 Report of the initial situation.
      - D.D.1.1 Project Web site
      - D.D.4.1 Communication Plan
      - D.E.1.1 Project Management Handbook
      - Inception Report
    - Annex 5.2 Mid-Term Report Deliverables:
      - D.B.3.1 First year experience with the demonstration plant
      - D.C.2.1 Report on initial situation UPDATED
      - D.D.4.1 Communication plan UPDATED
      - Mid-Term Report
    - Annex 5.3 Final Report Deliverables:
      - D.B.1.1. D.B.1.2. and D.B.1.3.Logic of control system UPDATED
      - D.B.2.1 Effect of flux-enhancer dosing in an MBR system on trace organic removal and toxicity
      - D.B.3.3 Third year experience with the demonstration plant
      - D.C.2.1 Report on initial situation UPDATED
      - D.C.2.2 Analysis of technology implementation.
      - D.C.1.2, D.C.2.2 & D.D.4.6. Env. CB analysis and analysis of technology implementation
      - D.C.2.3 Final report containing the socioeconomic impact of the project
      - D.D.2.1 Design of the notice boards
      - D.D.3.1 Layman's report
      - D.D.4.1. Communication plan UPDATED
      - D.D.4.2 Reports of the workshops/conferences attended.
      - D.D.4.3 Dissemination material: leaflets and brochures, press campaigns
      - D.E.2.1 Report on networking with other projects

- D.E.3.1 After-LIFE Communication Plan