LIFE17 ENV/ES/000331

Final Report

Covering the project activities from 01/09/2018 to 30/06/2023

Reporting Date

28/12/2023

LIFE MULTI-AD 4 AgroSMEs:

High performance multiphase anaerobic reactor for agroindustrial wastewater treatment

Data Project

Project location:	AGE Winery, Fuenmayor - La Rioja (Spain)
Project start date:	01/09/2018
Project end date:	28/02/2022 **Extension date:** 30/06/2023
Total budget:	2,177,143 €
EU contribution:	1,301,386 €
(%) of eligible costs:	60%

Data Beneficiary

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2. List of key-words and abbreviations

AD	Anaerobic Digestion
AEMA	Agua, Energía y Medioambiente servicios integrales, S.L.U.
ADM1	Anaerobic Digestion Model No.1
ATEX	ATmosphères Explosives
AS	Activated Sludge
CAPEX	Capital expenditure
CCCFPS	Croatian Competitiveness Cluster for Food Processing Sector
CFD	Computational Fluid Dynamics
CINEA	European Climate, Infrastructure and Environment Executive Agency
COD	Chemical Organic Demand
CSTR	Continuous Stirred Tank Reactor
D	Deliverable
DDIM	Data Driven Improved Model
DG	Directorate-General
DOE	Design of Experiments
EASME	Executive Agency for Small and Medium Enterprises
EC	European Commission
EEA	European Economic Area
EGA	Energygreen Gas Almazan S.L.
EU	European Union
F&D	Food and Drink
FDM	Food, Drink and Milk
GHG	Green House Gases
GPG	Green Procurement Guideline
GRP	Glass Reinforced Plastic
HPA	High-performance data analysis
HRT	Hydraulic Retention Time
I&S	Institutions et Stratégies
I/O	Inputs/Outputs
IPPC	Integrated Pollution Prevention and Control
ITAINNOVA	Instituto Tecnológico de Aragón
KPI	Key performance indicator
M	Milestone
MBR	Membrane Bioreactor
MTR	Mid-Term Report

MULTI-AD	High performance multiphase anaerobic reactor for agroindustrial wastewater treatment
N	Nitrogen
NGO	Non-governmental organisation
OLR	Organic Loading Rate
OPEX	Operational expenditures
P	Phosphate
P&ID	Process and Instrumentation Diagram
PLC	Programmable Logic Controller
RDM	Robust Design Methodology
ROM	Reduced Order Model
SIS	Societatea de Inginerie Sisteme SIS S.A.
SC	Steering Committee
SCADA	Supervisory Control And Data Acquisition
SMEs	Small and Medium Enterprises
TC	Technical Committee
TRL	Technology Readiness Levels
VFA	Volatile Fatty Acids
WFD	Water Frame Directive
WWTP	Wastewater Treatment Plant

3. Executive Summary

LIFE Multi-AD 4 AgroSMEs (hereon LIFE Multi-AD) aims to design and industrialise a high performance multiphase anaerobic reactor that generates methane-rich biogas, tailor-made for treating wastewater generated in Food and Drink (F&D) Small and Medium Enterprises (SMEs).

This main objective is divided into the following specific objectives:

1. The scale-up of the eco-innovative anaerobic reactor (patent ES-2541078-B1) from our current prototype of 100 L (0.1 m^3) to 25-500 m^3.
2. Optimisation and automatisation of the control system, to maximise the stability of the anaerobic process, and make it robust towards changes in the wastewater composition or operational conditions.
3. Construction of a 100 m^3 Multi-AD demo device and validation in a Spanish winery.
4. Development of the "Anaerobic Reactor Design Tool", software to be used for dimensioning future Multi-AD devices. It will allow designing Multi-ADs for a wide range of F&D sub-sectors.
5. Population of the software's data-base with data form the usage of our 100 L Multi-AD prototype in the Wastewater Treatment Plant "Depurados Azud A.I.E.".

The activities planned to the progress made during this period are summarised as follows:

B1. Fluid dynamic analysis: The aim of this action was to fix the main dimensions of the industrial scale Multi-AD reactor. The results obtained during this action produced inputs which were necessary for the forthcoming actions. Starting date: September, 2018; State: Completed.

As shown in deliverable **D1** "Description of the CFD model and its validation", multiphase CFD model used to replicate the performance of Multi-AD reactor was done, as well as its validation with experimental data obtained from the pilot-scale reactor (100 L). The results of the numerical analysis were used later to define Multi-AD reactor key design parameters and the conditions for its scaling-up. In deliverable **D2** "Description of the CFD model and scaling-up criteria was presented the design criteria established by Robust Design Methodology (RDM), the CFD simulation performed to evaluate the influence of different parameter on the behaviour of Multi-AD reactor and the proposed scale-up criteria to move from pilot to industrial scale. The need to keep the investment costs of Multi-AD industrial devices into reasonable levels lead to loss of geometrical similarity and the avoidance of biogas recirculation. These facts resulted in more simulations than expected therefore a time prolongation of this action was required. Various CFD models based on the initial one but with the capacity of reducing the computational time were developed to accelerate this redesign process. Milestone **M1** "Validation of the CFD model using data from the existing 100 L prototype" and **M2** "Proposal for designing a new 100 m^3 digester" were achieved.

B2. Control system development: The aim of this action was to design and develop an advanced control system that optimises Multi-AD's operation by adjusting the controllable output's variables. Starting date: May, 2019; State: Completed.

The design specifications were carried out for the control system development of LIFE Multi-AD technological solution. Deliverables **D3** "Control system specification" defined in detail the operating conditions, management of changes in the design of the control system at both conceptual and implementation level and provides technical specifications for all devices and control strategy. The control system automatically adjusted the controllable output variables (temperature, pH, flow) by using logic rules (if X then Y). The control logic was developed using a "cause-effect" approach by means of TIA Portal V16 software. Deliverable **D4** "PLC control logic and control cabinet" defined the control logic governing the plant operation, as well as provide clarifications of assumptions and strategy used in the logic. Simulation and testing procedures were carried out using the extensions PLCSim, to ensure the correct functioning of the control logic. The results were shown in Deliverable **D5** "Control system testing results". Finally, it developed the architecture to carry out the monitoring and control actions of Multi-AD technology in order to achieve an unattended and fully automated operation. Equipment and instrumentation of the demo unit were connected to the power and automation-control panel. The control

panel, which integrates the PLC and HMI, was connected to both the power panel and the remote-control centre. Detailed information on HMI can be found in the Operation Manual, annexed to Deliverable D8 "Operating manual for process control system". Milestone **M3** "Functional SCADA system for Multi-AD industrial units" was achieved.

B3. Design and construction of the 100 m^3 Multi-AD demo unit: The objective of this action was to design and build the first industrial-scale Multi-AD device, with 100 m^3 of capacity. Starting date: July, 2019; State: Completed.

The construction of the first industrial-scale Multi-AD reactor at AGE Winery was finished. The plant was built according to the design validated in Action B1, the specific requirement of AGE Winery WWTP, as well as the health and safety criteria procedure created *ad-hoc* for this project. Multi-AD reactor design allowed to reach a maximum daily treatment capacity of 2,000 kg COD and 200 m^3 of wastewater. Deliverable **D6** "Drawings and components of the 100 m^3 Multi-AD demo unit" and **D7** "Report on the construction of the 100 m^3 Multi-AD demo unit" show detailed information on the design and construction of the prototype. On the other hand, regarding the operation mode, control system operation manual was described in detail in Deliverable **D8** "Operating manual for process control". This document integrates all the equipment controlled by the PLC, describing the interlocks, alarms and automatic conditions, as well as the codes of tanks, equipment, valves and instruments referred to in the P&ID of the LIFE Multi-AD technological solution. Milestones **M4** "Feasible reactor design", **M5** "Construction of the 100 m^3 Multi-AD demo unit" and **M6** "FAT for process control" were achieved.

Action B4. Demo experience in real environment: The aim of this action was to validate in real industrial environment the 100 m^3 Multi-AD demo unit built in Action B3. Starting date: July, 2021; State: Completed.

First, the commissioning of the Multi-AD technological solution was carried out. The start-up process was performed using a methodical approach to ensure that all operational components of the Multi-AD technology solution worked as planned. Thus, the commissioning was executed in three consecutive phases: pneumatic and hydraulic, electromechanical and biological. Deliverable **D9** "Start-up the 100 m^3 demo unit" shows detailed information. Once the adaptation of the granular sludge was achieved, the reactor was operated in continuous mode, 24 hours a day, 7 days a week. During the demonstration period, the anaerobic reactor treated 10,088 m^3 of winery wastewater at increasing organic load. Despite influent variability, organic load was gradually increased from 200 to 1,000 kg COD/day thanks to COD based control strategy. It is especially important that during this task two different production stages were assessed at a winery: harvesting (high organic loads) and non-harvesting season. The results showed that Multi-AD reactor achieved COD removal higher than 95%, as well as biogas conversion of 0.36 m^3/kg COD removed. The combustible gas generated after Multi-AD technological solution was characterised by a methane mean value of 84%. Deliverable **D10** "Report with conclusions from testing the 100 m^3 demo unit" show the main results of first six months of continuous operation. Finally, Deliverable **D11** "Report on optimization of the Multi-AD's design and control system" describes the continuous improvement process carried out in Multi-AD technology, identifying the main challenges encountered (*i.e.*, 26), as well as the solution that must be performed to overcome them. Milestone **M7** "Adaptation of the granular sludge and anaerobic reaction running stable" and M8 "The 100 m^3 demo unit installed at AGE Winery reaches expected performance values" were achieved.

B5. Anaerobic reactor design tool: The objective of this action was to develop a design tool that can be used to pre-design and optimise new Multi-AD devices, taking into consideration all relevant parameters. Starting date: January, 2020; State: Completed.

The template of the technological solution based on the LIFE Multi-AD reactor and the simulation models for each of the subsystems that make up the technological solution were developed. It is noteworthy that the Multi-AD reactor module was divided in two sections: hydrodynamic and biochemical. The hydrodynamic model was a ROM (Reduced Order Model), based on the computational fluid dynamics developed in Action B1 whereas, biochemical one was based on ADM1 (anaerobic digestion model). Detailed information was shown in Deliverable **D12** "System model for template plants". On the other hand, data collection from 100 L prototype was performed in order to validate the model, as well as generate a data-base for populating the "Anaerobic reactor design tool"

software. In fact, 100 L demo unit treated with industrial wastewater from canned vegetable on continuous mode. Multi-AD reactor successfully operated with ORL of 20 kg COD/m^3·day, achieving COD removal higher than 90%. Finally, anaerobic reactor design tool was developed from this generated knowledge. In fact, the software can determine the optimal design and optimization of a Multi-AD reactor for agro-industrial wastewater treatment based on the integration of hydrodynamic and anaerobic digestion numerical models. Deliverable **D13** "Web-based application and GUI" introduces the novel design tool. Milestone **M9** "Reduce Order Model for digester to be available for control optimisation and for the design tool" and **M10** "Anaerobic Reactor Design Tool" were achieved.

B6. Market launching preparation: The aim of this action was to perform the development of national and international business strategy, and take care of the regulatory and knowledge protection tasks in order to guarantee that LIFE Multi-AD technology complies with the corresponding EU regulation and safety standards. Starting date: October, 2018; State: Completed.

The commercialization strategy of Multi-AD technological solutions was developed for the national and international market. During project implementation, return on investment (ROI) analysis was carried out in close customers in order to gain an in-depth understanding of the Multi-AD's position in the market. Deliverable **D14** "ROI for Multi-AD's clients" describes capital and operational expenditures, as well as ROI analysis for seven F&D SMEs. Then, a detailed analysis of the status of anaerobic digestion technology, as well as potential market and competing technologies of Multi-AD was carried out for the correct definition of the strategy. All this knowledge was used to develop the procedure for placing Multi-AD technology on the market, implementation schedule, business strategy and profitability. This information is presented in Deliverable **D15** "Business Plan". In order to facilitate the deployment of Multi-AD on a wide scale, a cross-border and trans-sector was done Deliverable **D17** "Replicability and Transferability Plan". On the other hand, LIFE Multi-AD technological solution obtained the CE certification. Instruction manual and technical dossier manual of Multi-AD was carefully performed in order to affirm that the anaerobic technological solution was in conformity with European health, safety and environmental protection standards. In this line, the required documentation to achieve intellectual property right (IPR) protection to the whole Europe was performed under application number EP23382586.8: Reactor for high-performance multi-stage anaerobic system. Deliverable **D16** "IPR management actions and certifications" shows the documents prepared to obtain the CE marking and IPR protection. Milestone **M11** "Business Plan" was achieved.

C1. Monitoring of the impact of the project action: This action covered the monitoring and assessment of the impact of the project. The monitoring involved both environmental and socio-economic impact. Starting date: October, 2018; State: Completed.

The consortium worked on the background scenario definition and on the list of indicators that indicated the viability of the LIFE Multi-AD technological solution that was shown in Deliverable **D18** "First report on the monitoring of the impact of the actions". Once the Multi-AD demo unit was commissioned, the technical advancements of the technological solution were follow-up by means of SCADA. A specific software tool was developed, based on PcVue software, in order to monitor the technical progression of the project. The environmental impact was assessed by comparing the background (AGE Winery based on aerobic process) to the Multi-AD scenario. Finally, data relating to socioeconomic impact of the LIFE Multi-AD project were collected during the following reporting period. All the cited information were presented in Deliverable **D19** "Second report on the monitoring of the impact of the actions", which was finished at the end of harvesting time and Deliverable **D20** "Third report on the monitoring of the impact actions" at the end of the project. Milestone **M12** "Update of the KPI web tool by midterm report 1", **M13** "All three reports on the monitoring of the impact of the actions successfully finished" and **M14** "Update of the KPI webtool by final report" were achieved.

D1. Dissemination and communication: The objective of this action was to disseminate the LIFE Multi-AD project through the website, social media and assistance to conferences or workshops to explain the advances of the project and the technology proposed. It was foreseen to organise networking activities with other LIFE projects and to participate in different LIFE events. Starting date: September, 2018; State: Completed.

The website and the social media are operative, generating content on a regular basis: 57 news published of LIFE Multi-AD. Seven newsletters were generated and sent to the contact list. Different material was made to facilitate dissemination throughout its implementation such as leaflet, notice board, poster or roll-up banner. LIFE Multi-AD technology was shown in 4 international congress, 20 thematic exhibitions, seminar or webinar, and 5 school, high-school or universities, as well as is part of a paper in peer review journal and the guide of Best Practices in Circular Economy (La Rioja). The consortium organised two technical workshops about anaerobic digestion. Specifically, the final event had 93 attendants and was an open-day to explain the technological solution to different stakeholders. Finally, active networking was carried out with 7 policy makers, other 18 relevant R&D projects and stakeholders: 4 technological platforms, 7 NGOs, 72 potential clients and 209 providers and potential providers. The deliverables submitted were **D21** "Dissemination and communication: report of planned activities", **D22** "Mid-term report on completed and planned Dissemination and communication activities", **D23** "Short report containing main highlights of technology relevant for policy maker", **D24** "Dissemination and communication materials produced including notice boards, layman's report and website", **D25** "Report stating the event or media reached for multiplying the project's impact" and **D26** "After-LIFE dissemination and communication plan". Milestone **M15** "Publishing of the project's dedicated website" was achieved.

E1. Project management: The objective of this action was to ensure the evolution of the project with timeliness and the further impact. Any deviation or relevant problems encountered in this period were explained in the following sections of this report. Starting date: September, 2018; State: Completed.

The consortium performed the tasks required to guarantee the correct project progress: Consortium Agreement signed, Guidelines to implement Green Procurement (deliverable **D27**), development of Quality Plan and Internal Audit, as well as technical and administrative meetings. It has to be highlighted the project management was restructured around the Steering Committee and the Implementation Teams, as well as PYRGUS was included as external consultant in order to ensure a detailed and appropriate management of technical, economical and administrative aspects of the project. On the other hand, AEMA (Project Coordinator) was bought by BONDALTI and its new trade name is BONDALTI WATER. It is important to emphasise that AEMA maintains its VAT No. ESB26334045. The significant change is that the company, AEMA, has a new owner. Deliverable **D28** "Report on LIFE Multi-AD's Project Management" summarises the main management actions, and associated documentation, carried out throughout the project. Milestone **M16** "Successful completion of the project" was achieved.

Identified deviations, problems and corrective actions: The main problem encountered during this period was related to the prototype localisation and start-up phase.

Prototype localisation

The demo unit was going to be located at Viñedos Winery (Aldeanueva, La Rioja) and was not able to be built there. The state of alarm in Spain, as a consequence of COVID-19, was picking up with uncertainty and fear by the global market. Under this economic situation, Viñedos Winery decided to stop the project in its facilities. This fact was because the winery expected to decline significantly its sales in 2020-21 and consequently, they decided to stop any new kind of building or investment.

Under these external circumstances, AEMA, as Coordinating Beneficiary, was actively seeking among their customers in order to find an end-user that fulfilled the whole requirements for the Multi-AD demo unit validation: from location to industrial sector. Among the different possibilities, the consortium selected AGE Winery, which accepted the construction and validation of the Multi-AD prototype on its WWTP. AGE is a winery located in the same European region as Viñedos Winery (*i.e.*, La Rioja), at the same industrial sector (*i.e.*, agri-food), as well as at the same business activity (*i.e.*, winery). Moreover, AGE Winery belongs to Pernod Ricard Group, a big company of alcoholic beverages with a strong commitment to the environment.

Due to the setbacks expected due to the COVID-19 outbreak and the delay accumulated in the design phase, it was impossible to finish Action B2 and B3 on time. Although the consortium was making a considerable effort in order to recover the delay accumulated; however, these external circumstances caused that the execution of Action B2 and B3 were slower than it was planned and therefore, they were delayed 20 months.

In the same way, Action B1, although it was finished, accumulated a significant delay of 8 months. This was a consequence of the need to keep the investment costs of Multi-AD industrial devices into reasonable levels leading to loss of geometrical similarity and the avoidance of biogas recirculation. These facts resulted in more simulations than expected therefore a time prolongation of this action was required. Various CFD models based on the initial one but with the capacity of reducing the computational time were developed to accelerate this redesign process.

Due to these circumstances faced in the implementation actions was *i)* exceptional, *ii)* unforeseeable and *iii)* demanding enough not to be covered by the original buffer time considered for contingencies in the project schedule, the consortium requested a postponement of the end data of the project. In fact, EC accepted an extension consisting in 16 months in order to ensure the continued development of the project and its ultimate success.

Start-up phase

To a lesser extent, another significant challenge was identified during the start-up phase, specifically issues detected along pneumatic and electromechanical tests. Test implementation led to the diagnosis of two main challenges to be fixed: gas tightness and power panel.

Thus, in reference to gas tightness, neither the Multi-AD reactor nor biogas line managed to maintain the working pressure, which made it necessary to check the valves and welds using a soapy water solution. Once the pores were identified, they were repaired by purged welding. In addition, the same tests identified an erroneous pressure setting in the plunger tubes (*i.e.*, overpressure safety elements) installed in the Multi-AD reactor. This fact required a redesign, construction and installation of new ones.

On the other hand, a re-design and modifications to the power cabinet components was needed. After performing the installation and electromechanical tests, it was diagnosed that the power panel had technical deficiencies that prevented the plant from operating correctly and CE certification. Therefore, SIS and AEMA teams, taking advantage of their know-how, carried out the redesign of the electrical power panel and made the necessary changes to the components of the electrical cabinet.

The occurrence of technical problems as mentioned had a clear impact in the effective progress of the project not to compromise both people and prototype safety. All measures were taken to solve the problems encountered and to limit additional delay as the Risk Management Plan was activated. However, the problems and deviations that occurred, unfortunately, were not identified in the plan referenced. This fact notwithstanding, an adequate assessment of the impact of these challenges on the outcomes of the project and different measures were taken to overcome or alleviate the problems in questions.

These facts caused a delay in the start-up of the Multi-AD reactor operation (*i.e.*, 5 months), which forced the consortium to re-planning the experimental phase. Thus, the demonstration phase process is going to be carried out over 12 months in two steps: Pre-harvesting and harvesting season (from July to November) and Non-harvesting season (from December to June). This fact allows assessment of Multi-AD reactors on the different production stages of a winery.

The proposed activities to be developed did not affect the objectives and expected results of the project, as stated in the approved proposal. Quite the opposite, not executing these activities would lead irretrievably to an incomplete achievement of the project objectives. Moreover, the estimated budget did not suffer any change. Additional expenses, if any, were to be supported by the consortium's own means.

The circumstances causing the delays and the results of the measures were taken to overcome them constitute a series of lessons learnt of tremendous value for the project. These very important lessons were a fundamental part of the demonstration character of the LIFE Multi-AD project. The risks and constraints faced and tackled by the project are critical for the technology. The lessons learnt through the project were therefore meant to be fundamental to the proper and successful implementation and use of the technology in the future. They were transferred to the stakeholders and the society through the proper deliverables that convey the results of the project.

4. Introduction

4.1. Description of background, problems and objectives

Background

The food and drink (F&D) industry, the largest manufacturing sector in the EU, comprises 290,000 small and medium enterprises (SMEs) – making up 99% of the entire industry. F&D SMEs are a highly water-intensive sector worldwide, producing a significant volume of wastewater. These industrial effluents are characterised by high concentration of biodegradable organic matter, which results in significant environment pressure.

Thus, they are most commonly treated by an aerobic biological system at the industrial facility where the wastewater is generated. Due to the typical process selection, aerobic biological treatment, relative energy consumption is high. Moreover, due to typical on- or near- site disposal of biosolids without biogas recovery, there is little or no opportunity for carbon emission offset.

On the other hand, anaerobic systems appear as a more environmentally friendly and economical process for treatment of high-load wastewater. However, high-rate anaerobic reactors already on the market (*e.g.*, UASB, EGSB or IC) are optimised for large enterprises (>1,000 m^3/d, being 2,500 m^3 a standard capacity) where economies of scale make vast technology investment affordable. In contrast, the F&D sector, dominated by SMEs, does not discharge enough organic load for existing anaerobic reactors to prove economically viable.

Cheaper reactors could help F&D SMEs use water resources in a safer and more efficient manner, as set out in the EU Water Framework Directive (2000/60/CE), and save natural resources, as described in the Industrial Emissions Directive (2010/75/UE).

Objectives

LIFE Multi-AD aims to design and industrialise an anaerobic digestion reactor capable of economically treating wastewater discharged by SMEs operating in Europe's F&D sector.

This main objective is divided into the following specific objectives:

- The scale-up of the eco-innovative anaerobic reactor (patent ES-2541078-B1) from our current prototype of 0.1 to 25-500 m^3.
- Optimisation and automatization of the control system, to maximise the stability of the anaerobic process, and make it robust towards changes in the wastewater composition or operational conditions.
- Construction of a 100 m^3 Multi-AD demo device and validation in a Spanish winery.
- Development of the "Anaerobic Reactor Design Tool", software to be used for dimensioning future Multi-AD devices. It will allow designing Multi-ADs for a wide range of F&D sectors.
- Population of the software's data-base with data from the usage of our 100 L Multi-AD prototype for wastewater treatment from vegetable processing industries.

Expected results

The main result is the industrialisation of a disruptive high-performance MULTI-phase (sludge mixed with liquid and gas) Anaerobic Digester, "Multi-AD", designed for its implementation in the F&D industries' SMEs.

The Multi-AD device will be manufactured on-demand, *ad-hoc* for the industry wastewater treatment needs, with a capacity range between 25 and 500 m^3. It will work continuous-wise, being able to treat all its volume in less than 20 hours. It will cut down by 90% the wastewater's Chemical Oxygen Demand (COD), and generate abundant biogas (0.42 m^3/kg COD removed).

This self-generated renewable energy, will be at least 80% methane-rich (1.55 kWh/kg COD removed), and will be used partially (50%) for operating the digester, and partially (50% surplus) for other operations (*e.g.*, boiling or heating) in the industry.

To attain this main result, we expect to:

- Obtain the final design for the scaled-up Multi-AD reactor of 25-500 m^3.
- Develop the advanced control system based on logic rules for automatizing the control of process parameters.
- Build a demo 1:1 industrial-scale Multi-AD reactor working unit of 100 m^3, and to validate its performance in a winery.
- Develop the "Anaerobic Reactor Design Tool" a software tool to design *ad-hoc* Multi-AD reactors.

4.2. Expected longer term results

LIFE Multi-AD has a demonstration character and it is a "close-to-the-market" project, since AEMA will be able to commercialise this device by the following years. In fact, our technological solution was built a 1:1 scale demo device (100 m^3), scaling up the processing capacity of our first prototype (100 L) and install in a Spanish winery where its capability to treat F&D wastewater was assessed (*i.e.*, from TRL 6 to 8).

Furthermore, once the LIFE Multi-AD project is completed, the anaerobic reactor will remain in operation at AGE Winery. This fact demonstrates that Multi-AD technology has reached maximum TRL, as well as its real transferability to the F&D industry. The plant will also be the prototype for new R&D initiatives to improve Multi-AD technological solutions, as well as accelerate its transferability and replicability.

Moreover, anaerobic reactor design tool will be able to mock-up *ad-hoc* requirements and constraints for the installation of this wastewater management system in other kinds of F&D industry. This adaptation will be in line with the replicability and transferability requirements of the LIFE programme, and will help attain an ultimate aim: to be able to broaden Multi-AD's applicability throughout the whole European F&D sector, and to launch to the market a cost-effective and eco-innovative wastewater treatment solution adapted for the particular constraints of SMEs (>99% of F&D industry in EU).

On the other hand, LIFE Multi-AD project will contribute to the implementation, updating and development of EU environmental policy and legislation in the following areas:

Water

LIFE Multi-AD project is based on anaerobic process, which is considered one of the most sustainable alternatives for wastewater treatment (Figure 1). LIFE Multi-AD technology can be considered as the solution to accomplish an optimal treatment of wastewater generated by F&D industry, in terms of energy cost (57% less energy), use of hazard reagents 100% reduction in the generation of liquid oxygen, as well as 74%, 54% and 89% reduction in the need of urea, phosphoric acid and polyelectrolyte, respectively) and sludge to manage (89% less amount of sludge is generated than in aerobic reactors).

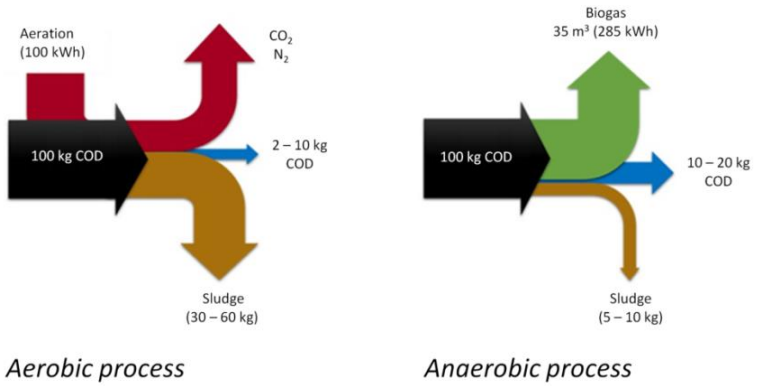


Figure 1. Comparative balance of aerobic and anaerobic wastewater treatment processes.

F&D industry is a highly water-intensive sector worldwide, according to the technical magazine Industrial WaterWorld, wastewater volumes derived from different industries indicate that the food and beverage sector produces roughly 2.17 million m^3/d of wastewater in Europe. Moreover, the F&D industry is a main source of biodegradable organic pollution in the European water basins. Nowadays, European F&D wastewater is generally treated in centralised WWTP under aerobic processes.

The LIFE Multi-AD project will contribute to ensuring the safe and efficient use of water resources, to have a resource-efficient-industrial sector in the whole EU. The implementation of this eco-innovative technology will promote the compliance with the EU Water Framework Directive and the aims set by EIP-Water, providing to European F&D SMEs a cutting-edge solution aligned with the global aims set in the Europe 2020 Strategy.

Moreover, transferability and replicability of Multi-AD technological solutions will lead to decentralised wastewater treatment in F&D industries, minimising the pressure on urban WWTP. This fact will facilitate compliance with the new urban wastewater treatment directive which decreases the discharge limits for physic-chemical parameters.

On the other hand, LIFE Multi-AD project objectives are properly aligned with the EC new circular economy action plan adopted in March 2020. LIFE Multi-AD technological solution will contribute to the EU's transition to a circular economy that will reduce pressure on natural resources.

Green House Emission

LIFE Multi-AD project can be considered a climate-related project as well, since it reduces by 59% the CO_2 emissions and by 57% the energy requirements of each industry that implements our system. This reduction is achieved by the combination of two key facts:

- Unlike aerobic reactors, Multi-AD does not need high-energy demanding air blowers (50-75% of the energy consumed in the WWTP of the F&D sector is associated with the air blowers).
- The generation of methane-rich gas during the process, provides a source of energy to *i*) operate the Multi-AD reactor and *ii*) convert other operations with the industry (*e.g.*, boiling or heating).

Since 99% of the EU27 F&D industries are SMEs (our target users) – that currently depend on either aerobic reactors or on centralised WWTP – our project has a huge potential to reduce the F&D CO_2 emissions throughout the whole EU and therefore, contribute to climate-change mitigation.

LIFE Multi-AD project objectives are properly aligned with the EC strategic long-term vision for climate neutrality by 2050 according to the European Green Deal. The strategy shows how Europe can lead the way to climate neutrality by investing in realistic technological solutions and aligning action in key areas such as industrial polity. According to Food Drink Europe "European F&D manufacturing accounts for approximately 1.5% of total EU GHG emissions".

Therefore, LIFE Multi-AD technological solution will contribute to meeting the 55% emissions reduction target by 2030, as well as 2050 climate neutrality goal, as well as help to the Commission's zero-pollution ambition.

Sludge

LIFE Multi-AD brings other important environmental benefits that arise mainly from the fact that Multi-AD generates 89% less amount of sludge. Sludge management has become one of the most critical issues for the wastewater industry worldwide, due to the very fast increase in sludge production resulting from increasing numbers of new WWTPs, more industries and more equivalent inhabitants connected to existing sewerage systems and upgrading of existing facilities to meet stricter discharge criteria.

The project's objectives fit the needs set in the baseline scenario resulting from the assessments on sewage sludge management carried out by the DG Environment of the EC in the process engaged for the revision of Directive 86/278/CEE, on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. LIFE Multi-AD is coherent with the Roadmap to a Resource Efficient Europe regarding the objective of turning waste into a resource.

5. Administrative part

AEMA, as Project Coordinator, was in charge of the overall technical and financial management of the project, supported by the responsibility of each partner. At the beginning of the project, LIFE Multi-AD counted with an Executive Board. Multi-AD's Executive Board included one representative person from each organisation, except for AEMA, the Coordinating Beneficiary, which participated with two persons. Besides the Executive Board, the project counted with a reduced management team, to deal with daily managerial tasks.

However, due to the necessity for improving project management and more specifically the financial and administrative management, AEMA redefined the chart of Multi-AD project. There were two major limitations for proper management. On the one hand, several members of the Executive Board left the Multi-AD project [redacted]. On the other hand, the original organisation chart was too flat and subsequently, all the technical and financial management of the project fell to four members. Thus, LIFE Multi-AD project management was re-structured around the Steering Committee (SC) and the Implementation Teams, as shown in the next diagram (Figure 2).

The SC was the highest authority within the Project. It included representatives from all partners and was headed by the Coordinating Beneficiary through the Project Manager. Its role is to advise and support the decisions of the Project Manager on operational and management issues. As a general rule, the SC met face to face once a year. In the meantime, their normal tasks have been carried out by conference calls and emails. The SC members sent comments, decisions and confirmations to the Project Coordinator. The role of the Technical Committee was the supervision of day-to-day technical work. It includes technical representatives from all partners, and it is coordinated by the Technical Coordinator from AEMA. This Technical Committee meets twice a year, being one at the same time as the SC meeting.

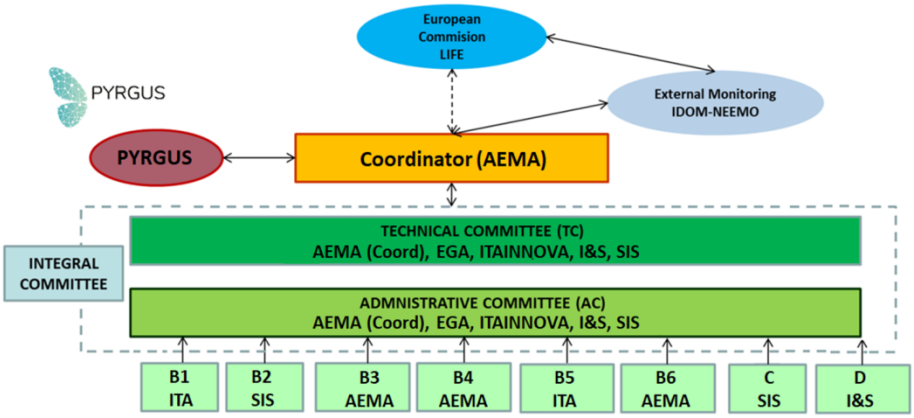


Figure 2. Organisation chart of LIFE Multi-AD project.

Moreover, it was included an external support for the financial management of LIFE Multi-AD project *i.e.*, PYRGUS Consulting as consultant. In fact, PYRGUS, together with [redacted] (AEMA), developed a Quality Plan, whose aim was to give a quick and short overview of the most relevant information, procedures and conditions for the partners in the LIFE Multi-AD such as guidelines for financial reporting. In order to keep a continuous track of the partners and to ease the follow-up of the costs incurred by each beneficiary, the control of Summary of Costs in the project was done on a 6-monthly basis. [redacted] AEMA was responsible for monitoring and checking the financial reports.

Partners were provided with a "Financial report template" which was used by each of the partners for the financial justifications in each of the reporting periods. The template was also used for the internal control of the project costs. Timesheets, certificates and all invoices of the costs reported by each partner and were marked with the name of the project as well as stored in their respective folder of OneDrive platform. All these financial documents were audited by PYRGUS, which carried out several audits 2018-2019, 2020, 2021, 2022 and 2023.

AEMA was the single point of contact for the Commission and the only participant to report directly to the Commission on the technical and financial progress of the project. The Coordinating Beneficiary was communicated regularly with the Monitoring Team to report the project progress. In order to ensure an appropriate management and coordination of the project partners, monthly meetings were organised by the coordinator via Microsoft Teams platform. A copy of the presentation of these meetings was regularly sent to all partners.

The LIFE Multi-AD Project suffered during this reporting period the following relevant issues that was communicated to European Commission:

On 22 January 2019, Project Coordinator informed that the beneficiary PURAL must be replaced [redacted]. The proposed solution was based on replacing PURAL by ENERGY GREEN GAS ALMAZAN S.L. (EGA). [redacted] This fact caused Amendment nº1 to the Grant Agreement.

On 2 March 2020, Project Coordinator sent a Progress Report to the Executive Agency for SMEs (EASME – the Agency). The report carried out an overall assessment of the achievements of the LIFE Multi-AD project, showing that it was progressing with some delays in the technical actions which were caused by the design and scale-up of the prototype issues. These deviations prevented the consortium from spending the pre-financing, mainly because AEMA did not acquire the equipment and materials needed to construct the demo plant. As a consequence, the Mid-Term Report was delayed from October 2019 and it was necessary to change it to a Progress Report, which it was foreseen for at the end of 2020.

On 12 March 2020, [redacted] communicated during the Second General Assembly (Zaragoza) that he would leave the project at the end of March and [redacted] will be the new LIFE Multi-AD Project Coordinator. The meeting was attended by the EASME through a representative of NEEMO and Project Monitor, [redacted].

On 17 November 2020, the consortium requested the authorisation for changing localisation of the demonstration unit. The prototype, which was going to be located at Viñedos Winery (Aldeanueva, La Rioja), was not able to be built there. The state of alarm in Spain, as a consequence of COVID, was picking up with uncertainty and fear by the global market. Under this economic situation, Viñedos Winery decided to stop the project in its facilities. Under these external circumstances, AEMA, as Coordinating Beneficiary, found an end-user that fulfilled the whole requirements for the Multi-AD demo unit validation (from location to industrial sector): AGE Winery (Fuenmayor, La Rioja).

On 14 May 2021, Project Coordinator sent the Mid-term Report to CINEA. The report performed an overall assessment of the achievement of the LIFE Multi-AD project, showing that it was progressing with some delays in the technical actions which were caused by the problems with the localisation of the prototype. The consortium declared that it was making a considerable effort in order to recover the delay accumulated, however, these external circumstances caused that the execution technical implementation was slower than it planned and they were delayed up to 14 months.

On 3 October 2022, Project Coordinator sent a Progress Report to CINEA. The report reviewed the progress made in LIFE Multi-AD project, showing that it was advancing with some delays in the demonstration phase. This fact was caused by issues detected along pneumatic and electromechanical tests of start-up phase. The cited delay did not affect the objectives and expected results of the project as stated in the approved proposal. The circumstances causing the delays and the results of the measures taken to overcome them constituted serious lessons learnt of high value for the Multi-AD technology.

Finally, the consortium requested a postponement of the end of the project considering an extension period of 16 months on 22 November 2022. The implementation of the LIFE Multi-AD project faced, compared with the original schedule, some challenges related to the design and construction of the demo unit. However, the circumstances faced in the project implementation were exceptional, unforeseeable and demanding enough not to be covered by the original buffer time considered for contingencies in the schedule. The delays in these critical actions made it necessary to postpone the end of the activities, in order to ensure that the viability and results of the project are maintained. CINEA agreed to the requested modification therefore, this fact caused Amendment nº2 to the Grant Agreement.

6. Technical part

6.1. Technical progress per Action

6.1.1. Action B.1: Fluid dynamic analysis

Beneficiary responsible		Status
ITAINNOVA		Finished
Time schedule	**Starting date**	**End**
10 months	September 2018	June 2019
Real-time schedule	**Starting date**	**End**
18 months	September 2018	February 2020

The aim of this action was to fix the main dimensions of the industrial scale Multi-AD reactor. The results obtained during this action produced inputs which were necessary for the forthcoming actions.

<u>Action TB.1.1:</u> Computational Fluid Dynamics -CFD- simulations

Definition of requirements: This task presented the numerical model used to simulate the performance of the Multi-AD reactor prototype. CFD was used to model the pilot-scale reactor behaviour and provide a deep understanding of the physical, chemical and biological processes involved in the digestion. After that, a Robust Design Methodology (RDM) was used to determine the optimal design of the industrial-scale reactor (Figure 3).

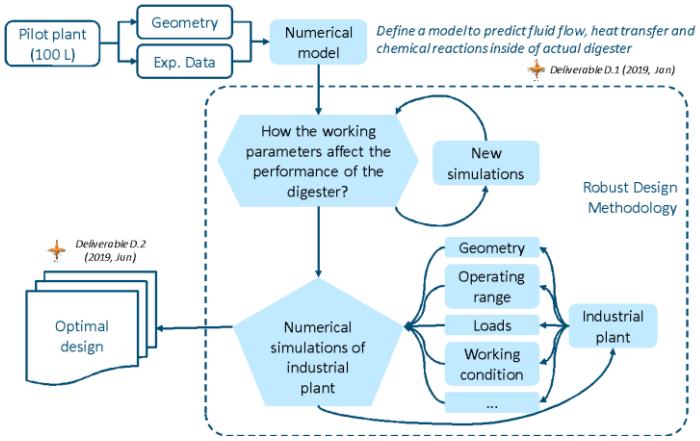


Figure 3. Fluid Dynamic Analysis.

System description and experimental data: A detailed description of AEMA's patented pilot-scale prototype reactor and a summary of the physical and chemical phenomena involved in the simulation are presented in deliverable **D1** "Description of the CFD model and its validation". This cited deliverable also summarised the experimental data acquired during 218 days in the pilot plant for the validation of the model (Figure 4).

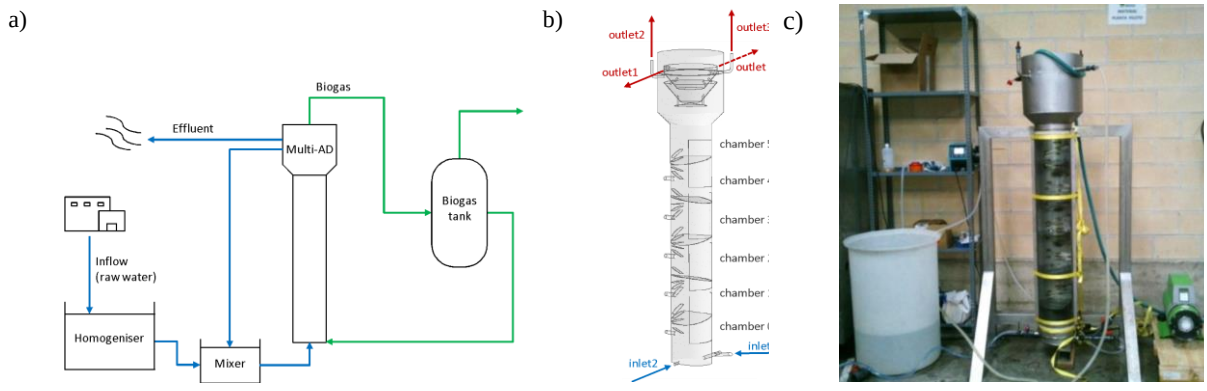


Figure 4. (a) Process diagram of Multi-AD prototype plant, (b) reactor geometry and (c) picture.

CFD model definition: The numerical model was defined to predict the three-phase fluid flow (*i.e.*, solid-granule, liquid-water and gas-biogas), heat transfer and chemical reaction inside the Multi-AD reactor was solved by the double-precision pressure-based solver in ANSYS Fluent 19.2 assuming steady state. The problem requires using a multiphase model, a 3D geometry (meshed in ANSYS Meshing 19.2) (Figure 5), non-Newtonian fluid phases, a turbulence model, and solving energy and species transport equations, thus the whole numerical model is highly complex.

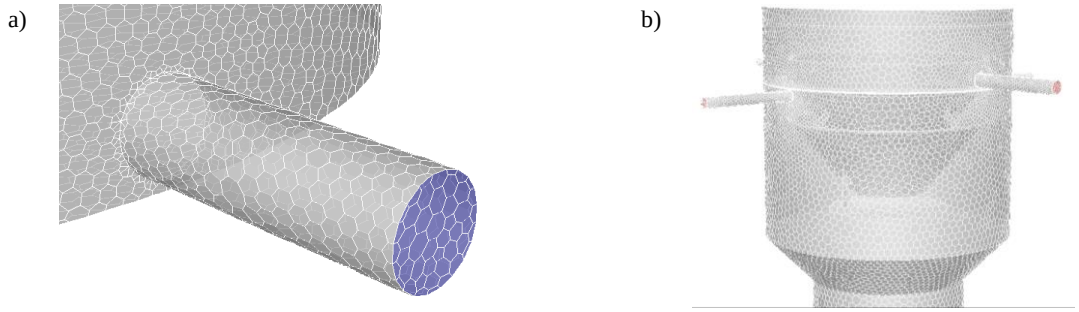


Figure 5. Details of the 3D mesh: (a) liquid inlet, (b) three-phase separator

A summary table of the CFD configuration was presented in deliverable **D1** "Description of the CFD model and its validation". This computational model was described in terms of numerical domain, meshing, boundary conditions, and models and numerical methods applied in the simulation.

<u>Action TB1.2:</u> Fluid dynamic analysis of the three-phase system

CFD model validation: The results obtained in each of the three stages of the numerical strategy used to model the behaviour of the Multi-AD reactor are presented (Figure 6). Theses stages are:

1) Initial solution.
2) Inert flow. In this stage, the pressure, temperature, distribution of the gas and solid phases, the velocity field of the liquid phase and the flow field of the liquid, gas and solid phases are analysed.
3) Reactive flow. In this stage, the distribution of solids, methane production and chemical kinetics in the reactor are analysed

The model is able to adequately predict the hydrodynamic behaviour of the three phases within the Multi-AD reactor and has proved that the size of the solid particles determines its behaviour. The hydrodynamics of the phases was strongly related to the evenness in the removal of Volatile Fatty Acids (VFAs) and production of biogas along the reactor chambers. The higher was the number of particles suspended in the liquid and the more homogeneous was their distribution throughout the reactor; the better was the removal of VFAs.

Regarding the prediction of the methane production, the current numerical model only considered the concentration of VFAs and temperature, and neglects the influence of other important parameters (*e.g.*, pH, particle size distribution and microbial growth kinetics). Therefore, it was only able to predict the methane generation under certain experimental conditions, described in the case setup and adjusted to fit one single operation day measurements. Detailed information was shown in **D1** "Description of the CFD model and its validation".

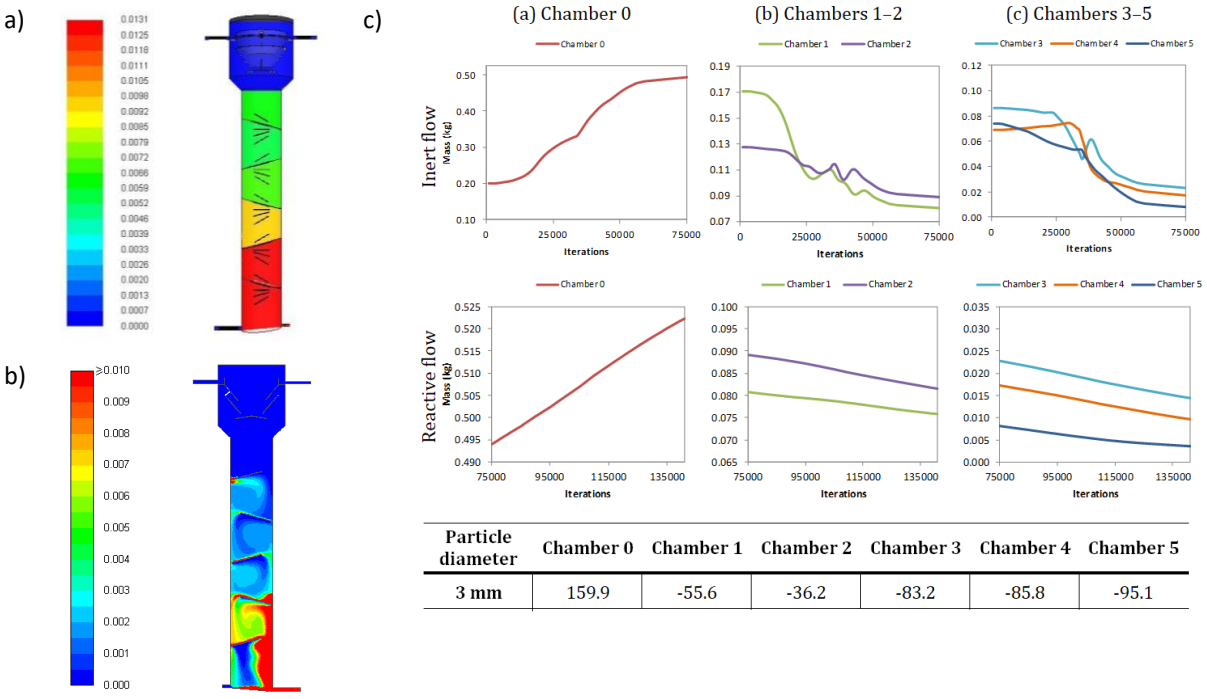
CFD analysis for scaling-up: To address the task of selecting the proper scale-up criteria to design an industrial Multi-AD reactor, it was decided to simplify the simulation model and focus the attention on the fluid-dynamic behaviour of the phases. The objectives of the project were not affected by these facts. Four different scale-up criteria were defined to design an industrial Multi-AD reactor, based on the following variables:

- Mass of solids in each chamber (Criterion 1)
- Liquid velocity (Criterion 2)
- Momentum of the solid phase (Criterion 3)
- Momentum of the liquid phase (Criterion 4)

The simulations of the fluid flow during this project task comprise the following phenomena, what permits much faster simulations:

- Mixing of the liquid flow facilitated by the gas generated in the AD process (COD removal).
- Transport of solid particles by the liquid flow (and, to a lesser extent, gas flow).

In addition, to decrease the investment and operation costs and to reduce the risk of explosion and avoid the definition of ATEX zones, which simplifies the safety criteria, the external recirculation of biogas using a gas compressor was not considered in the new designs.



Particle diameter	Chamber 0	Chamber 1	Chamber 2	Chamber 3	Chamber 4	Chamber 5
3 mm	159.9	-55.6	-36.2	-83.2	-85.8	-95.1

Figure 6. Contours of solids fraction at (a) initialization stage (b) inter flow and (c) reactive flow.

In deliverable **D2** "Description of the CFD model and scaling-up criteria" was presented the design criteria established by RDM, the CFD simulation performed to evaluate the influence of different parameter on the behaviour of Multi-AD reactor and the proposed scale-up criteria to move from pilot to industrial scale.

Milestone M1 "Validation of the CFD model using data from the existing 100 L prototype" was achieved with the development of this task.

Design proposal for a 100 m^3 digester: Various reactor geometries were tested focusing on the interaction between liquid, solid and gas phases. The simulations presented in deliverable **D2** "Description of the CFD model and scaling-up criteria" were classified into three groups:

- *Base analysis*: To provide information about the influence of the aspect ratio (D/h) and liquid flow rate when there was an external contribution of gas to the system (Figure 7).
- *Without biogas recirculation*: To evaluate whether solely an increase in the liquid flow rate was capable of reproducing the fluid-dynamic behaviour observed when there was an external biogas recirculation
- *Grid-type inlet*: To assess the effect of using a grid-type liquid inlet placed at the bottom of Chamber 0 instead of a tube.

Finally, CFD model developed was used for optimising the performance of the 100 m^3 demo unit that was built, with special emphasis being placed on influent distribution, chamber baffles and three-phase separator (Figure 7). Figure 10 show some significant results of CFD simulation carried out in order to design proposal of 100 m^3 Multi-AD reactor.

Figure 7. Base analysis - Contours of liquid velocity (a) D/h = 1.0, (b) D/h = 1.5, and (c) D/h = 2.0.

Action TB1.3: Determination of key parameters for scale-up

Selection of scale-up criteria: Several limitations and new boundary conditions appear when scaling-up a process to the industrial level. Among them, the followings were considered as critical parameters: structural design to achieve a cost-effective technological solution, degree of mixing of solid-liquid-gas without external biogas circulation and effective three-phase separator.

The structural design of the reactor was considered as a key parameter. Technical solutions as simple as possible were required to achieve a cost-effective product, which entails an increase of the reactor diameter/height ratio. In this line, the three-phase separator design was an important influence on AD efficiency. An efficient phase separator leads to retention of a larger sludge mass, which means that the mean solids retention time is increased, a fundamental operational parameter of anaerobic reactor.

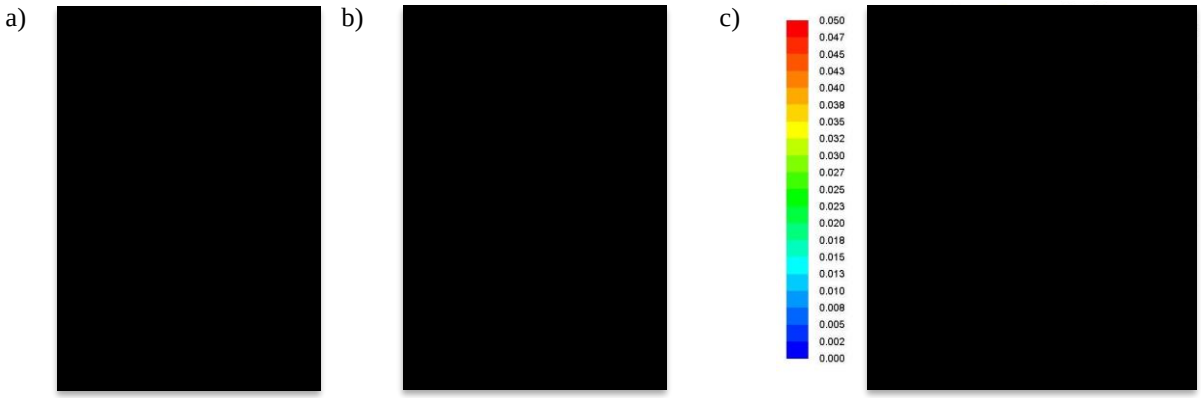


Figure 8. Multi-AD reactor components studied during CFD simulation: (a) feed distribution pipping, (b) chamber baffles, (c) three-phase separator.

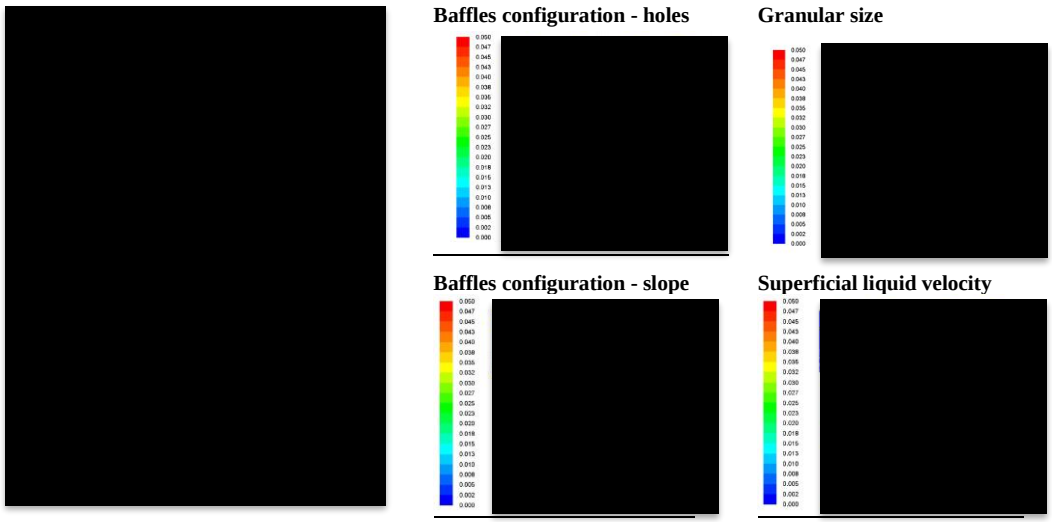


Figure 9. Drawing of Multi-AD reactor and results of different CFD simulation to final design proposal.

The last parameter that highly influences the operation of the reactor was the degree of mixing that makes the liquid flow capable of maintaining the solid particles in suspension. This parameter was especially important after elimination of external biogas circulation to decrease the investment and operation costs, as well as to reduce the risk of explosion and avoid the definition of ATEX zones, which simplifies the safety criteria. The scale-up criteria to design an industrial Multi-AD reactor must therefore aim to achieve a liquid velocity distribution within the new reactor capable of reproducing, to the extent possible, the fluid dynamics of the pilot-scale Multi-AD reactor.

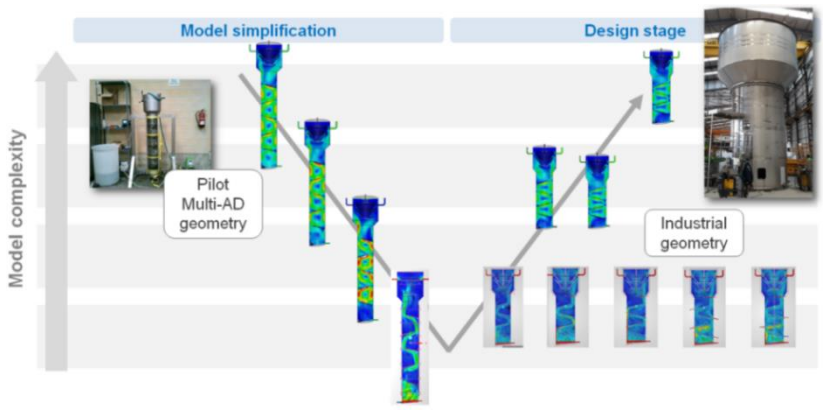


Figure 10. Graphical abstract of Action B. Fluid Dynamic Analysis.

Final proposal for the 100 m^3 digester: An analysis of the different numerical simulations was carried out applying the selected scaling criteria mentioned above. The same conclusions were obtained from the analysis of momentum of the liquid and the solids. The main conclusions were that:

- The external contribution of gas has a significant influence on the liquid behaviour, as the gas assists in the mixing of the phases.
- The removal of external biogas recirculation demands a significant increase in the liquid flow rate in order to maintain turbulence and an adequate mixing: [redacted].
- The superficial liquid velocity in Multi-AD reactor should be [redacted] m/h however, the optimum value should be determined during demonstration operation between [redacted] m/h.
- The core of a Multi-AD reactor should be composed of [redacted] chambers, [redacted].
- The dimension of Multi-AD reactor should be D/h = [redacted] in order to achieve a cost-effective technological solution.
- The increase in Multi-AD reactor influent flow would also entail a significant reduction of the residence time and increase the risk of particles being dragged by the liquid flow.
- The design of three-phase separator [redacted] in order to lead to retention of a larger sludge mass, *i.e.*, solids retention time is increased.
- The baffle configuration at [redacted] significantly improves the solid distribution in each chamber; on the contrary, the presence [redacted] shows a slight influence on solid phase.
- The developed feed distribution piping (influent system of Multi-AD reactor) provides promising results, assuring optimal distribution.

Milestone M2 "Proposal for designing a new 100 m^3 digester" was achieved with the development of this task.

6.1.2. Action B.2: Control system development

Beneficiary responsible		Status
SIS		Finished
Time schedule	Starting date	End
10 months	May 2019	February 2020
Real-time schedule	Starting date	End
30 months	May 2019	October 2021

The main objective of this action was to design and develop an advanced control system that will optimise Multi-AD's operation by adjusting the controllable outputs' variables.

Action TB2.1: Control system design

Monitored parameters: Physic-chemical characteristics of wastewater (*i.e.*, pH, TSS or COD) and biogas (*i.e.*, CH_4, CO_2, H_2S), water and gas flow, as well as AD operational parameters (*i.e.*, TRH, superficial linear velocity, temperature, gas pressure or ORP) were selected as monitored parameters that must be measured to the control of LIFE Multi-AD technology. The parameter monitoring was performed on-line, continuously and automatically by means of commercial devices (*e.g.*, SCAN, Hach-Lange, Endress Hauser or Siemens).

Advance control system: P&ID of LIFE Multi-AD technological solution was developed from the CFD analysis of Action B1 "Fluid Analysis Dynamics" and physic-chemical characterization of raw winery wastewater. As Figure 11 shows, P&ID can be separated in four major sections: pre-treatment or conditioning process, anaerobic process, biogas line and existing winery WWTP (*i.e.*, aerobic process).

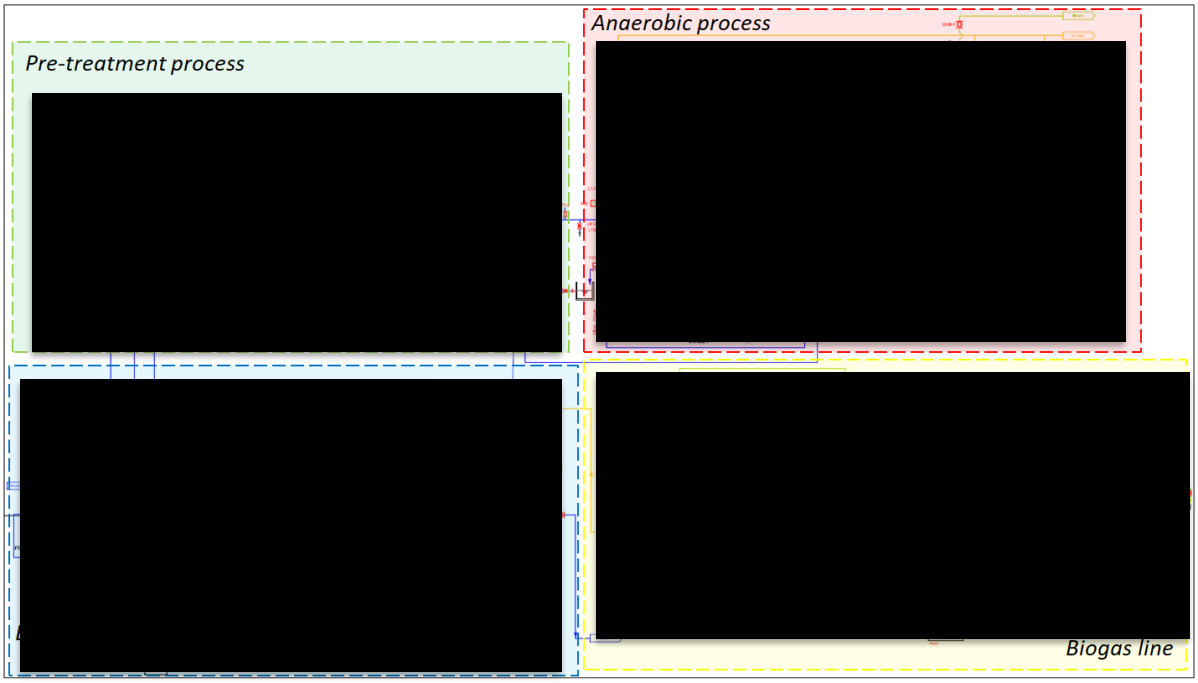


Figure 11. Process and Instrumentation Diagram (P&ID) of LIFE Multi-AD.

Action TB2.2: Control system development

The control system strategy was developed based on the monitoring and operational control parameters, as well as the P&ID of LIFE Multi-AD technological solution. These technical specifications, defined in Deliverable **D3** "Control system specification", enabled the design of the electrical panels (*i.e.*, control and automation and power) that facilitate the physical operation of the control system of the demonstration prototype (Figure 12).

The control logic developed was responsible for the supervision and control of the three main sections of the LIFE Multi-AD technological solution:

- *pre-treatment of anaerobic process*, homogenisation (flow rate and organic load) of the industrial effluent, decantation, conditioning of wastewater (pH, macro and micronutrients and increase of the temperature up to process value).
- *anaerobic process*, mixing of pre-treated and recirculated effluent, fine tuning of pH and temperature to process value set-point, as well as biological wastewater treatment.
- *biogas line*, hydrogen sulphide cleaning, homogenisation of biogas (flow rate and methane content), as well as valorisation of thermal energy in a boiler.

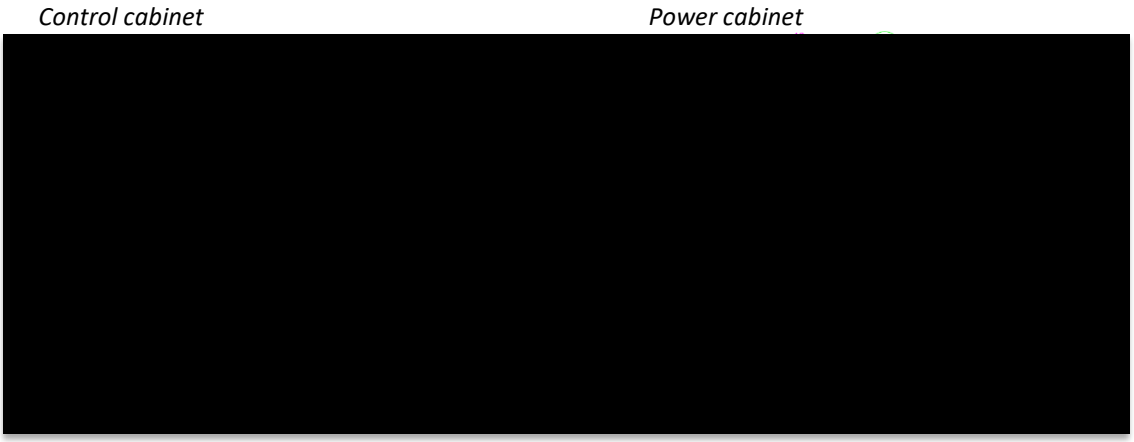


Figure 12. Graphical representation of the electrical panels designed for the control and operation of the LIFE Multi-AD prototype.

Within the section, the control logic was developed using "cause-effect" approach by means TIA Portal V16, which is structured in process blocks assuming the following assumptions:

- each function block (FB) from the PLC (programmable logic controller) logic was described by a diagram, keeping the same name for easier reference.
- the physical inputs were marked as red in the logic and the physical outputs as green.
- for level switch sensors, it was considered 1, the value when the liquid reaches the limit and 0, the value when the liquid is under the sensor.
- the values for the limits, constants and set-points are provided as real type values in the HMI (human machine interface) and were marked with blue in the logic. The values for the timers were provided in seconds in the HMI and were marked with yellow in the logic.

The structure of the implemented logic for each actuation element had three networks (Figure 13): the LIFE Multi-AD technological solution:

- *interlocks*, handling all the required safety conditions for the equipment or *item* to start.
- *auto-timer*, handling the automatic ON/OFF actions according to timer values present in the HMI
- *command*, handling the switch between manual and automatic mode, as well as sending the proper value to the physical output.

It is noteworthy that all actuation *items* (*e.g.*, pumps, solenoid valves or blowers) can operate in manual or automatic mode. As an example, the logic described in the diagrams in Figure 14 corresponds to the automatic mode. The operation of manual or automatic mode was described in detail in Deliverable **D4** "PLC control logic and control cabinet". Simulation and testing procedures were carried out using the extensions PLCSim, to ensure the correct functioning of the control logic. The results were shown in Deliverable **D5** "Control system testing results".

<u>Action TB2.3:</u> Advanced SCADA remote operations

An architecture for the monitoring and control of the technological solution was developed with the aim that the Multi-AD device to have an unattended and fully automated operation (Figure 15). Thus, all equipment and instrumentation were connected to the power and the control cabinet. The control cabinet, which integrated the PLC and HMI, was in turn connected to both the power panel and the Remote-Control Centre of SIS. AEMA, as the company in charge of the operation of the Multi-AD prototype, had remote access to the plant through the aforementioned centre.

It is important to note that operation and control of LIFE Multi-AD technological solutions were carried out on-site, by means of the HMI, and remotely, thanks to a computer application where the SCADA is developed.

On the one hand, HMI, as a physical interface, is the main tool used by AEMA's technical specialists to control and operate the processes taking place in the plant. As shown in Figure 16, with the help of the

WinCC Siemens software, a graphical representation of LIFE Multi-AD technological solution was developed to convert the anaerobic process variables into useful and actionable information. HMI allows the change of setpoints, the activation and deactivation of equipment or the monitoring of parameter values of a given process. Detailed information on the HMI can be found in the Operation Manual, annexed to Deliverable **D8** "Operation Manual for the control of the process system".

On the other hand, remote control and operation was carried out by means of a SCADA software application. This tool, developed using PcVue software, was a replica of WinCC but with a more user-friendly appearance, as well as with the capacity to control and supervise LIFE Multi-AD process remotely. Software tool facilitates real-time feedback with the plant devices and controls the process automatically. In addition, it provided all the information generated in the operation of the prototype (*e.g.*, data, graphs or alarms), as well as allowed its management and intervention.

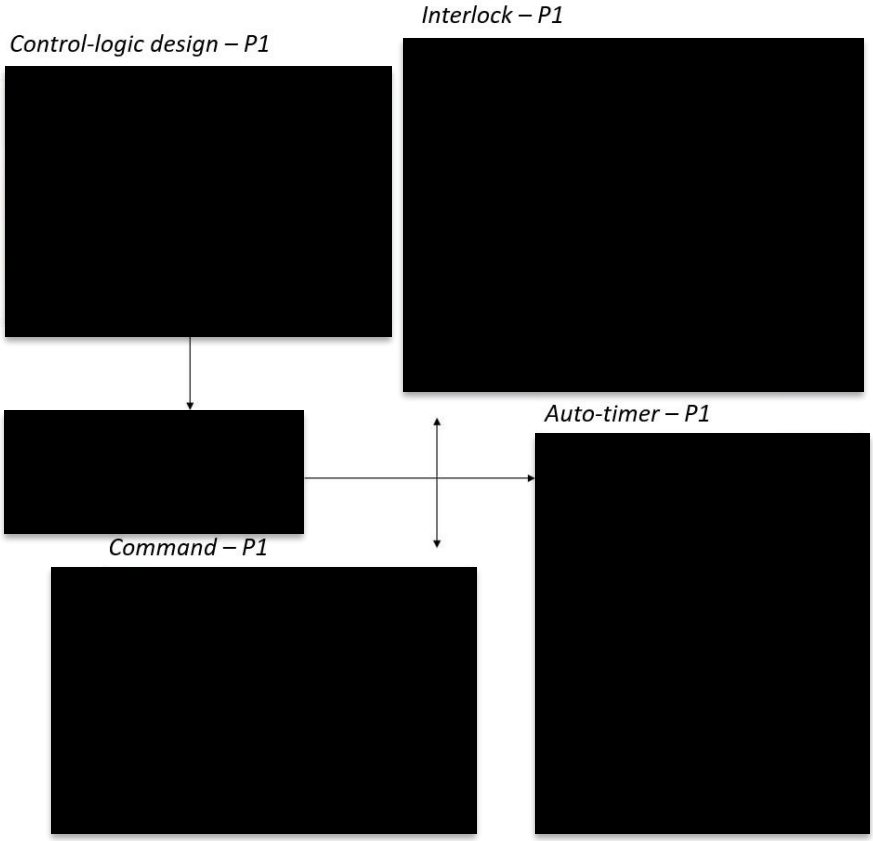


Figure 13. Structure of the control logic for the P-1 pump of the LIFE Multi-AD technological solution.

Figure 14. Control system architecture of LIFE Multi-AD technological solution.

Figure 15. HMI screen installed in the control and automation panel of the LIFE Multi-AD plant.

Figure 16. SCADA screen of the control and operation system of the LIFE Multi-AD plant.

Milestone M3 "Functional SCADA system for Multi-AD industrial units" was achieved with the development of this task.

6.1.3. Action B.3: Design and construction of the 100 m^3 Multi-AD demo unit

Beneficiary responsible		Status
AEMA		Finished
Time schedule	Starting date	End
8 months	July 2019	February 2020
Real-time schedule	Starting date	End
28 months	July 2019	October 2021

The aim of this action was to build the first industrial-scale Multi-AD device with 100 m^3 of capacity.

Action TB3.1: Reactor scaling-up and process flow diagram

The configuration of the first LIFE Multi-AD plant was deeply developed in accordance with the validated design in previous Action B1 and the special requirements of the industrial WWTP of AGE Winery. Moreover, several technical meetings with the providers ( ) and AGE Winery (on May, June and September 2020), as well as technical visits to industrial anaerobic treatment plant ( ) were carried out in order to increase the consortium knowledge and, in that way, achieve the most appropriate technological solution (Figure 17).

Figure 17. Technical meeting with provider ( ), AGE Winery and visit to AD plants.

Thus, the configuration of LIFE Multi-AD technological solution included:

- *pre-treatment process*:
- *anaerobic process*:
- *biogas line*:
- *sea container*:
- *pipping*:

Layout design of LIFE Multi-AD prototype was performed considering two main aspects: low foot-print (*i.e.*, 250 m^2) and ATEX zoning classification. Figure 18 shows the lay out in 2 and 3D. For this last one, SolidWorks software was used.

Figure 18. Construction drawings in 2 and 3D of LIFE Multi-AD technological solution.

A feasible design of Multi-AD rector was done based on the results of Action B1 and raw wastewater from AGE Winery (Figure 19). Thus, the demo 1:1 industrial-scale Multi-AD reactor, with a volume of 111 m^3 (9 m of height and 8.5 m of diameter at the bottom), had a maximum organic load of 2,000 kg COD/d and was capable to treat up to 200 m^3/d of wastewater. Multi-AD reactor was made up of influent distribution system, anaerobic reactor core ([redacted]) and gas-liquid-solid separation system.

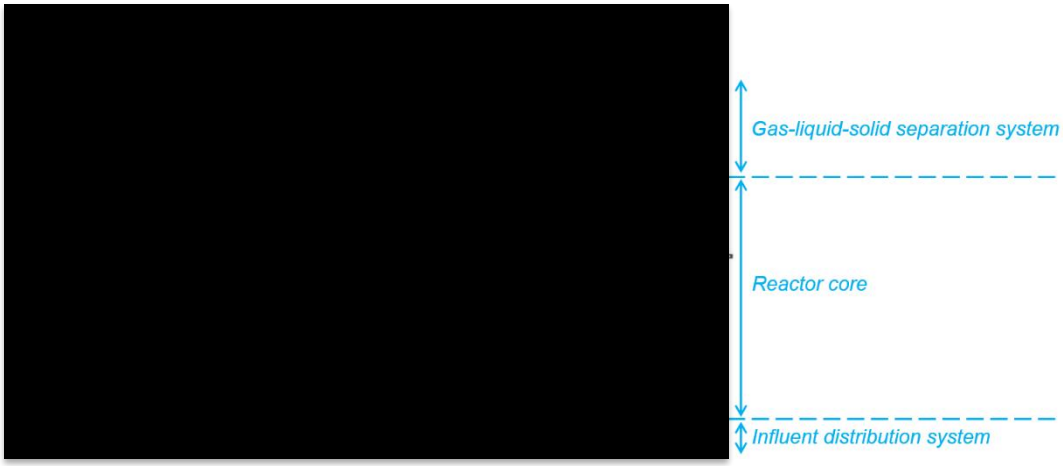


Figure 19. Drawing of LIFE Multi-AD reactor.

Deliverable **D6** "Drawings and components of 100 m^3 Multi-AD demo unit" showed detailed drawings of equipment, as well as Abismo.net data sheets of each component of LIFE technological solution. Milestone **M4** "Feasible reactor design" was achieved with the development of this task.

It is worth noting that several modifications must be made on the LIFE Multi-AD technological solution when compared to the proposal in order to adapt to the new site localisation, *i.e.*, AGE Winery. LIFE project objectives were not affected by the following modifications:

- *Multi-AD reactor*: [redacted]
- *water line*: [redacted]
- *gas line*: [redacted]
- *sea container*: [redacted]

<u>Action TB3.2</u> Manufacturing of 100 m^3 Multi-AD demo unit and control system implementation

The manufacturing of LIFE Multi-AD technological solution was performed focus simultaneously on three different elements, which is being manufactured in different places:

- *Multi-AD reactor*: [redacted]
- *sea container*: [redacted]
- *civil work, equipment installation, as well as mechanical and electrical assembly*: [redacted]

Figure 20. LIFE Multi-AD reactor at the premise of

Figure 21. Sea container, which hosts a heating room, in AEMA workshop (Alfaro, SPAIN).

Figure 22. Civil work equipment installation, as well as mechanical and electrical assembly in AGE Winery (Fuenmayor, SPAIN) to build the LIFE Multi-AD demo unit.

In general terms, the LIFE Multi-AD prototype consists of:

- *pre-treatment*: a set of elements aimed at achieving the physic-chemical characteristics of the wastewater suitable for the anaerobic process).

- *anaerobic process*: units whose group objective was to achieve the operational parameters for wastewater purification, as well as the valorisation of organic matter into biogas ([redacted])
- *biogas line*: set of elements with the common objective of treating biogas for thermal recovery in the plant itself [redacted]

In these three main sections, a set of elements were installed that enable the technological solution to be safely controlled, operated and monitored (Figure 23):

- *instrumentation*: group of elements to measure, transmit, control and/or record process variables [redacted].
- *health and safety*: units that aim to ensure safe operation of the Multi-AD plant [redacted].
- *labelling:* group of elements used for the quick and clear identification of each of the prototype units, as well as to facilitate the explanation and understanding of the technology ([redacted].

A greater degree of detail on each of the physical components of the LIFE Multi-AD demonstration plant was shown in Deliverable **D**7 "Report on the construction of the 100 m^3 Multi-AD demonstration unit".

Finally, the operating manual for the process control system of LIFE Multi-AD technological solution was described in Deliverable **D8** "Drawing and operating manual for process control system", which handles all the equipment that is controlled by the PLC. Interlocks, alarms and automatic conditions were handled in this manual, as well as all tag numbers of tank, equipment, valve and instrument refers to LIFE Multi-AD P&ID. The manual first described how the specific part of the process needs to work and, afterwards, all equipment was described in detail.

Milestone **M5** "Construction of the 100 m^3 Multi-AD demo unit" and **M6** "FAT for Process control" were achieved with the development of this task.

6.1.4. Action B.5: Demo experience in real environment

Beneficiary responsible		Status
AEMA		Finished
Time schedule	Starting date	End
26 months	January 2020	February 2022
Real-time schedule	Starting date	End
20 months	November 2021	June 2023

The aim of this action was to validate in real industrial environment the 100 m^3 Multi-AD demo unit built in Action B3.

<u>Action TB4.1:</u> Starting up and testing the 100 m^3 demo unit at the winery

The commissioning process was performed using a methodical approach to ensure that all operational components of the Multi-AD technology solution worked as planned. First, a specific protocol for the start-up of Multi-AD technological solutions was created. This hand-book described in a procedural manner the different stages to be carried out in order to achieve a planned commissioning, regulation and balancing of the equipment and systems. Thus, start-up was executed in three consecutive phases: pneumatic and hydraulic, electromechanical and biological.

Pneumatic and hydraulic phase: This phase was carried out by performing the tightness tests of the equipment and tanks that make up the water and gas lines in accordance with a protocol specifically generated by AEMA. In order to ensure the safe operation of the plant, special attention was paid to the

correct functioning of the safety valves installed in the biogas line and of the integrated plunger tubes in the head of the anaerobic reactor.

Figure 23. Details of LIFE Multi-AD instrumentation, health and safety and labelling elements.

Figure 24 shows the evolution of the water film height and pressure of the Multi-AD reactor, as well as the ambient temperature during a tightness test. As can be seen in the graph, the pressure drop inside the reactor after 48 hours was less than [redacted] mbar, which allows us to conclude that, according to the start-up protocol, the reactor had an appropriate tightness.

Figure 24. Pressure and water film height of the Multi-AD reactor and ambient temperature during leak test.

Electromechanical phase: This phase was performed following the procedure specially created for this phase. Thus, it was carried out an exhaustive monitoring of LIFE Multi-AD technological solution, checking the state of materials, equipment, instrumentation, as well as related documentation. Subsequently, live electromechanical tests were carried out, sequentially checking the powering up of all the equipment and its correct operation. In addition, the different calibrations and necessary verifications of the plant's instrumentation were carried out.

Finally, AEMA supervised the correct operation of the automation and control system of each of the processes that make up the Multi-AD technological solution. Specifically, the configuration and alarm parameters were checked in detail, as well as the wet operation of each of the equipment. As a result of the electromechanical phase, a checklist was generated of each of the equipment that make up the LIFE Multi-AD technological solution.

Biological phase: Biological phase started with the seeding of granular sludge ( ) from the anaerobic reactor of in order to increase the speed and robustness of the start-up (Figure 25). This fact is especially relevant in a high load anaerobic reactor such as Multi-AD, mainly due to the low growth and granulation rates of the anaerobic biomass.

Figure 25. Images of the Multi-AD reactor seeding process.

Once biomass was seeded, hydraulic and organic load of Multi-AD reactor was increased in order to achieve a rapid adaptation of the anaerobic granular sludge to the wastewater to be treated (Figure 26). It is important to note that, during this period, the prototype was carefully monitored to ensure a specific load in the water to be treated. AEMA paid special attention to the physic-chemical characteristics of the effluent, as well as to the process parameters of the anaerobic digestion.

Specifically, the technological solution was fed with loads up to 10% of the design values: 200 kg COD/d. The loading was increased once the Multi-AD reached steady state for several hydraulic

retention times, *i.e.*, selected process parameters reached constant value (COD degradation >80% and VFA <200 mg/L). More detailed information about start-up phase was described by Deliverable **D9** "Start-up on the demo unit installed".

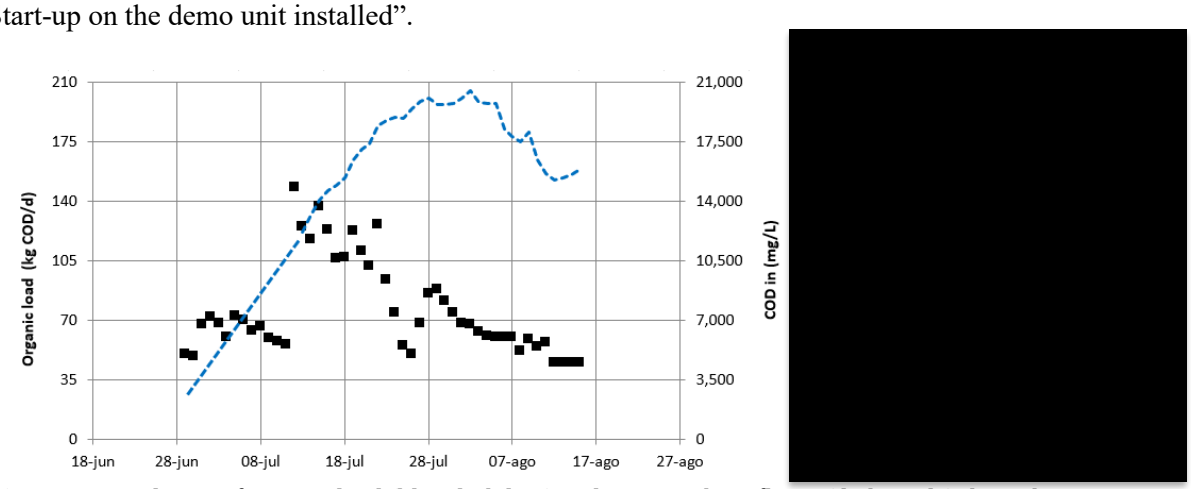


Figure 26. Evolution of organic load (blue dash line) and COD in the influent (dark circle) throughout start-up process, as well as imagines of winery wastewater.

On the other hand, during the start-up period, training was provided for the personnel who operated and controlled the plant. In this way, training and informative actions were carried out on the health and safety of biogas plants (ATEX UNE 60079-14+UNE 60079-17), operation and maintenance of biogas lines, basic fundamentals of anaerobic processes, as well as control and operation of the LIFE Multi-AD plant (Figure 27).

Figure 27. Pictures of the training and informative actions of the LIFE Multi-AD operation staff.

Milestone **M7** "Adaptation of the granular sludge and anaerobic reaction running stable" was achieved with the development of this task.

Action TB4.2: Running testing procedures and Action TB4.4. Validation of final design

Multi-AD technological solution was operated in continuous mode (24 hours per day, 7 days per week) during twelve months: pre-harvest, harvest and post-harvest period. During this demonstration phase, the anaerobic reactor treated 10,088 m^3 of winery wastewater with 112,214 kg COD.

Technical assessment of anaerobic process: Despite influent variability, organic was gradually increased from 200 to 1,000 kg COD/day by means of COD based control strategy, which automatically operated Multi-AD technological solution at constant organic load by means of a mass balance over the anaerobic reactor (Figure 28).

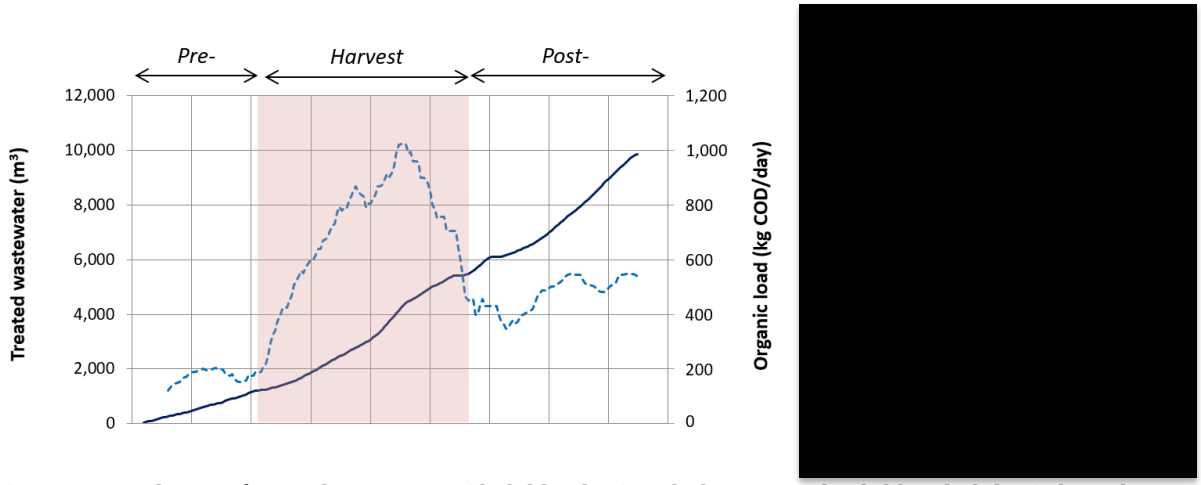


Figure 28. Evolution of treated wastewater (dark blue line) with the organic load (blue dash line) throughout continuous operation time in the Multi-AD technological solution. Picture

The planned increase in organic load took place once the anaerobic reactor reached steady state. Thus, the values of the following process parameters were evaluated: pH (6.8-7.2), alkalinity (>1,000 mg $CaCO_3$/L), VFA (<200 mg/L) and COD (<800 mg/L). Figure 29 shows that pH, alkalinity and VFA had optimal values for the anaerobic digestion process, which shows that Multi-AD devise did not have any episodes of destabilisation or overloading.

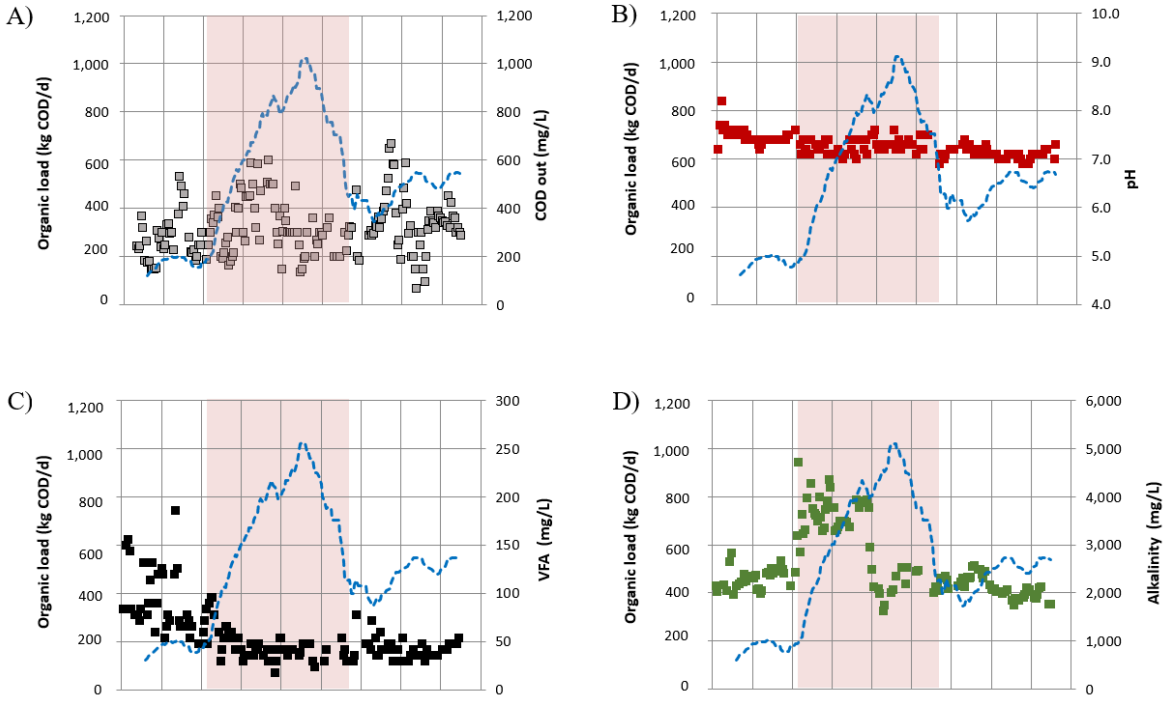


Figure 29. Evolution of COD (grey square), pH (red square), VFA (dark square) and alkalinity (green square) with the organic load (blue dash line) throughout continuous operation time in the Multi-AD technology.

It important to note that the effluent COD concentration was always lower than 700 mg/L during the validation period, regardless of operating temperatures (*i.e.*, 36 or 28ºC). This fact, considering the influent COD concentration, resulted in a mean degradation efficiency above 95% (Figure 30). These results are in line with previous studies with this kind of wastewater.

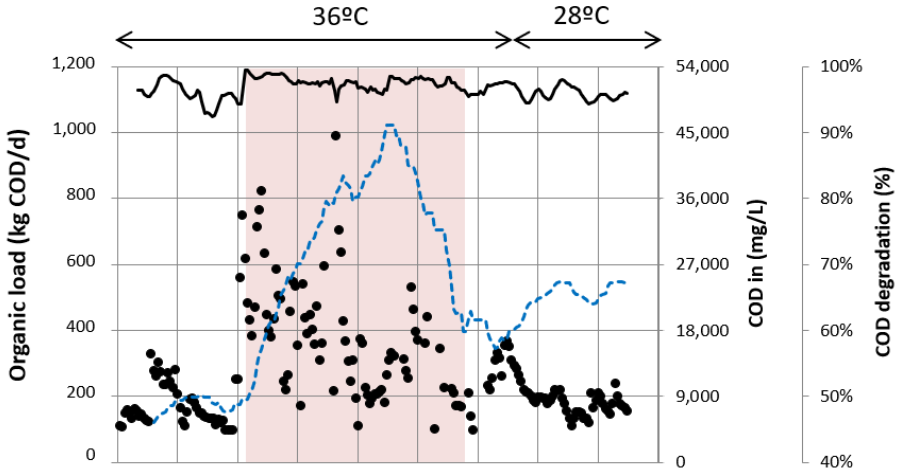


Figure 30. Evolution of COD in the influent (dark circle) and COD degradation (dark line) throughout continuous operation time in the Multi-AD technological solution.

Figure 31 shows that there was a decrease in soluble organic matter through Multi-AD reactor chambers. It can be seen, therefore, that there was a stepwise conversion, chamber by chamber, in line with the design purpose of a multi-stage reactor, where each chamber behaved as a continuous stirred tank reactor (CSTR). This fact may indicate that a Multi-AD reactor was capable of achieving better degradation rates for the same volume than a conventional anaerobic reactor such as UASB.

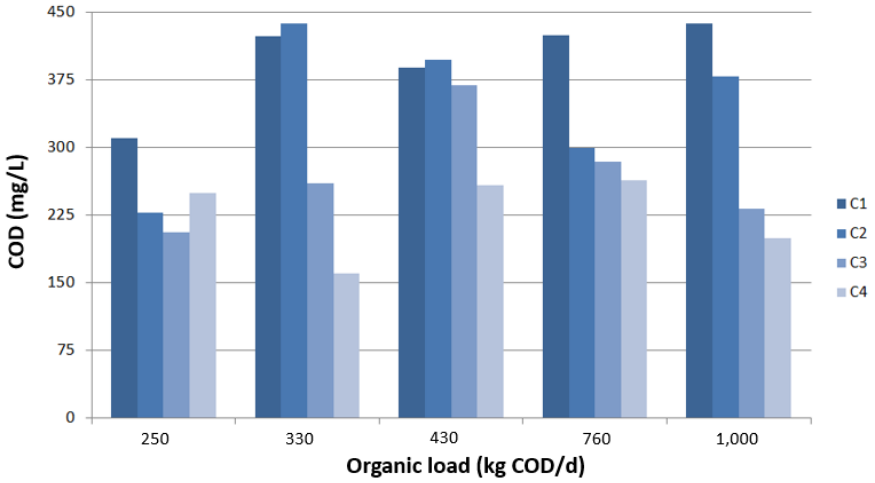


Figure 31. Evolution of soluble COD of wastewater throughout Multi-AD reactor (*i.e.*, chambers) at different organic loads.

Anaerobic digestion process carried out a valorisation of the organic matter resulting in the production of biogas. Figure 32 shows the flow rate and composition of biogas along different organic load. The increase in the organic load produced a notable increase in the biogas flow rate, which reached maximum values of 450 m^3/day. In fact, Multi-AD degradation of winery wastewater generated biogas conversion of 0.36 m^3/kg COD removed, with a biogas production of 3.3 m^3/m^3·day at the highest studied organic load (*i.e.*, 1,000 kg/d).

The combustible gas generated after Multi-AD technology was characterised by a methane mean value of 84%. It is noteworthy that organic load increase did not produce notable variations in the composition of the biogas, which had a mean methane content higher than 80%. High concentration in hydrogen sulphide up to 3,000 ppm, biogas pollutant that was removed by the bioscrubber. Specifically, the

desulphurization tower achieved yield removal higher than 99% and subsequently, hydrogen sulphide concentration in the treated biogas lower than 10 ppm.

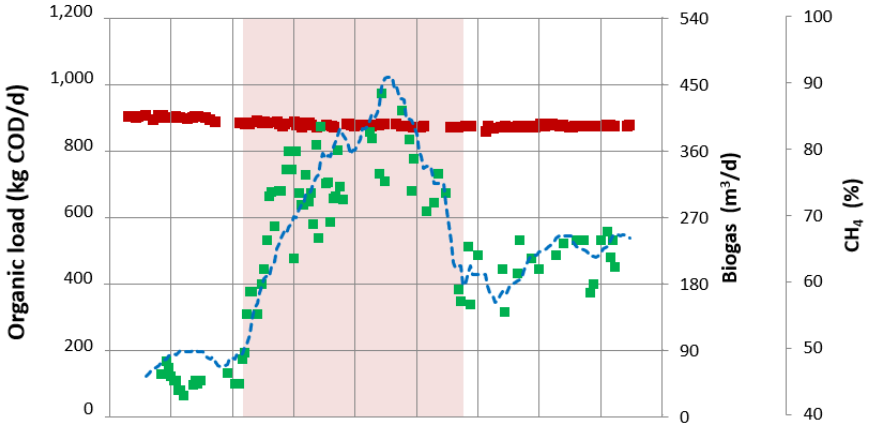


Figure 32. Evolution of COD in the influent (dark circle) and COD degradation (dark line) throughout continuous operation time in the Multi-AD technological solution.

Finally, it is important to emphasise that physico-chemical monitoring was done at the demo unit plant as well as laboratory tests by AGUAS RIOJA, LABORATORIOS ALFARO (accredited laboratory) and AGE Winery. This fact highlights the robustness of the data obtained.

Economical assessment of anaerobic process: Throughout the continuous operation of the Multi-AD plant, the consumption of chemicals as well as other energy-related resources, such as diesel and electricity, was recorded (Table 1).

Table 1. Consumption of chemical compounds and other resources during the continuous operation process. It was considered: 10,088 m^3 of wastewater treated and 121 tn COD.

Chemical compounds	Total amount	Relative amount	
		Volume	Organic load
Sosa	[redacted]	[redacted]	[redacted]
Hydrochloric acid	[redacted]	[redacted]	[redacted]
Urea	[redacted]	[redacted]	[redacted]
Phosphoric acid	[redacted]	[redacted]	[redacted]
Ferric chloride	[redacted]	[redacted]	[redacted]
Micro-nutrients (TE-310)	[redacted]	[redacted]	[redacted]
Other resources	**Total amount**	**Volume**	**Organic load**
Diesel	[redacted]	[redacted]	[redacted]
Electrical energy	[redacted]	[redacted]	[redacted]

Among the chemical compounds, soda is the main reagent used as a consequence of the low pH of the effluent coming from the winery. Multi-AD technology had demands of [redacted] kg/m^3 of treated water. Finally, it is noteworthy that the plant had a constant electricity consumption within the range [redacted] kWh/day independent of the treated water flow. This fact resulted in consumptions of [redacted] kWh/m^3.

More detailed information about the running test was described in Deliverable **D10** "Report with conclusions from testing the 100 m^3 demo unit". Conclusions obtained during the validation period allowed to reach Milestone **M8** "The 100 m^3 demo unit installed reaches expected results" of this task.

<u>Action TB4.3:</u> Re-design and optimization of the scaling-up

The results achieved throughout the continuous operation of the demo unit were constantly analysed by the consortium in order to carry out a process of continuous improvement of the Multi-AD technological solution.

This evaluation made it possible to detect 26 challenges, which were studied in detail in order to identify the solution to be carried out to improve Multi-AD (Table 2). In fact, 42% of the issues took place in the biogas line, which highlights the improved level of knowledge of the consortium in the industrial development of technologies based on anaerobic processes. It is also important to note that nine challenges were related to safety and health aspects (two directly and seven indirectly), which should be considered as priority issues for future Multi-AD plants.

On the other hand, engineering design was the main task to improve since more than 70% of the challenges were as a consequence of its activity. The rest of tasks (*i.e.*¸ equipment design, mechanical assembly and programming) add up to only five issues.

Table 2. List of issues of Multi-AD technology, which was identified along the demonstration phase.

Code	Issue	Point	Task
[redacted]			

Deliverable **D11** "Report on optimization of the Multi-AD design and control system" contained a datasheet of each of the issues, identifying its location in the P&ID, as well as describing the incident and the action required to solve it.

6.1.4. Action B.5: Anaerobic reactor design tool

Beneficiary responsible		Status
ITAINNOVA		Finished
Time schedule	Starting date	End
26 months	January 2020	February 2022
Real-time schedule	Starting date	End
48 months	January 2020	June 2023

The objective of this action was to develop a design tool that can be used to pre-design and optimise new Multi-AD devices, taking into consideration all relevant parameters.

Action TB5.1: User requirement analysis

Multiple template technological solutions are included in the toolkit since the designed plant has to be adapted to the F&D industry (*i.e.*, flow and characteristics of wastewater), as well as to the requirements of the discharge final destination (*i.e.*, collector, where wastewater will be finally treated in a municipal WWTP or natural water body such as river or lake).

The combination of two Multi-AD reactor geometries [redacted]; four different systems for the biogas treatment [redacted] and three post-treatment configurations [redacted] were presented in this action. All of them may be combined to develop the most adequate plant design. Up to 48 different plant configurations could be obtained when combining the possibilities regarding wastewater treatments, Multi-AD reactor geometries and biogas treatments assessed in the design tool (Figure 33).

Figure 33. Different configurations of the LIFE Multi-AD technology solution are defined.

A modelling methodology and software are configured (*i.e.*, Python for modelling, data imported/exported to .csv or excel files and modular model) in order to define all the input and outputs needed for the design of new technological solutions (layout, process parameters, mass and energy balances or instrumentation restriction).

Action TB5.2: Simulation and data analysis

The models the subsystems that make up LIFE Multi-AD technological solution are defined and created (Figure 34). Among others, the Multi-AD reactor model should be highlighted due to its novelty. It integrated the biochemical model ADM1 (Anaerobic Digestion Model No.1) with hydrodynamics real-time model (Reduced Order Model, ROM). This model will be improved making use of the data obtained in the experimental campaign with which the Data Driven Improved Model (DDIM) for mixing and elutriation will be developed.

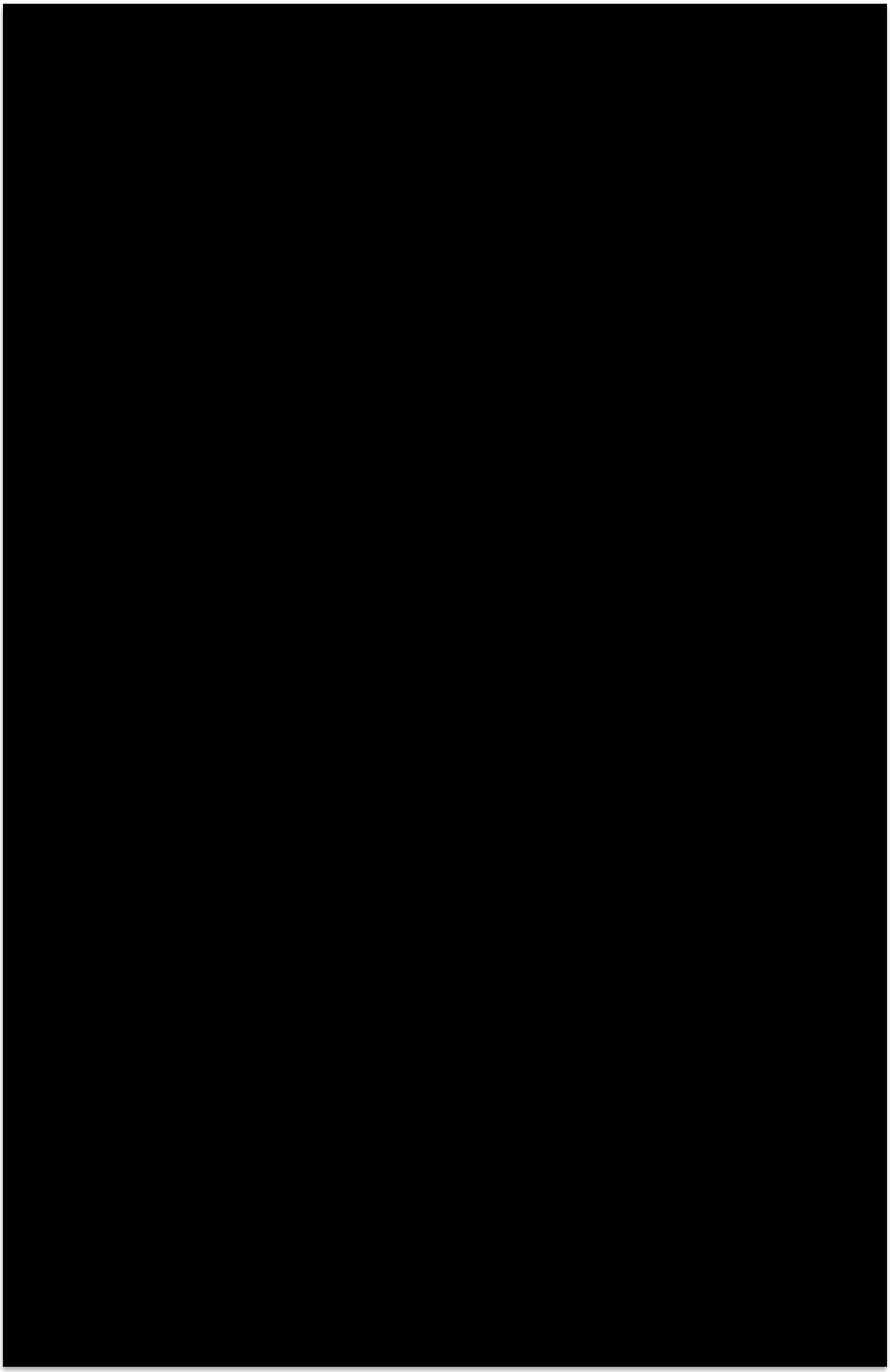


Figure 34. Equations of each of the modules that make up the LIFE Multi-AD technological solution.

Hydrodynamics real-time model: A real-time ROM was developed to introduce the CFD simulation in the reactor module. This ROM was built following these steps:

- *definition of the virtual Design of Experiments (DOE)*. The DOE generation tool was based on a library previously developed by ITAINNOVA aimed to provide optimal DOEs according to the characteristics of the model.
- *workflow creation.* A workflow was created to launch the batches of CFD simulations in an HPC infrastructure.
- *development of the ROM*. Once CFD results were obtained, a high-performance data analysis (HPA) tool developed by ITAINNOVA was used and adapted to analyse data from the simulations. The HPA tool is based on tensor factorization techniques.

Biochemical model: ADM1, widely used for biogas generation plant modelling, was implemented in the tool developed following a recently published simplification (Figure 35).

Figure 35. Systematic procedure for the simplification of the ADM1 model).

It is important to note that this model was improved by integrating it with both the mixing results of the hydrodynamic model and the experimental data. In this line, this improved model based on data (DDIM) of the integrated biochemical and hydrodynamic phenomena gave a better calculation of the composition of the treated water, as well as the flow rate and composition of the biogas.

Deliverable **D12** "Plant template system models jointly defined by AEMA and ITAINNOVA" explained in detail all the information described above. All this generated knowledge makes it possible to achieve the milestone **M9** "Reduce Order Model (ROM)".

<u>Action TB5.3:</u> Data collection from 100 L prototype demo experiences

The 100 L prototype was modified in order to obtain design similarity with 100 m^3 demo unit installed in AGE Winery (*i.e.*, reactor and water process line) with aim of assessing Multi-AD reactor capability to treat wastewater from vegetable processing industries (Figure 35). Data collection was performed in order to validate the model, as well as generate a data-base for populating "Anaerobic reactor design tool" software.

Technical assessment of anaerobic process: Prototype was operated in continuous mode, 24 h per day and 7 d per week. During demonstration phase, organic load rate (ORL) was gradually increase from 2 to 20 kg COD/m^3·d (*i.e.*, 200 to 2,000 g COD/day). The planned increase in OLR took place once anaerobic reactor reaches the steady state according to process parameters such as pH, alkalinity, VFA and COD.

Multi-AD reactor showed very high organic matter degradation performances. In particular, as shown in Figure 36, removal rates above 90% were demonstrated. Therefore, although a rise in COD of the anaerobic effluent was observed with increasing ORL, this fact is not caused by a notable decrease in the degradation capacity of the reactor but by the notable increase in the organic load to be treated.

The anaerobic reactor performed a valorisation of organic matter resulting in the production of biogas: 0.33 m^3/COD removed. Figure 37 shows the biogas flow rate and methane composition with ORL increasing. The increase in the ORL leaded to a rise in the flow of biogas generated. It is noteworthy that this increase in the volumetric load did not produce notable variations in the composition of the biogas, which had a minimum methane content of 75%.

Figure 36. 100 L LIFE Multi-AD technological solution installed at AEMA (Alfaro) and anaerobic reactor dimension.

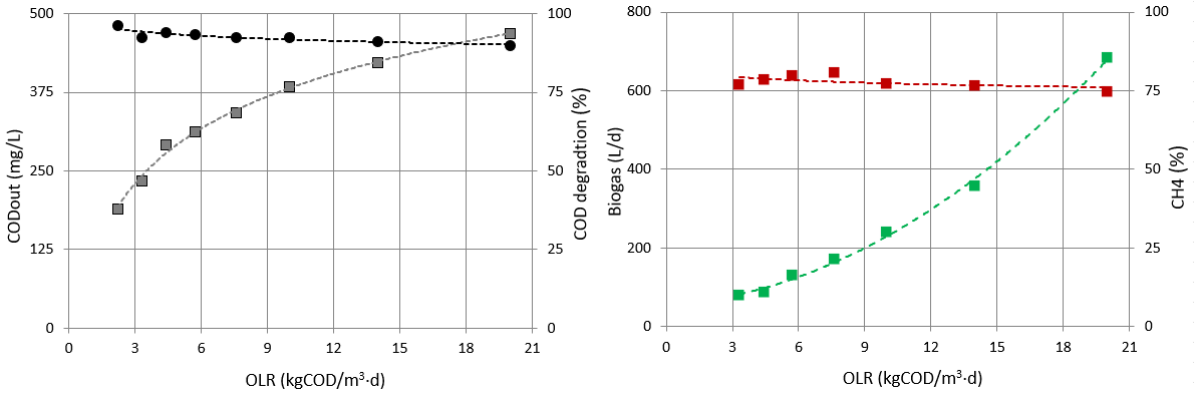


Figure 37. Evolution of COD in the effluent (grey square), COD degradation (dark circle), biogas flow (grey square) and methane percentage (red square) throughout organic load rate (ORL).

Scenario assessment: The results obtained in the experimental phase allowed for scenario assessments of technical feasibility of incorporating the Multi-AD solution in the WWTP of vegetable processing industry, in which the degradation of organic matter is performed by means of an aerobic biological process (*i.e.*, base-aerobic scenario) (Figure 38).

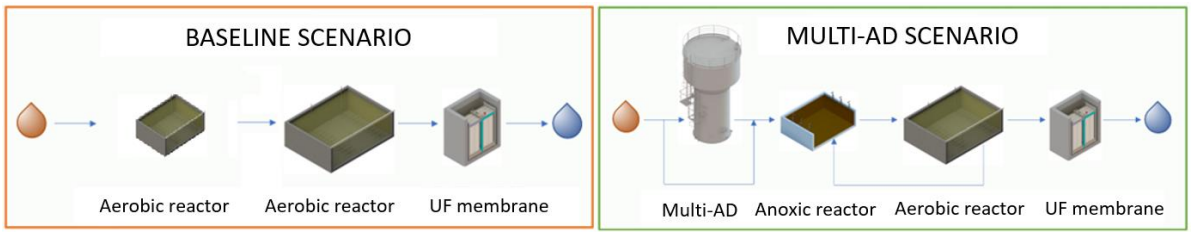


Figure 38. Graphical abstract of the two scenarios analysed: base scenario and Multi-AD.

Multi-AD scenario consists of a process line that modifies the current WWTP, integrating, downstream of the homogeniser, a 450 m^3 anaerobic reactor. The anaerobic reactor, designed for volumetric loads

of 20 kg/m^3·d and maximum daily flows of 1,250 m^3, enables of sustainable treatment of organic loads of up to 9,000 kg COD/d with minimum TRH of 9 h. It is important to note that the process line did not consider that a Multi-AD reactor treated wastewater flow because, due to the degradation performances: high COD and low nitrogen. In this line, the integration of the Multi-AD technological package in the WWTP under study required the integration of an anoxic-aerobic process in order to carry out the elimination of nitrogen up to concentrations that allowed fulfil the limits for discharge into watercourses.

The theoretical comparison of scenarios, based on aerobic and Multi-AD processes, showed that the integration of the anaerobic system reduces the energy consumption of the industrial WWTP by 60%, as well as minimising sludge production by 71% (Table 3).

Table 3. Energy consumption and waste generation baseline scenario (aerobic) and Multi-AD (anaerobic).

Consumption	Scenario					Variation
	Base	Multi-AD				
	Aerobic	Anaerobic	Anoxic	Aerobic	Total	
Electrical energy (kWh/kg COD)						
Electrical energy (kWh/kg N)						
Total electrical energy (kWh/d)						
Electrical energy (kWh/m^3)						60%
Sludge (kgCODsludge/kgCOD)						
Sludge (kgVS/kgCOD)						
Sludge (kgVS/kgN)						
Sludge (kgVS/kgTS)						
Sludge (kgTS/d)						
Sludge (kgTS/m^3)						71%

Action TB5.4: GUI and Cloud service development

The aforementioned simulation models were integrated into the Design Tool, which resulted in a robust and user-friendly software interface to assess the feasibility and to optimise the design of Multi-AD reactors. This novel software tool allows users to simulate and evaluate several reactor configurations, process parameters and wastewater characteristics to find the most efficient solution.

The main features of the Design Tool include:

- *wastewater characterization*: the relevant wastewater parameters are inputs of the tool; thus, users can evaluate the efficiency of Multi-AD reactor for their specific agro-industrial context.
- *reactor configuration*: the tool enabled users to explore Multi-AD reactors for three different diameter-height ratios and compare the corresponding results in terms of geometric and process parameters.
- *biogas production*: the ADM implemented in the Design tool allows to assess the biogas production potential, estimating the quantity and quality of the biogas generated from the stated wastewater properties.

The creation of the Design Tool involved a software development process whose aim was to obtain a robust and usable tool that can be easily incorporated into AEMA productive systems. Thus, the Design Tool software consisted of an Excel file in .xlsm format linked to a Python script. The Excel file served as the user interface (Figure 39), providing a popular platform for users to input the data and configure parameters for quick scenario analysis.

Additionally, the .xlsm format supported the required macros to link Python and Excel. Connected to the Excel file, the Python script functions represented the computational engine. Python's robust libraries allowed it to process the input data, perform complex iterative calculations and provided accurate results. For this reason, Python was a suitable tool for the efficient implementation of the Anaerobic Reactor Design Model. Figure 40 shows flowchart of Design Tool for a give D/h ratio as example.

As this tool aimed at being utilised in industrial context, the following features for the design of this software must be considered:

- *easy-to-use*: all the target users of the Anaerobic Reactor Design Tool, such as engineers, researchers and practitioners involved in agro-industrial wastewater treatment, with varying levels of expertise, must be able to work with the software.
- *interchangeability*: many industries already rely on Excel as a widely used tool for data analysis and reporting. Therefore, the Design Tool became compatible with existing workflows, and it facilitated the inclusion of the tool into their processes.
- *accurate*: the main goal of the tool was to assess the performance of anaerobic reactor designs for wastewater treatment that allowed the users to make informed decisions regarding the design, operation and optimization of the Multi-AD reactors.

Figure 39. Design Tool Interface.

Figure 40. Flowchart of Design Tool for a give D/h ratio

Deliverable **D13** "Web-based application and GUI" explained in detail all the information described above. The knowledge generated in this activity allowed it to reach the milestone **M10** "Anaerobic Reactor Design Tool".

6.1.5. Action B.6: Market launching preparation

Beneficiary responsible		Status
AEMA		Finished
Time schedule	Starting date	End
20 months	July 2020	February 2022
Real-time schedule	Starting date	End
40 months	July 2020	June 2023

The aim was to perform the development of national and international business strategy, and took care of the regulatory and knowledge protection tasks in order to guarantee that the Multi-AD technology complies with the corresponding EU regulation and safety standards and that it could be exploited.

Action TB6.1: Commercialisation strategy and preparatory steps for commercialisation

Return on investment (ROI) analysis: Among all AEMA customers (>600 references in the F&D sector), seven representative clients were selected to analyse the integration of Multi-AD technology into their facility: [redacted] (meat-slaughterhouse), [redacted] (dairy) [redacted] (beverage - winery), [redacted] (canned vegetable).

The selected group of companies is characterised by:

- representing each subsector of the F&D industry.
- being preferably SMEs, irrespective of whether it belongs to a group of companies.
- having an environmental challenge that can be overcome with the integration of Multi-AD.
- discharging treated water either to municipal sewers or to the public water body.
- localising as close as possible to AEMA headquarter in order to reduce OPEX and CAPEX
- having financial capacity to carry out an investment of Multi-AD technological solutions.

ROI was used to evaluate the efficiency or profitability of Multi-AD investment for selected potential customer. The values showed a strong variability due to the specific characteristics of each case study, however it is possible to identify a pattern depending on the sub-sector under study (Figure 41).

Figure 41. Return of investment (ROI) for Multi-AD potential clients along 10 years by Food and Drink sector: beverage (red), canned (green), meat-slaughterhouse (yellow) and dairy (blue).

The investment in Multi-AD could be quickly recouped in the two companies in the canned vegetables subsector. ROI values close to 400% and return periods of around two years were achieved on case study of [redacted]. Both companies are characterised by high operational costs associated with

reagent consumption (i.e., liquid oxygen) and sludge management, mainly associated with peach season [redacted] and pea [redacted].

On the other hand, in the beverage subsector, wineries ([redacted]) had ROI between 8 and 56% with return-on-investment periods between 6 and 9 years, whereas companies associated with the meat-slaughterhouse ([redacted]) and dairy ([redacted]) subsector had low ROI and high return on investment: <5%.

Deliverable **D14** "ROI for Multi-AD's clients" described capital and operational expenditures, as well as return on investment analysis in detail.

Business plan: First, a detailed analysis of European anaerobic wastewater technology market overview was carried out from a macro perspective. This fact allowed for identifying drivers, restraints, opportunities, trends, market investment feasibility, opportunity orbits, among others.

Figure 42 shows PEST (political, economic, social, and technological) analysis, a management method that examines the effect that events or influences from outside may have on the performance of our "company" LIFE Multi-AD. Focus on the technological impact, which the consortium influenced with the LIFE Multi-AD technological solution:

- *positive impact of technologies such as Multi-AD*. It impacts positively through the development of new trends and more advanced technologies. Technology that should result in a more efficient WWTP as well as a more feasible reactor.
- *negative impact is overcome with Multi-AD*. Incorrect or inefficient installation operated by unskilled labour that may affect the operation of the WWTP or may cause nuisance. This impact was expected to hinder market growth. Therefore, LIFE Multi-AD generated knowledge to facilitate the correct operation of the technological solution through technical manuals and fully automatization.

Figure 42. PEST analysis of anaerobic wastewater treatment.

Moreover, a segmentation of this global sector was done based on product type (*i.e.*, UASB, EGSB and IC), industry vertical (*i.e.*, food and drink, paper and chemistry) and countries (*i.e.*, Germany, France, UK, Russia, Italy, Spain and Rest of Europe).

On the other hand, a micro perspective was performed. Specifically, market analysis was carried out taking into account target customer (*i.e.*, F&D SMEs), market size ([redacted]), growth (*i.e.*, slowly decreasing), market segmentation (none of all F&D subsector produce wastewater to be treated by Multi-AD) and potential market penetration (*i.e.*, 0.001% for micro, 0.02% for very small, 0.22% for small and 2.2% for medium enterprises).

Finally, analysis of current technological alternatives to Multi-AD detected a market gap addressed for anaerobic processes applied to the food and beverage sector. In fact, AEMA, as responsible for

commercialisation of Multi-AD, was the first company to offer a disruptive and cost-effective solution specifically designed for SMEs. Due to AEMA current position in the F&D sector it had means to scale it industrially and commercialise it. Moreover, Multi-AD product offers the best value for money: 66% cheaper on average than current method (aerobic process) (Table 4).

Table 4. Comparison of Multi-AD with state-of-the-art alternatives.

	Aerobic treatment	Anaerobic treatment	Muti-AD
Reactor volume			
Treatment time			
Pollution degradation			
Sludge generation			
Convenience of use			
Environmental impact			
Operation cost			
Purchasing price			

All this knowledge was used to developed the procedure for placing Multi-AD technology on the market, implementation schedule, business strategy and profitability:

- *Procedure for placing Multi-AD on the market*. It was defined in six stages, each of them contributing with their individual know how. The Multi-AD devise to be marketed will be developed in contribution with other partners integrating the consortium, and to do so, each of them contribute with their individual know-how (Figure 43).

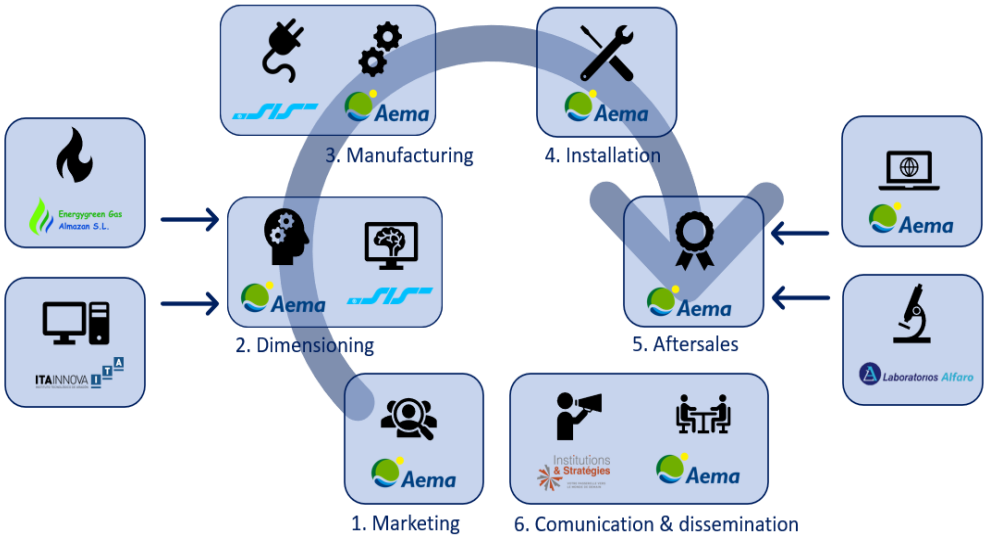


Figure 43. Procedure for placing Multi-AD technological solutions on the market.

- *Implementation schedule and business strategy*. Multi-AD technological solutions need to reach the market in an effective manner in order to have a wide impact. A preliminary schedule was defined involving six stages of development of the technology (Table 5).

Table 5. Implementation schedule from 2030 to 2040.

Year	Stage	Place	Potential market	Strategy
[redacted]				

- *sales*. They were predicted depending on the market that a Multi-AD technological solution is directed (*i.e.*, company size, year or expansion stage) (Table 6). 164 Multi-AD devices could potentially be up taken by the European market in within seven years post-project, generating a total sales volume of € million. This number of reactors represents 0.06% of the total number of F&B SMEs in Europe. Most Multi-AD reactors could be installed in medium companies (*i.e.*, 135 devices), which means 2.21% of enterprises of this size.

Table 6. Sales forecast of Multi-AD technological solutions from 2024-2030.

Sector	Micro SMEs[1]		Very small SMEs[2]		Small SMEs[3]		Medium SMEs[4]		SMEs	
	Units	€	Units	€	Units	€	Units	€	Units	€
[redacted]										

- *profitability*. ROI of 1,125% could be achieved in 2030. Considering a consortium investment in the LIFE Multi-AD project [redacted] ROI value would be less than three years.

More detailed information was described in Deliverable **D15** "Business Plan". This deliverable allowed us to reach Milestone **M11** "Business Plan" of this task.

Replicability and transferability plan: The consortium elaborated a Replication and transferability plan in order to facilitate the deployment of Multi-AD on a wide scale, cross-border and trans-sector. This action was greatly facilitated by the fact that the project demonstrated that the Multi-AD technological solution is a "close-to-market" project.

To this end, the consortium defined a schedule, in which the three first stages are key in order to achieve the replication and transferability of Multi-AD technological solution:

- *AGE Winery kick-off stage*. The objective was to carry out a process of continuous improvement of the facility for future Multi-AD plants. Multi-AD devices will treat all of the wastewater from the winery, as well as other effluent from surrounding industries during off-season periods in order to maximise the treatment capacity of the anaerobic system. Moreover, Multi-AD will be an innovation hub for anaerobic processes (*e.g.*, future R&D initiatives or specialised training)

as well as the demo plant in operation may be visited by future clients to facilitate the sales process.

- *Expansion in Spain.* In the first period, the entry into the market will be carried out with agri-food SMEs in the Ebro Valley, which is the main Food Production Hub in Spain. The target is F&D SMEs, companies that do not generate enough wastewater volume to justify the investment in large-scale anaerobic reactors. The companies analysed within the framework of the ROI study will be offered the technological solution. In a second period, penetration will be carried out in the rest of the Spanish market, paying main attention to F&B SMEs that discharge to municipal collectors and that demand the construction of a new WWTP where the investment returns are more friendly.
- *Jump to the Romania stage.* In 2026, Multi-AD will first penetrate into a market outside of Spain. Romania, in addition to being a local market of one consortium partner, is one of the largest wine producers in Europe. Another important fact is the growth potential that is established in this territory due to the need for new treatment facilities in wineries. Taking into account the international strategy, AEMA will build a local sales network integrated by a group of collaborating entities. It will be coordinated by a team of two international sales delegates from AEMA. The sales delegates as well expand the local sales network.

The lessons learned during the project must be taken into account in order to achieve a satisfactory execution of transferability and replicability of Multi-AD. Moreover, several tools should also be used to achieve the goal of the plan such as dissemination actions (*e.g.*, webpage, training activities, video, social media, among others), pre-designs *in silico* (*i.e.*, using "Anaerobic reactor design tool"), end-user 100 L pilot test or new R&D project.

More detailed information was found in Deliverable **D17** "Replicability and Transferability plan".

Action TB6.2: IPR management

The required documentation to achieve intellectual property right (IPR) protection to the whole Europe was performed under application number EP23382586.8: Reactor for high-performance multi-stage anaerobic system (Figure 44). The consortium counted with the help of the Spanish company PROTECTIA to manage the IPR application since this company was in charge of filling the application for the patent ES-2541078-B1, the origin of the project.


PROTECTIA
PATENTES Y MARCAS

SOLICITUD DE PATENTE EUROPEA

Núm. **23382586**
Denominación: **REACTOR PARA SISTEMA ANAEROBIO MULTI-ETAPA DE ALTO RENDIMIENTO**
Fecha solicitud: **13/06/2023**
Titular: **AGUA, ENERGÍA Y MEDIO AMBIENTE, SERVICIOS INTEGRALES, S.L.U., Instituto Tecnológico de Aragón**

Acknowledgement of receipt

We hereby acknowledge receipt of the following subsequently filed document(s):

Submission number	12175195
Application number	EP23382586.8
Date of receipt	27 June 2023
Receiving Office	European Patent Office, The Hague
Your reference	2023/0691
Applicant	All applicants as on file
Documents submitted	package-data.xml epf1038.pdf (1 p.) ep-sfd-request.xml TRANEAPP-1.pdf\2023-0691 Translation into English.pdf (16 p.)
Submitted by	CN=Alvaro Gonzalez Lopez Menchero 32391
Method of submission	Online
Date and time receipt generated	27 June 2023, 13:11 (CEST)
Message Digest	CB:DB:46:45:7B:4C:C6:21:E2:29:12:F8:29:44:21:EA:B0:2B:B7:14

/European Patent Office/

Figure 44. Screenshot of patent application form and acknowledgement of receipt from European Patents Office (EPO).

Furthermore, AEMA and ITAINNOVA are working on the IPR management of the Anaerobic Reactor Design Tool by a registration of intellectual property on the www.safecreative.org platform.

All the documentation generated in the IPR management process was part of the Deliverable **D16** "IPR management actions and certification".

Action TB6.3: Acquisition of necessary certification for market launching

Multi-AD technological solutions obtained the CE certification, which means that the product conforms with European health, safety, and environmental protection standards. The CE marking is required for goods sold in the European Economic Area (EEA), but is also found on products sold elsewhere that have been manufactured to EEA standards. The CE mark indicates that the product may be traded freely in any part of the EEA, regardless of its country of origin.

The required documentation to obtain the CE certification was carefully detailed in order to obtain the marking of the completed Multi-AD technological solution. All this documentation is grouped in two files that you can find in the annexes:

- *instruction manual*: the document contains instructions for installation, use and maintenance of Multi-AD products. The manual integrates CE declaration of conformity, which contains all relevant information to enable the identification of the applicable directives, as well as the details of the manufacturer (*i.e.*, AEMA) and Multi-AD product.
- *technical dossier manual*: the document intended to provide information on the design, manufacture and operation of the product. The technical file must be kept for at least 10 years from the date of manufacture of the product.

Figure 45 show different imagines of CE marking installed in the demo unit localised at AGE Winery.

Figure 45. Imagines of CE marking installed in Multi-AD technological solution installed in AGE Winery.

Deliverable **D16** "IPR management actions and certification" contained the documents generated to achieve the CE marking.

6.1.6. Action C.1: Monitoring

Beneficiary responsible		Status
SIS		Finished
Time schedule	**Starting date**	**End**
42 months	October 2018	February 2022
Real-time schedule	**Starting date**	**End**
54 months	October 2018	June 2023

The objective of this action was to take care of regularly monitoring the compliance of the developments in Multi-AD in order to ensure minimal possible deviation from the targeted values.

Action TC1.1: Assessment of the environmental impact

Twelve indicators were defined in order to assess the environmental impact of the implementation project actions, which can be classified in 4 groups:

- Reduction/substitution of dangerous substance
  - Oxygen liquid
  - Phosphoric acid
  - Urea
  - Flocculant

  - Soda
- Waste management
  - Sludge generation
  - Treated wastewater
  - COD in effluent
- Energy
  - Energy consumption
  - Generation for renewable energy
- GHG
  - Carbon footprint
  - Biogas generated

AGE Winery WWTP were defined as baseline scenarios in order to assess the impact of the LIFE Multi-AD project. The existing industrial WWTP has two process lines: water and sludge (Figure 46). Water process line is composed by:

- *primary treatment*: physical separation by rotatory screen, as well as equalisation and neutralisation by buffer tank.
- *secondary treatment*: biological treatment carried out by activated sludge process in two different aerobic tanks. First, a High load tank, in which liquid oxygen is used, and subsequently, Low load tank, where air is transferred to the liquid phase. Finally, the aerobic reactor together with the module of ultrafiltration membrane composes a Membrane Bioreactor (MBR).

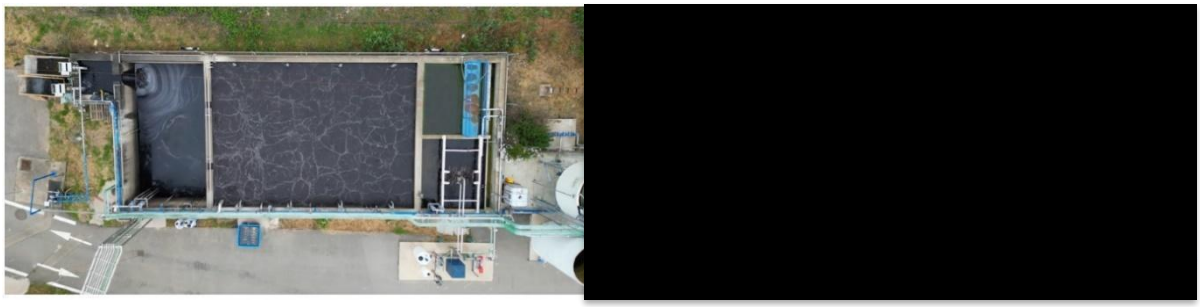


Figure 46. P&ID of existing industrial WWTP of AGE Winery.

Collected data and information, indicators and project performance parameters were computed in order to assess the contribution of the LIFE Multi-AD system to the reduction of greenhouse and hazardous pollutant emission and to the energy consumption. The measured benefits were compared to the current baseline and to the expectations defined at proposal stage: 3 different LIFE Multi-AD scenarios (Figure 47).

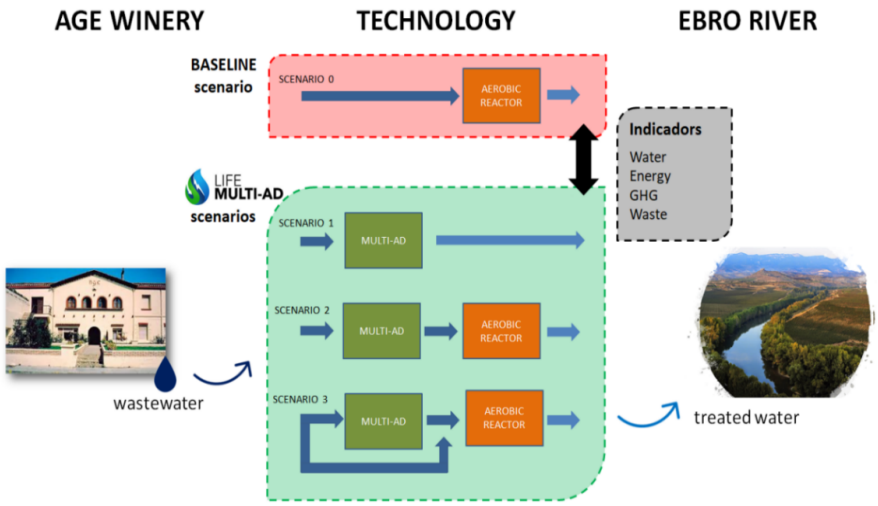


Figure 47. Graphical abstract of Action TC1.1 Monitoring of environmental impact of LIFE Multi-AD.

The outcomes of the evaluation (at demo scale) were projected and extrapolated to obtain indications about potential impacts at long-term, *i.e.*, 5 years after the project conclusion.

Table 7 shows the values of environmental indicators of baseline (Scenario 0), end of demonstration action (Scenario 1, 2 and 5) and long-term of scenario 2 once the Multi-AD plant will achieve the optimisation of the anaerobic process.

It is important to note that AGE Winery had a reduction in wastewater discharge from the baseline scenario (period from July 20 to June 21) to those studied in the project (period from July 22 to June 23) as a consequence of water management improvement measures inside the industry. These technological measures have not led to an increase in the pollutant load arriving at the WWTP, therefore the ratio per tonne of COD is considered the most appropriate for scenario comparison.

Indicators show that Scenario 1 (anaerobic process and discharge to municipal sewer) produces the greatest environmental improvements. This is a consequence of the savings in inputs such as energy or chemicals, the minimisation of waste such as sludge and the generation of renewable energy. All this translates into a significant reduction in the carbon footprint associated with water treatment.

Table 7. Value of environmental indicators of baseline scenario of LIFE Multi-AD project.

Indicator		Baseline	End demonstration action			Long term
		Scenario 0	Scenario 1	Scenario 2	Scenario3	Scenario 2
Treated wastewater	(m^3/year)	[redacted]				
Organic load to be treated	(tn COD/year)					
	(g COD/m^3)					
Treated organic load	(tn COD/year)					
	(g COD/m^3)					
COD effluent	(g COD/m^3)					
Liquid oxygen	(kg/year)					
	(kg/m^3)					
	(kg/tn COD)					
Urea	(kg/year)					
	(kg/m^3)					
	(kg/tn COD)					
Phosphoric	(kg/year)					
	(kg/m^3)					
	(kg/tn COD)					
Soda	(kg/year)					
	(kg/m^3)					
	(kg/tn COD)					
Flocculant	(kg/year)					
	(kg/m^3)					
	(kg/tn COD)					
Sludge production	(tn/year)					
	(kg/m^3)					
	(kg/tn COD)					
Biogas	(Nm^3/year)					
	(Nm^3/m^3)					
	(Nm^3/tn COD)					
Energy consumption	(kWh/year)					
	(kWh/m^3)					
	(kWh/tn COD)					
Energy consumption by anaerobic	(kWh/year)					
	(kWh/m^3)					
	(kWh/tn COD)					
Energy generation (thermal)	(kWh/year)					
	(kWh/m^3)					
	(kWh/tn COD)					
Carbon foot print	(CO2 tn/year)					
	(CO2 tn/m^3)					
	(CO2 tn/tn COD)					

<u>Action TC1.2:</u> Assessment of the socioeconomic impact

Fifty indicators were defined in order to assess the socioeconomic impact of the implementation project actions, which can be classified in 4 groups:

- Information and awareness raising of the general public
  - Workshops and other local events
  - Events attended at international levels
  - Project website and social media
  - Other tools for reaching/raising awareness of general public
    Presentation to client about the technology and the environmental problem addressed
- Capacity building
  - Relevant project contacted
  - Stakeholders interested on using the LIFE Multi-AD results
  - Scientific publications prepared
- Governance indicator
  - Involvement of NGOs and other relevant stakeholders in project activities
  - Policy maker meetings
- Indicators related to contribution to economic growth
  - Running cost during project and expected in case of continuation after project
  - Continuation/replication/transfer after the project period
  - Jobs created

The assessment of socioeconomic impact of LIFE Multi-AD project was performed by the following interactive phases (Figure 48):

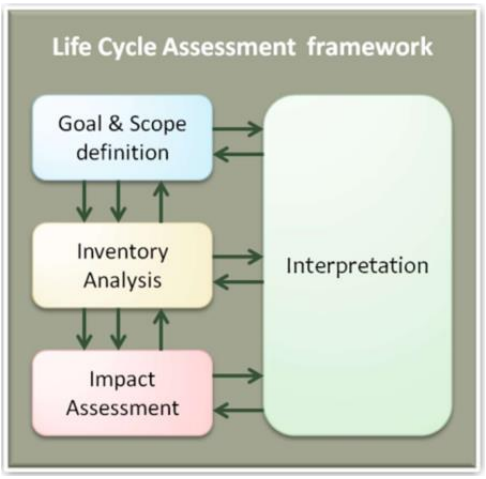


Figure 48. Graphical abstract of Action TC1.2 Monitoring of socioeconomic impact of LIFE Multi-AD.

Two approaches were considered to define the baseline scenario to identify the starting situation. On one hand, an overall assessment of the EU wine sector was done referring to 2018, as this was the year in which the project started. On the other hand, the measurable indicators related to the knowledge on the use of treatments methods were assessed throughout a questionnaire submitted to a large number of stakeholders (mainly wineries) contacted at the beginning of the project activities.

Table 8 shows the values of socio-economic indicators of LIFE Multi-AD project after the reporting period. In Deliverable **D18** "First report on the monitoring of the impact of the actions", **D19** "Second report on the monitoring of the impact of the actions" and **D20** "Third report on the monitoring of the impact of the actions" are shown detailed information of monitoring of the impact of LIFE Multi-AD project.

Milestone **M12** "Update of the KPI web tool by midterm report 1 (31 October 2019)", **M13** "All three reports on the monitoring of the impact of the actions successfully finished" and **M14** "Update of the KPI webtool by final report" were achieved.

Table 8. Value of socio-economic indicators of LIFE Multi-AD project.

Indicator name	End demonstration action	No of reached audience	Project impact assessment
1. Workshops and other local events organised	7	284	SI
2. Events attended at international level	28	6,688	SI
3. Project website and social media	116,355	25,904	SI
4. Other tools for reaching/raising awareness of general public	Leaflet: 300	300	SI
	Panels: 3	363	
	Newsletter: 7	113	
	Press release: 3	300,000	
	Posts: 57	25,904	
5. Presentation to client about the technology and the environmental problem addressed	14	-	SI
6. Relevant R&D project contacted	18	-	SI
7. Stakeholders interested on the results of Multi-AD: providers or potential providers	316	-	SI
8. Scientific publication prepared (paper and congress contribution)	5	-	SI
9. Involvement of NGOs and other relevant stakeholders in projects such as technological centres and platforms, universities or institutes.	10	-	SI
10. Policy makers meeting	7	-	SI
11. Running cost/operating cost during the project and expected in case of continuation after the project period	35,232,451.90€	-	SI
12. Future funding	2,000,000€	-	SI
13. Continuation/replication/transfer after the project period	36,728,121€	-	SI
14. Jobs	2.09	-	SI

MI: Medium Impact
SI: Significant Impact
NA: not applicable

6.1.7. Action D.1: Dissemination and Communication

Beneficiary responsible	Status	
I&S	Finished	
Time schedule	Starting date	End
42 months	September 2018	February 2022
Real-time schedule	Starting date	End
58 months	September 2018	June 2023

The aim was to provide LIFE Multi-AD with sufficient tools and resources to perform a successful communication activity and reach a wide dissemination of the project's activities and its results.

Action TD1.1: Dissemination and communication plan and material

A guideline was developed to help the consortium in performing the dissemination and communication actions and confirm that the activities targeted were successfully achieved or, if necessary, to act in consequence to do so. Thus, Deliverable **D21** "Dissemination and communication: reported of planned activities" includes the following sections:

- Strategy of communication
- Plan of communication and dissemination of the project
- Plan of implementation

This guideline set the dissemination strategy of LIFE Multi-AD, including goals of the plan, target audience, messages and channels, implementation, activities, schedule and proposal of ideas for technical articles and press releases.

As shown in Figure 49, communications actions during 2018-20 were scheduled in a more generalist way (low-profile) through blogs, webs and social media. They should focus on reaching the attention to the problems addressed in the project. On the other hand, actions during 2021-23 were scheduled in a more specific way (high-profile) through specialised press. They should focus, first, in disseminating prototype development, and then, the results of the demonstration experiments, *i.e.*, achievements.

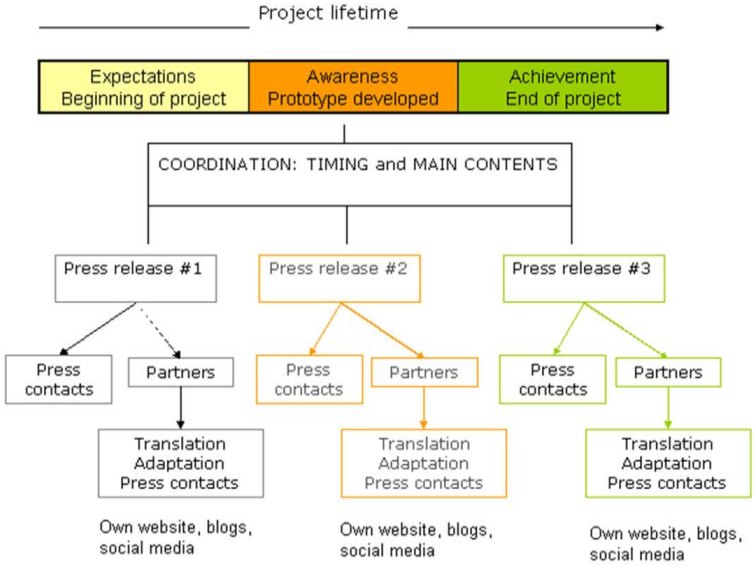


Figure 49. Communication plan graphical abstract of LIFE Multi-AD project.

LIFE Multi-AD visual identity was designed and developed. In order to create a coincidence of mark between LIFE Multi-AD and its corporate image, since the launch of LIFE Multi-AD, the project had its own image. The rule concerning the use of this logotype was that it was used together with the emblem of the LIFE program.

LIFE Multi-AD project website was created: www.lifemultiad.eu (Figure 59). It contains the relevant open access information of the project, as well as a member area, which was developed to make the confidential information exchange among partners. Furthermore, the website compiles information on some of the networking projects, documentation, dissemination references, as well as a landing page specifically created for the final workshop. The website includes a 'Responsibilities' section, which indicates that any communication or publication related to the project made by the beneficiaries jointly or individually in any form and using any means shall indicate that it reflects only the author's view and that European Commission is not responsible for any use that may be made of the information it contains.

The different sections of the website were improved and updated periodically and was available in English, Spanish, French and Rumanian, so that it was accessible to the target public or any interested stakeholder wherever they may be in the world. Milestone **M15** "Publishing of the project's dedicated website" was achieved.

The webpage is linked to social networks profiles, where it was published new posts or events, and where we interact with different groups from the target audience:

- LinkedIN: LIFE Multi-AD 4 AgroSMEs | LinkedIn
- X: LIFE Multi-AD 4 AgroSMEs (@lifemultiad) / X
- Facebook: LIFE Multi-AD 4 AgroSMEs - Inicio | Facebook

As specified on the web page and in the elements published on it, messages in social networks were written in English and in Spanish at least (Figure 50). It is worth to note that every member of the consortium was helping spread through their own websites and social networks, the dissemination and communication material.

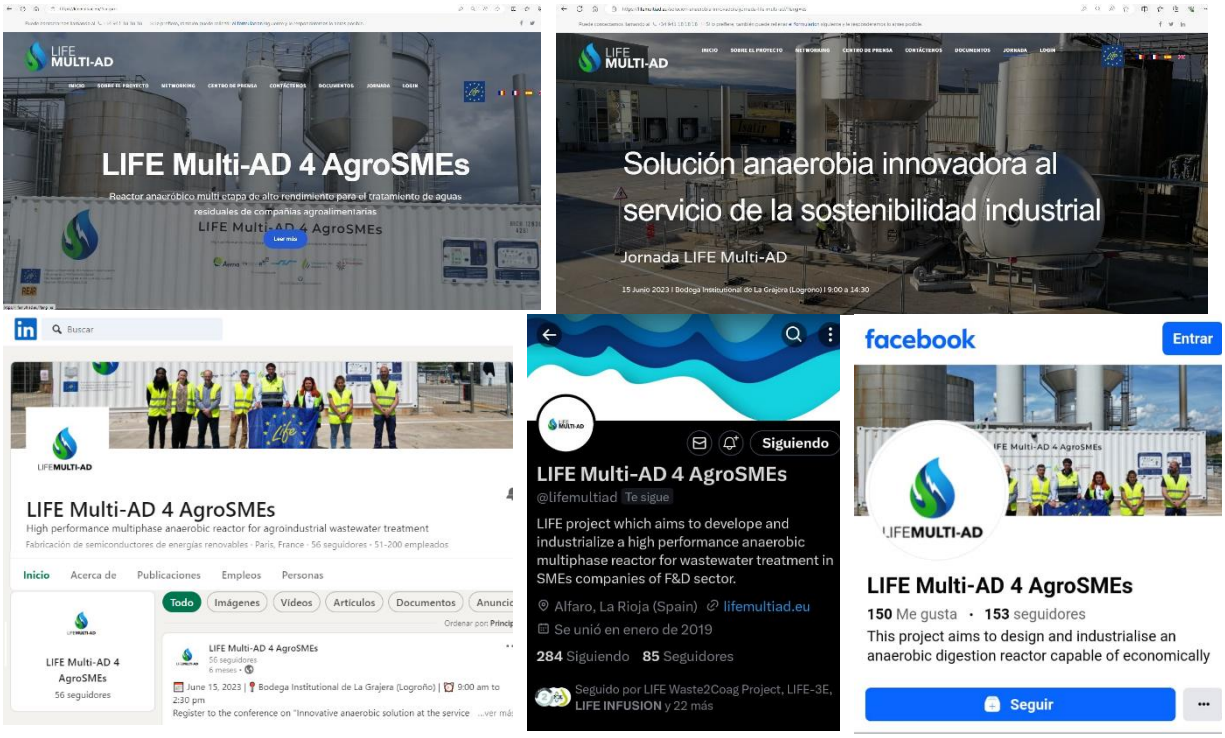


Figure 50. Webpage and social media (LinkedIn, Twitter and Facebook) of LIFE Multi-AD project.

The informative documents were designed and printed. General project leaflet, notice board, roll up banner and posters were produced in order to disseminate the project in mainstreaming activities and display them in visible place, accessible to the public (Figure 51). In this line, Layman's report was produced in several languages to reach the general public and contribute in disseminating project's results and LIFE initiative. The design was made similarly in Spanish, English, French and Rumanian in order to enlarge the impact. The electronic versions of aforementioned material are available on the web page, as well as on the Deliverable **D24** "Dissemination and communication materials produced"

Finally, an After-LIFE communication plan was produced during the project execution: Deliverable **D26** "After-LIFE dissemination and communication plan". It will be used to prepare active dissemination of the project results after the end of the project. The communication plan took into account the long-term visibility of the project and its results. The after-project communication plan should ensure the project viability and visibility after the end of the project.

<u>Action TD1.2:</u> Participation on thematic conferences and seminars, and networking with another relevant project

The LIFE Multi-AD participated in 28 conferences and seminars, in 24 of which the project itself, its objective and expected results were presented. The audience was formed by agri-food clusters, stakeholders, F&D companies and the local community. Thanks to these events, the audience was able to get to know different ways of reaching the ultimate goal: Multi-AD technology is considered one of the most sustainable alternatives for wastewater treatment in the F&D SMEs industry.

A list of events and some images of them are shown in Table 9 and Figure 52, respectively. Particularly relevant events were *International Bioenergy Congress - Valladolid* (583 attendees in 2021 and 4,386 attendees in 2023), *IWA International Conference on eco-Technologies for Wastewater Treatment - Girona* (500 attendees), *14th World Congress in Computational Mechanics and ECCOMAS Congress* (3,000 attendees), as well as the *MBR technology for the treatment of urban and industrial wastewater Master Class – online* (901 attendees).

Figure 51. Informative documents of LIFE Multi-AD project.

Table 9. List of events in which LIFE Multi-AD was shown.

Event	Organiser	Place	Date	Attendants
LIFE Annual meeting	EU	Brussels, BELGIUM	06/11/18	300
LIFE SEACAN networking event "Sustainable waste and wastewater management from agricultural and food industries"	SEACAN project	Santiago, SPAIN	23/01/19	10
Meeting against climate change at ENOMAQ	FEV&PTV	Zaragoza, SPAIN	04/03/19	70
Workshop "Innovative systems in the management and valorisation of wine by-products"	WETWINE project	Logroño, SPAIN	06/06/19	25
Workshop "I cross-border encounter on circular economy in the F&D sector"	ORHI project	Bayone, FRANCE	18/06/19	115
EU Water Innovation Conference EWIC 2019	MCUBO project	Zaragoza, SPAIN	11/12/19	900
LIFE Platform Meeting on Urban Waste Water	EASME	Barcelona, SPAIN	29/01/20	188
14th World Congress in Computational Mechanics and ECCOMAS Congress 2020	ECCOMAS	Online	11-15/01//21	3,000
LIFE VALOR PORC Event	VALOR PORC project	Ejea, SPAIN	25/03/21	10
IV International Technical Seminar on Water Management in Agri-Food Industries	AINIA	Valencia, SPAIN	30/09/21	130
15th International Bioenergy Congress	AVEBIOM	Valladolid, SPAIN	5-6/10/21	583
Plant Engineering Workshop (PEW 2023)	InIPED	Zaragoza, SPAIN	12/01/22	50
Biodigestion – LIFE Multi-AD 4 AgroSMEs Workshop	MULTI-AD project	Alfaro, SPAIN	3-4/11/22	32
II Techweek: Efficient and Circular Industry	ITAINNOVA	Online	23/11/22	56
MBR technology for the treatment of urban and industrial wastewater Master Class	AGUASRESIDUALES.info	Online	16/02/23	901
Best practices in the circular economy. ENORREGION Project	La Rioja Government	Logroño, SPAIN	27/04/23	43
11th International Workshop on Interdisciplinary Approaches in Fractal Analysis	IAFA	Bucharest, ROMANIA	25/05/23	50
Biogas as partner of in decarbonisation	ITAINNOVA	Zaragoza, SPAIN	31/05/23	35
Sustainability in the wine sector and the role of the ancillary industry	FER	Logroño, SPAIN	02/06/23	115
Innovative anaerobic solution for industrial sustainability	MULTI-AD project	Logroño, SPAIN	15/06/23	93
6th IWA International Conference on eco-Technologies for Wastewater Treatment	IWA	Girona, SPAIN	26-29/06/23	500
Water reclamation and reuse webinar	PTV	Online	14/09/23	151
Alimentaria FoodTech exhibition	IRTA	Barcelona, SPAIN	28/09/23	40
16th International Bioenergy Congress	AVEBIOM	Valladolid, SPAIN	3-4/10/23	4,386

LIFE Multi-AD had established a network of projects within the area of wastewater treatment and water management in the F&D industry, with which synergises have started to appear, by taking advantage of the experience and knowledge acquired in other projects.

Figure 52. Different events where LIFE Multi-AD project has actively participated.

Initially, the consortium identified several projects in the field of wastewater treatment and water management in the F&D industry that had synergies with LIFE Multi-AD. Then, contact was made via email and, once they showed interest in collaborating, a template was sent, where the project main data and contact information was collected, in addition to develop synergies existing between both projects. Moreover, this information appears in the Project website in a specific tag so that it is reflected. Table 10 shows a list of 18 R&D projects with which LIFE Multi-AD established networking activities and Figure 53 some imagines of meeting with the project of established network.

In this line, LIFE Multi-AD project actively took part in several networking activities, which have helped both to promote the project results and to raise awareness on the project main concern. Such activities include a networking event in the LIFE Platform Meeting on Urban Waste Water organised by EASME, several press releases to promote the project within the networking network, and virtual/personal meetings to share results and tackle common challenges with 9 technological centres (*e.g.*, AINIA or IRTA), 4 universities (*e.g.* Politehnica University of Bucharest or University of Santiago) and 2 innovation institutes (*e.g.*, International Institute of Plant Engineering and Design).

Table 10. List of projects with which LIFE Multi-AD project has stablished a network.

Project	Synergy
LIFE ALGAECAN: Adding sustainability to the fruit and vegetable processing industry through solar-powered algal wastewater treatment (LIFE16 ENV/ES/180).	Wastewater treatment in F&D industry
LIFE AMIA: Innovative combination of WWT Technologies for water reuse: anaerobic-aerobic, microalgae and AOP processes (LIFE18 ENV/ES/000170)	Anaerobic treatment
LIFE ANADRY: Dry anaerobic digestion as an alternative management & treatment solution for sewage sludge (LIFE14 ENV/ES/000524).	Anaerobic treatment
LIFE ECODIGESTION 2.0: Innovative technology scale-up for the control and automation of codigestion in WWTPs to produce green energy on demand (LIFE19 ENV/ES/000098).	Anaerobic treatment
LIFE iCirBus-4industry: Innovative circular businesses on energy, water, fertilizer &construction industries towards a greener economy (LIFE14 ENV/ES/688).	Organic matter valorisation
LIFE LEMNA: Lemna cultivation technology to improve nutrient management in pig production systems pig production systems LIFE15 ENV/ES/000382).	Water polishing treatment of nutrients
LIFE MCUBO: Modelling, Measurement and Improvement of the water management environmental impact in the food Industry (LIFE15 ENV/ES/000379).	Water management in F&D industry
H2020 HYDROUSA: Demonstration of water loops with innovative regenerative business models for the Mediterranean region (H2020/776643).	Anaerobic treatment
LIFE SEACAN: Reducing the pressure of fish canneries on the marine environment with novel effluent treatment and ecosystem monitoring	Wastewater treatment in F&D industry
LIFE PureAgroH2O: Pilot operation of innovative photo-catalytic nanofiltration technology for pollutant removal and water re-use of agro-industrial effluents (LIFE17 ENV/GR/000387).	Water reuse of F&D industry
LIFE STO3RE: Synergic TPAD and O3 process in WWTPs for resource efficient waste management (LIFE15 ENV/ES/000379).	Anaerobic treatment
LIFE AMIA: Innovative combination of WWT Technologies for water reuse: anaerobic-aerobic, microalgae and AOP processes (LIFE18/ENV/ES/000170)	Anaerobic treatment
LIFE ENRICH: Enhanced nitrogen and phosphorus recovery from wastewater and integration in the value chain (LIFE16 ENV/ES/000375)	Nutrient valorisation
WATER2RETURN: Recovery and recycling of nutrients turning wastewater into added-value products for a circular economy in agriculture (H2020/730398)	Wastewater treatment in F&D industry
INBEC: Boosting and developing a sustainable economy through innovation and business cooperation (Project 0627_INBEC_6_E)	Organic matter valorisation
WALLNUT: Closing waste water cycles for nutrient recovery (H2020/101000752)	Nutrient valorisation
MODEL2BIO: Modelling tool for giving value to agri-food residual streams in bio-based industries (H2020/887191)	Organic matter valorisation
LIFE DRY4GAS Wastewater sludge solar drying for energy recovery through gasification GAS (LIFE16 ENV/ES/000342).	Organic matter valorisation

Figure 53. Some networks events in which LIFE Multi-AD project with LIFE AMIA and LIFE DRY4GAS.

It is also important to emphasise that LIFE Multi-AD participated in the technological solutions forum promoted by LIFE PureAgroH2O. Emilia Markellou, Project Coordinator of LIFE PureAgroH2O, promoted the creation of a forum for the exchange of ideas and knowledge between the different stakeholders interested in the efficient management of wastewater. The forum, in which LIFE Multi-AD participated in the first meeting (1 September 2020), served to disseminate the best technologies developed in the framework of the recovery of resources from waste and the reuse of wastewater. The forum was also paying attention to the contribution of the different projects to the achievement of the European Green Deal by defining the best available technologies.

<u>Action TD1.3:</u> Reaching relevant stakeholders for multiplying the project's impact

The consortium identified a group of relevant stakeholders for multiplying the LIFE Multi-AD project's impact. This group involved all actors which could collaborate with the consortium on the search and successful achievement of new market opportunities. They could be both public and private actors. A list of sixteen relevant stakeholders is shown in Deliverable **D21**.

LIFE Multi-AD project was presented to 4 relevant technological platform (Spanish Wine Technology Platform, Croatian Competitiveness Cluster for Food Processing Sector, Spanish Food+i Cluster, Spanish National technology platform for F&D industry) and 7 NGOs (Federation of business persons from La Rioja, La Rioja Wine Auxiliary Industry Association, National Interprofessional Wine Organisation, National Wine Board, Association of Authorised Tasters of Romania, Association of Romanian Wine Producers and Exporters, Innovation Industrial Cluster in La Rioja). Moreover, LIFE Multi-AD project applied for innovation awards promoted by 2 private foundations with close contact to F&D industry: Institut Cerdá and Rafael del Pino.

It has to be highlighted that PTV included the LIFE Multi-AD project in its 3rd Strategic Innovation Plan. Special R&D Projects 2017-2019 presented by the PTV classifies these initiatives around the six areas including Sustainability and Climate Change. It is in this area where the LIFE Multi-AD project is framed. Moreover, the precursor project of LIFE Multi-AD, AD-Wine project, was the winner of the Innovation Awards 2019 of PTV. These facts showed the continuing interest of the aforementioned stakeholder in the project, as well as its ability for multiplying the project's impact (Figure 54).

Figure 54. Special R&D Projects 2017-2019 presented by PTV and PTV Innovation Awards 2019.

Furthermore, LIFE Multi-AD project was directly presented to 316 entities. The technological solution had almost 103 different providers and 106 potential providers, each of whom was informed about the project. These companies were considered as stakeholder because they are interested in the technology as a business. Furthermore, LIFE Multi-AD project was shown to 72 potential customers in webinar, conference and even in the Multi-AD installation itself and 15 competitors attended the project's communication days. The rest of the companies were 7 policy makers, 4 technological platforms and 7 NGOs. Figure 55 shows the logo of some of the LIFE Multi-AD technological providers and some imagines of technical meetings with providers and potential consumers.

Figure 55. LIFE Multi-AD technological providers and potential customer.

<u>Action TD1.4:</u> Dissemination and communication activities

Three main press release were published following the communication and dissemination of the project (Figure 49):

- *Press Release 1*: Multi-AD, a new reactor tailor-made for SMEs (18 October 2018). The main objective was to generate expectations about ground-breaking technology, *i.e.*, Multi-AD reactors.
- *Press Release 2*: LIFE Multi-AD, technological innovation at the service of sustainability (2 November 2021). The main objective was to show the awareness of the prototype developed.
- *Press Release 3*: A consortium led by AEMA develops a technology that improves sustainability in the European agri-food sector (24 May 2023). The main objective was to emphasise the achievements of the LIFE Multi-AD project.

Among the cited press release, 57 news were published in the press centre of LIFE Multi-AD webpage. All news related to the progress of the project, as well as information that may be of interest to the target audience of the same, are published in www.lifemultiad.eu, in English, Spanish, French and Rumanian, keeping the information constantly updated.

The consortium elaborated a video that summarises the project, its objective, as well as showing in detail the final prototype and its performance in an entertaining way to reach a wider and more varied audience. The video is uploaded both on the project website and LIFE Multi-AD YouTube channel.

LIFE Multi-AD website received 104,094 pageviews. This data was collected in four stages: 3,465 since February 2019 to March 2020, 86,562 in 2020, 10,583 from January 2021 to May2023 and 836 since June to October 2023 (Figure 56). It is worth noting that the high amount of visitor to the webpage could be due to share the name with medical device of BRAUN: MULTI-AD® Fluid Dispensing System (bbraunusa.com) or USA marketing company (http://www.multiad.com).

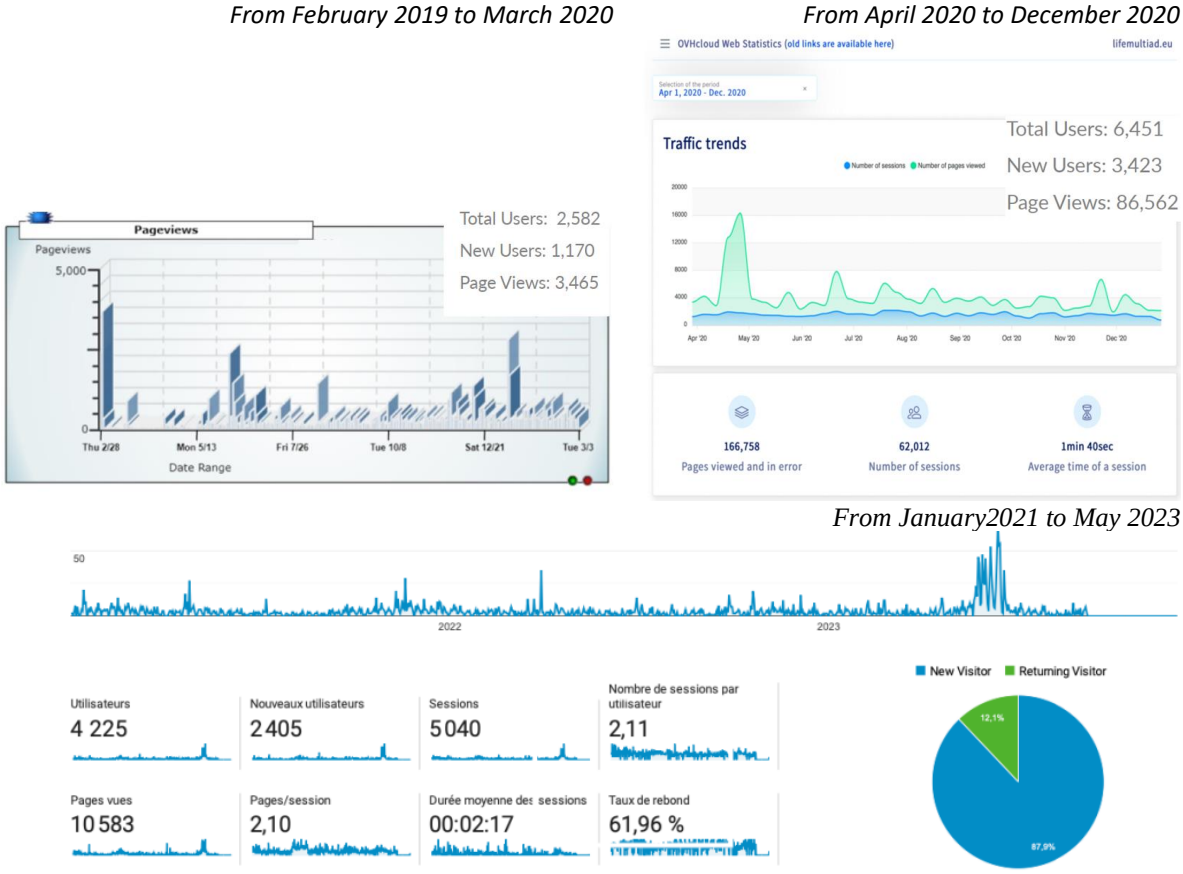


Figure 56. Visits of website of LIFE Multi-AD project according OVHcloud web statistics.

Similarly, the social networks were created to increase the impact of dissemination are constantly updated and interact with other similar profiles to increase the reach of dissemination and website visits.

Table 11. Indicators of social media of LIFE Multi-AD project.

Social media	Followers	Publications	Impressions	Mean impression per publication
Facebook	153	31	1,557	138
X	85	62	8,651	274
LinkedIn	56	25	1,601	216

Seven newsletters were developed since the beginning of the LIFE Multi-AD project. They were aimed at companies and technology centres. In these electronic bulletins, the consortium communicates the state of the project, last progresses being made and upcoming events. They are visible through the web page and social networks, in addition to be sent to the main agents and audience every 8 months. In addition to the submission, they have been uploaded on the web (News section) so that they can be made available for public download (Figure 56). The mean targeted audience was 114 people.

The results achieved during LIFE Multi-AD project were presented in 4 international congresses (Table 9), an article published in peer-reviewed journal (A practical approach for biochemical modelling in the CFD evaluation of novel anaerobic digester concepts for biogas production), as well as is part of the Guide of Best Practices on Circular Economy - La Rioja and the dissertation for Chemical Engineering degree – University of Zaragoza of Blanca Goicoechea. All these peer-reviewed

communications demonstrate the objective validity of the research conducted by LIFE Multi-AD according to scientific institutions, academia and public administrations.

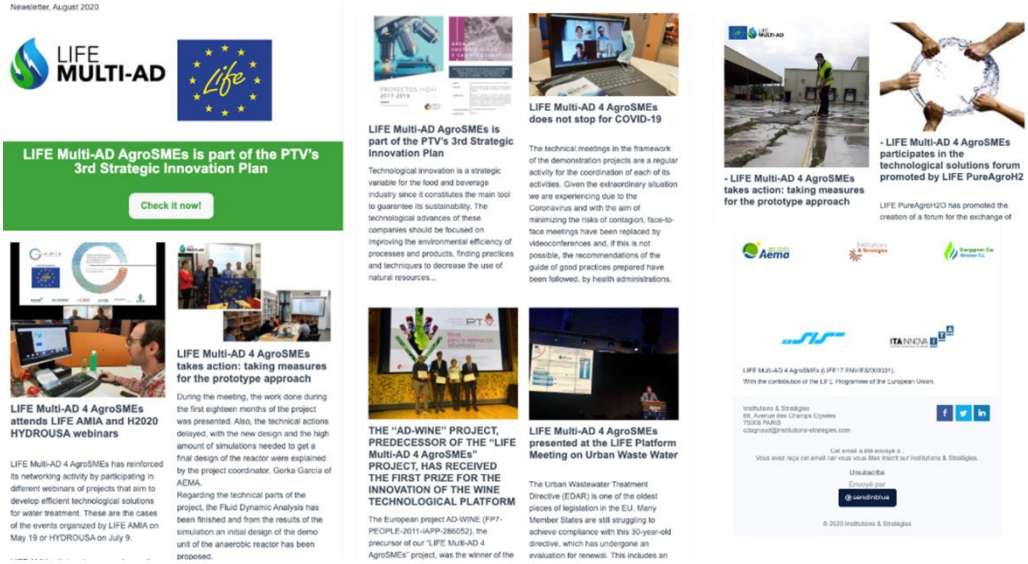


Figure 57. 3rd newsletter of LIFE Multi-AD project.

The consortium organised two kinds of events: local conference for general audience in order to increase social impact and technical workshop for a technology stakeholder. 5 local events were carried in school, high-school or university, in which more than 124 persons aged between 8 and 25 years (Figure 57). A commemorative LIFE Multi-AD project T-shirt was designed to amplify the social impact after the event. On the other hand, two technical workshops about anaerobic digestion were organised with 123 attendees. Specifically, the final event had 93 attendants and was an open-day to explain the technological solution to different stakeholders. The presentations were filmed and uploaded in the LIFE Multi-AD YouTube channel (Figure 59).

Figure 58. Imagines of local event organised in school, high-school and universities by LIFE Multi-AD.

Finally, active networking was carried out with 7 policy makers. LIFE Multi-AD technology was presented to Regional Government (Regional Development Department) and innovation agencies, as

well as sanitation entities such as EPSAR (Valencia Region), Consorcio de Aguas y Residuos (La Rioja) and ESAMUR (Murcia Region). The main result of these actions was the introduction of Multi-Ad technology within the Guide of Best Practices on Circular Economy – La Rioja (Figure 60).

Figure 59. Imagines of the final event of LIFE Multi-AD: technical workshop and open day.

Figure 60. Imagines of policymaker meetings.

More detailed information is found in Deliverable **D22** "Mid-term report on completed and planned Dissemination and communication activities", **D23** "Short report containing main highlights of technology relevant for policy makers", **D25** "Report stating the event or media reached for multiplying the project's impact".

6.1.8. Action E.1: Project Management

Beneficiary responsible		Status
AEMA		Finished
Time schedule	Starting date	End
42 months	September 2018	February 2022
Real-time schedule	Starting date	End
58 months	September 2018	June 2023

The aim of this action was to ensure a smooth technical, administrative and financial implementation of the project. The responsible partner was AEMA but all the other partners collaborate.

Action TE1.1: Project management and monitoring

AEMA as Coordinating Beneficiary was in charge of the overall technical and financial management of the project, supported by the responsibility of each partner. The project management was structured around the Steering Committee and the Implementation Team.

The SC was the highest authority within the Project. It included representatives from all partners and was headed by the Coordinating Beneficiary through the Project Manager. Its role was to advise and support the decisions of the Project Manager on operational and management issues. As a general rule, the SC met face to face once a year. In the meantime, their normal tasks were carried out by conference calls and emails. The SC members sent comments, decisions and confirmations to the Project Coordinator. The role of the Technical Committee was the supervision of day-to-day technical work. It included technical representatives from all partners, and it was coordinated by the Technical Coordinator from AEMA. This Technical Committee meets twice a year, being one at the same time as the SC meeting.

Moreover, it included external support for the financial management of LIFE Multi-AD project *i.e.*, PYRGUS as consultant. In fact, PYRGUS, together with [redacted] (AEMA), developed a Quality Plan, whose aim was to give a quick and short overview of the most relevant information, procedures and conditions for the partners in the LIFE Multi-AD such as guidelines for financial reporting.

In order to keep a continuous track of the partners and to ease the follow-up of the costs incurred by each beneficiary, the control of Summary of Costs in the project was done on a 6-monthly basis. [redacted] from AEMA was responsible for monitoring and checking the financial reports. Partners were provided with a "Financial report template" which has been used by each of the partners for the financial justifications in each of the reporting periods. The template was also used for the internal control of the project costs. Timesheets, certificates and all invoices of the costs reported by each partner and were marked with the name of the project as well as stored in their respective folder of OneDrive platform. All these financial documents have been audited by PYRGUS, which carried out six audits 2018-2019 and 2020, 2021, 2022 and 2023.

The Quality Plan and the internal audits contributed to guarantee that the invoices included a clear reference to the LIFE project in addition to the project's stamp. As a result, partners acquired the habit to ask project's providers to include explicitly the project's code in the description or detail of the invoice.

The Consortium Agreement among all partners was discussed and signed by AEMA and the corresponding beneficiary. Moreover, an additional partnership agreement was prepared and signed "Grant Agreement Commitment". This document replicated the arrangements approved in the Grant Agreement however, it included additional information and clarifications about the responsibilities among partners in the implementation of the project. Furthermore, Grant Agreement Commitment included clear indications about possible consequences of each partner in case of not accomplishing their responsibilities both at technical and financial level and the requirements established by the LIFE programme and EASME. This document contributed to clarify the role of each partner in the project and strengthen their commitment.

The communication procedures and tools used during the project were as simple as possible. 13 meetings gathering all project partners were held, including an initial kick-off meeting of the consortium, 6 project progression meetings and 5 general assemblies (Table 12). Furthermore, in order to ensure an appropriate management and coordination of the LIFE Multi-AD project, monthly meetings were organised by the coordinator via Microsoft Teams platform since November 2020. A copy of the presentation of these meetings, with the summary of the work carried out in each action, was regularly sent to all partners.

Table 12. Meeting calendar of LIFE Multi-AD project

Date	Place	Meeting
12/09/2018	Alfaro, SPAIN	Kick-off meeting of the consortium, official start of the project
26/09/2018	Paris, FRANCE	1st General assembly

Table 12. Meeting calendar of LIFE Multi-AD project (continued from previous page)

Date	Place	Meeting
06/10/2018	Brussels, BELGIUM	Kick-off meeting with the Contracting Authority representatives
19/12/2018	Online (Skype)	1st Project progression meeting
07/05/2019	Online (Skype)	2nd Project progression meeting
12/03/2020	Zaragoza, SPAIN	2nd General assembly – Monitoring meeting
02/10/2020	Online (Teams)	3rd Project progression meeting
05/02/2021	Online (Teams)	3rd General assembly – Monitoring meeting
23/09/2021	Online (Teams)	4th Project progression meeting
22/10/2021	Alfaro, SPAIN	4th General assembly – Monitoring meeting
27/09/2022	Online (Teams)	5th Project progression meeting – Monitoring meeting
26/04/2023	Fuenmayor, SPAIN	6th Project progression meeting
08/06/2023	Fuenmayor, SPAIN	5th General assembly – Monitoring meeting

Finally, AEMA was the single point of contact for the Commission and the only participant to report directly to the Commission on the technical and financial progress of the project. The Coordinator Beneficiary has communicated regularly with the Monitoring Team to report the project progress.

<u>Action TE1.2:</u> Risk management

Risk and contingency plan was foreseen identifying potential technological and commercial risks related to different actions. 15 risks were rated with a likeliness level (1 to 5 scale, from less -1 to more plausibility -5-) and an estimation of the potential risks. The consortium proposes mitigation actions and contingency plans to solve them in the most economic, practical and easy way. The consortium carried out a closely follow of the advancement of the project, identifying the potential risk of each action (Figure 61).

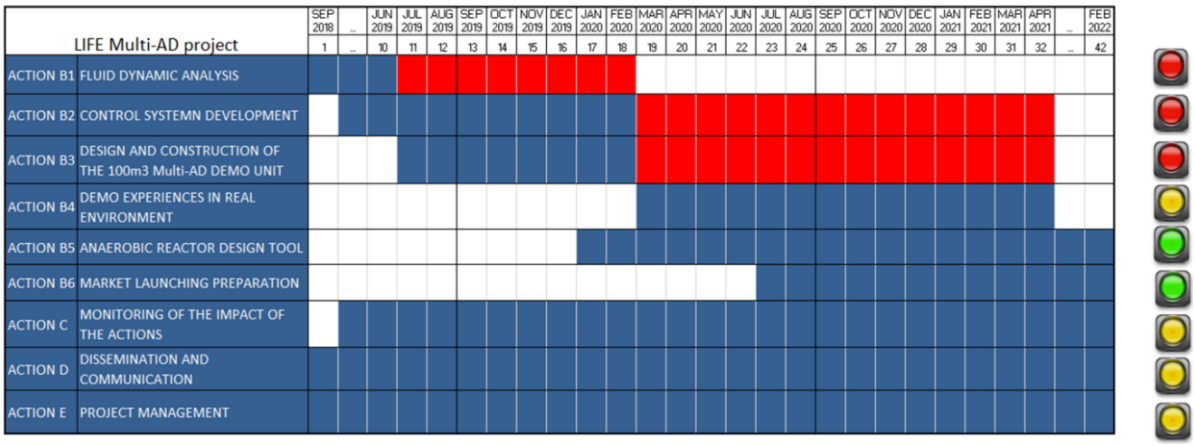


Figure 61. Grant chart of LIFE Multi-AD project including delay (red) and risk levels for each action.

Different problems and deviations were encountered in the project duration. Risk Management Plan was activated however, the problems and deviations that occurred, unfortunately, was not identified in the plan referenced. This fact notwithstanding, an adequate assessment of the impact of these challenges on the outcomes of the project and different measures were taken to overcome or alleviate the problems in questions (Figure 61).

<u>Action TE1.3:</u> Audit report

In order to ensure an accurate financing and administrative performance of the project, PYRGUS consulting carried out periodical audits. However, external audit to obtain a certificate by an approved auditor was not necessary to perform due to the maximum grant amount indicated for each of the beneficiaries and its affiliated entities in the estimated budget as reimbursement of actual cost is lower than 750,000 €.

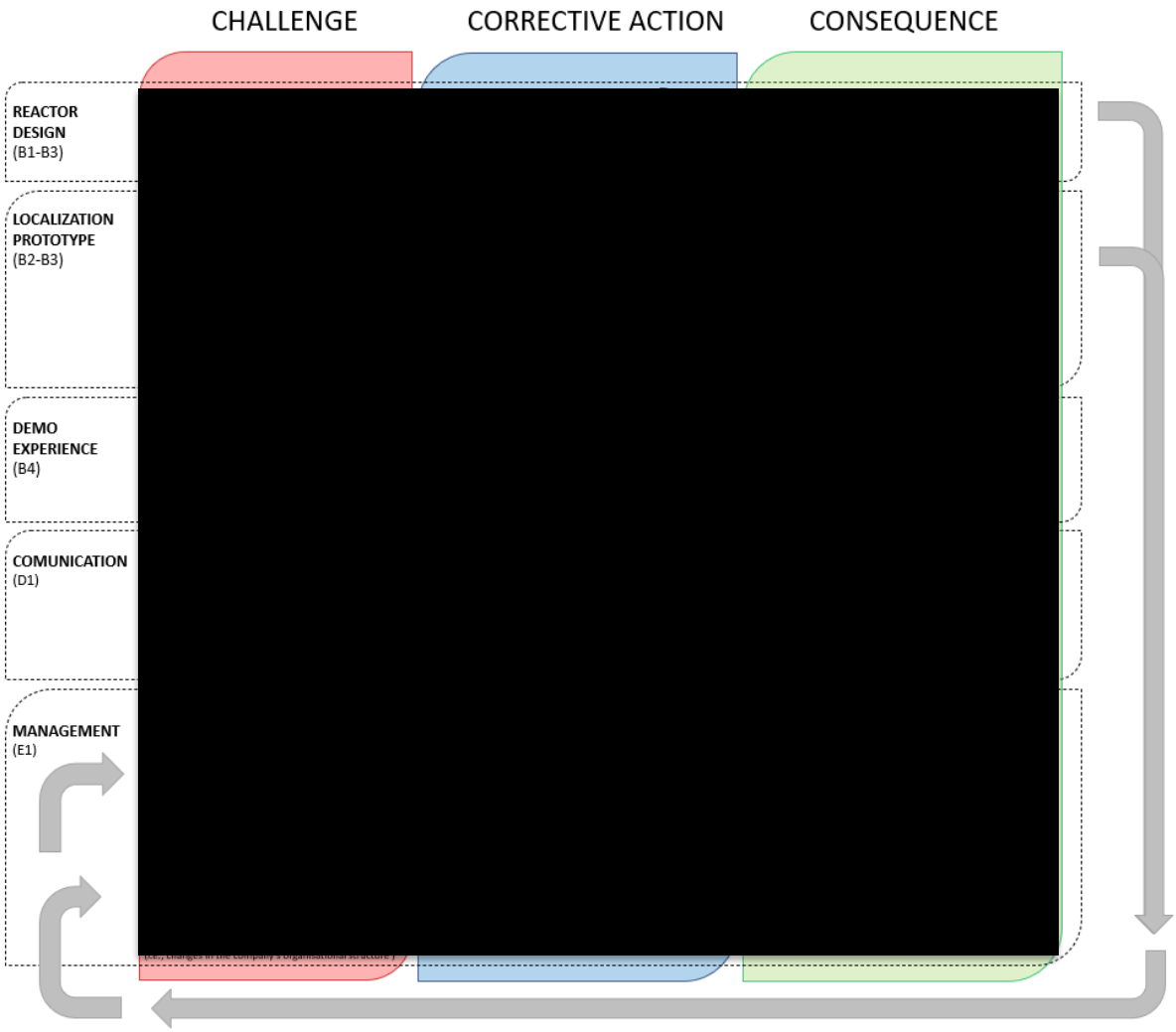


Figure 62. Graphic abstract of risk management carried out during the LIFE Multi-AD project.

<u>Action TE1.4:</u> Implementation of Green Procurement principles in the LIFE Multi-AD project

The consortium elaborated the Green Procurement Guideline (GHP) in order to ensure that the measures for fostering the use of Green Procurement principles. Deliverable **D27** "LIFE Multi-AD project guidelines to implement Green Procurement" has been developed to help all beneficiaries in procuring material, services and goods from responsible sources and from suppliers that use resources sustainably for a better environment.

Deliverable **D27** "Report on LIFE Multi-AD's Project Management" showed the activities performed in this action along the project. All the information described above allows to reach Milestone **M16** "Successful completion of the project".

6.2. Main deviations, problems and corrective actions implemented

The main deviations, problems and corrective action implemented by actions were:

Action B.1: Fluid dynamic analysis

Proposal for designing a new 100 m^3 Multi-AD reactor were delayed due to the necessity of ensuring an adequate performance of the anaerobic digester taking into account the limitations associated to the industrial-scale size. The height of the reactor should be reduced to keep the investment costs into reasonable levels. The geometrical similarity between the 100 L prototype and the industrial-scale

reactor is therefore lost. Moreover, biogas recirculation should be eliminated to avoid increasing the operating costs of the plant. These facts made necessary the modelling and simulation of different reactors to find a design able to carry out the wastewater treatment. Various CFD models based on the initial one but with the capacity of reducing the computational time were developed to accelerate this redesign process.

Action B.2: Control system development

First, changes to P&ID and process description were needed during 2019 to accommodate the deviations identified in the CFD simulations. Then, a new P&ID and process description were necessary to be carried out along 2020 because of the change of localization of the Multi-AD demo unit. There exit significant differences between Viñedos Winery and AGE Winery in term of wastewater (*i.e.*, flow and physico-chemical characteristics), space available for demo unit construction, as well as technical interconnection between LIFE Multi-AD prototype and existing winery WWTP. As a result, multiple changes were needed in the control system specification and PLC control logic. At this point, based on the final PID and description of the operating conditions we needed to rebuild the control system specification and PLC control logic.

Action B.3: Design and construction of the 100 m^3 Multi-AD demo unit

Changes to the design of the reactor and layout were needed during this period based on the CFD results and the scaling-up. As a consequence, the design of the three-phase separator had to be fully modified twice. Moreover, removal of biogas recirculation implied that the flow of liquid has to be recalculated and evaluated with the CFD model therefore the time to get a solution increased. This delay with the calculation of flow rates had prevented fixing the main elements of the plant (*i.e.*, pumps, pipes and tanks) delaying the final design, the acquisition of equipment.

Moreover, this action was notably affected by the unexpected setbacks due to the COVID-19 outbreak. On the one hand, the prototype, which was going to be located at Viñedos Winery (Aldeanueva, La Rioja) was not able to be built there. The change of localisation of demo unit, as mentioned above, significantly influenced on the design of Multi-AD reactor (*i.e.*, volume, geometry and materials), as well as the rest of elements which were part of the technological solution (*i.e.*, kind of process required and equipment dimensioning, among others). For instance, a decanter was designed in order to remove the high concentration of suspended solids in the raw wastewater. On the other hand, the state of alarm, which occurred during 2020 in Spain, did not allow the consortium to perform measurements in the end-user and the delivery time of material providers was notably affected during the period after the state of alarm. Therefore, due to the setbacks expected caused by the COVID outbreak, as well as the delay accumulated in the design phase, the execution of Action B3 was slower than the consortium planned in the first quarter of 2020.

Despite the consortium making a considerable effort in order to recover the delay accumulated, it was impossible to finish the prototype construction (TB.3.2) in October 2021.

Action B.4: Demo experience in real environment

The main problems encountered during this action was related to the start-up phase, specifically issues detected along pneumatic and electromechanical tests. Test implementation led to the diagnosis of two main challenges to be fixed: gas tightness and power panel.

Thus, in reference to gas tightness, neither the Multi-AD reactor nor biogas line managed to maintain the working pressure, which made it necessary to check the valves and welds using a soapy water solution. Once the pores were identified, they were repaired by purged welding. In addition, the same tests identified an erroneous pressure setting in the plunger tubes (*i.e.*, overpressure safety elements) installed in the Multi-AD reactor. This fact required a redesign, construction and installation of new ones.

On the other hand, a re-design and modifications to the power cabinet components was needed. After performing the installation and electromechanical tests, it was diagnosed that the power panel had technical deficiencies that prevented the plant from operating correctly and CE certification. Therefore,

SIS and AEMA, taking advantage of their know-how, carried out the redesign of the electrical power panel and made the necessary changes to the components of the electrical cabinet.

The occurrence of technical problems as mentioned had a clear impact in the effective progress of the project not to compromise both people and prototype safety; different measures were taken to overcome or alleviate the problems in questions. These facts caused a delay in the start-up of the Multi-AD reactor operation (*i.e.*, 5 months), which forced the consortium to re-planning the experimental phase. Thus, the demonstration phase process was carried out over 12 months in two steps: Pre-harvesting and harvesting season (from July to November) and Non-harvesting season (from December to June). This fact allowed assessment of Multi-AD reactors on the different production stages of a winery.

The circumstances causing this delay and the results of the measures that were taken to overcome them constitute a series of lessons learnt of tremendous value for the project. These very important lessons were a fundamental part of the demonstration character of the LIFE Multi-AD project. The risks and constraints faced and tackled by the project are critical for the technology. The lessons learnt through the project were therefore meant to be fundamental to the proper and successful implementation and use of the technology in the future. They were transferred to the stakeholders and the society through the Final Report and other deliverables that convey the results of the project.

Action D.1: Dissemination and communication

Before COVID pandemic, in the action TD1.2, the consortium had identified the next difficulties: the time distance between one event and another, the response time in our applications, the price of some sought-after events. In this context, we were seeking for more regional conferences and seminars that could make the investment less important and have a better impact. However, due to the COVID pandemic, the consortium prioritises the participation in the thematic conferences and seminars via online.

Furthermore, with the aim of increasing the impact of LIFE Multi-AD project in web page and social media, dissemination and communication plan was reinforced. More specifically, news was periodically being published in the project webpage. News should focus on reaching the attention to the problems addressed in the project. On the other hand, dissemination and communication actions during 2021-23 were scheduled in a more specific way (high-profile) through specialised press, as well as thematic conferences and seminars. Dissemination and communication actions were focused, first, in disseminating prototype development, and then, the results of the demonstration experiments, *i.e.*, achievements.

Action E.1: Project management

At the beginning of the project, [redacted] it had to be replaced by ENERGY GREEN GAS ALMAZÁN S.L. The new company included the same researchers from PURAL therefore it was carried out the same tasks without any change in the objectives of the project and budget.

After the second monitoring meeting, AEMA was encouraged to improve project management, and more specially the financial management. It is this worrying fact that AEMA redefined the management chart of the Multi-AD project. The original project chart (*i.e.*, Executive Board) had two major limitations for proper management. On one site, several members of the Executive Board had left the Multi-AD project such as [redacted].
On the other hand, the original organisation chart was too flat and subsequently, all the technical and financial management of the project fell to four members. Thus, LIFE Multi-AD project management was re-structured around the SC and the Implementation Teams, as was shown in the previous diagram (Figure 2). Moreover, it included an external support for the financial management *i.e.*, PYRGUS as external consultant. In this line, in order to ensure an appropriate management and coordination of the project partners, monthly meetings were organised by the coordinator via Microsoft Teams platform. A copy of the presentation of these meetings was regularly sent to all partners. Moreover, several technical meetings were performed among partners in order to improve the teamwork in each action.

The prototype, which was going to be located at Viñedos Winery (Aldeanueva, La Rioja), was not able to be built there. The state of alarm in Spain, as a consequence of COVID, was picking up with

uncertainty and fears by the global market. Under this economic situation, Viñedos Winery decided to stop the project in its facilities. This was because the winery expects to decline significantly its sales in 2020-21 and consequently, they decided to stop any new kind of building or investment. Under these external circumstances, AEMA, as Coordinating Beneficiary, was actively seeking among their customers in order to find an end-user that fulfilled the whole requirements for the Multi-AD demo unit validation: from location to industrial sector. Among the different possibilities, the consortium selected AGE Winery, which accepted the construction and validation of the Multi-AD prototype on its WWTP. AGE is a winery located in the same European region as Viñedos Winery (*i.e.*, La Rioja), at the same industrial sector (*i.e.*, agri-food), as well as at the same business activity (*i.e.*, winery). Moreover, AGE Winery belongs to Pernod Ricard Group, a big company of alcoholic beverages with a strong commitment to the environment. Thus, LIFE Multi-AD consortium found AGE Winery location as the way to success. For all of these reasons, the initial project objectives were not modified by the new location. The expected results on the technical, economic and environmental viability assessment of the Multi-AD reactor will not be affected by the change of the prototype site.

Technical setbacks to the prototype design, reactor scale-up and change of localization of the demo unit prevented the consortium from spending the pre-financing, mainly because AEMA had not acquired the equipment and materials needed to construct the demo plant. As a consequence, the Mid Term report was delayed from October 2019. Due to this fact, it was necessary to change the Mid Term Report to a Progress Report which was foreseen at the end of 2020.

The consortium requested a postponement of the end of the project considering an extension period of 16 months. The implementation of the LIFE Multi-AD project had faced, compared with the original schedule, some challenges related to the design and construction of the demo unit. However, the circumstances faced in the project implementation were exceptional, unforeseeable and demanding enough not to be covered by the original buffer time considered for contingencies in the schedule. The delays in these critical actions made it necessary to postpone the end of the activities, in order to ensure that the viability and results of the project were maintained.

Finally, AEMA (coordinating beneficiary) was bought by BONDALTI and its new trade name is BONDALTI WATER. AEMA maintained its VAT No. ESB26334045 however, there were various changes in the company organisational structure which affected the legal representative, among others. In fact, Mr. Víctor Navajas ceased to have executive powers after the last reorganisation of the AEMA Executive Board. The legal representation of AEMA toward the EC was done since June 2023 by the Executive Board, [redacted].

It is important to emphasise that despite the problems and difficulties that the consortium had encountered during this period; it continued to work to solve them. In order to address these contingencies, LIFE Multi-AD was raised human resources to recover the delay accumulated. In addition, the consortium was trying to undertake the over expenditure without affecting the initial budget of the project. Thus, the LIFE Multi-AD consortium, despite the delays it incurred, found suitable solutions to solve the inconveniences, making important modifications in the design of the reactor and P&D, as well as adapting to the changes that have arisen. As a result, the objectives of the project and the work plan were successfully achieved.

6.3. Evaluation of Project Implementation

6.3.1. Methodology assessment

Each action required specific methods to carry out the activities and to get the results in accordance to the objectives. Internal organisation foreseen at the beginning of the project was adapted as the consortium had to be modified because of PURAL leaving. Distribution of activities and methodologies were adapted in order to keep the same objectives with the same budget but taking into account the profile of the new partner EGA and the moment of approval of its participation.

In general, the methodology of work presented in the proposal was giving the results as expected. However, some little changes in methodology were considered in order to adequate the actions to the real situation. In fact, the consortium believed that the methodology with the changes introduced allowed reaching the foreseen objectives at the end of the LIFE Multi-AD project without significant modifications in the overall budget.

The beneficiary responsible for each action led its execution adopting green procurement methods described in Deliverable **D27** "LIFE Multi-AD project guidelines to implement Green Procurement". Actions were carried out combining different methodologies leading with the diverse classes of works: emails, phone contacts, online meeting and/or face-to-face meetings among partners to clarify specifications or agree decisions, among others.

A pull of the mentioned methodologies showed to be needed in order to handle arising points in an efficient manner. For instance, depending on the case, written instructions or messages showed to be more effective to avoid misunderstanding whereas in other cases phone calls were the most useful manner to solve difficulties promptly. In specific occasions the most clarifying way was to arrange an *in-situ* meeting to see issues physically and together in a cost-effective manner although this method was proved to be so useful in combination with the others. It is worth noting that *in-situ* meetings were significantly minimised due to the COVID-pandemic.

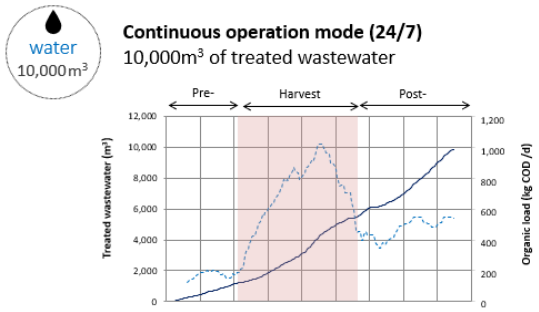
The partner responsible for each action regularly reported the evolution of each action to the Technical Committee. This committee closely followed the advancement of the project in order to judge where it would be necessary or not to activate the Multi-AD Risk Management Plan and implement either the Mitigation actions or any Contingency plan considered to be necessary. If a non-considered in the Risk Management Plan problem or deviation occurs, the Steering Committee meets urgently in order to achieve a corrective action, as well as to assess its consequence on the project.

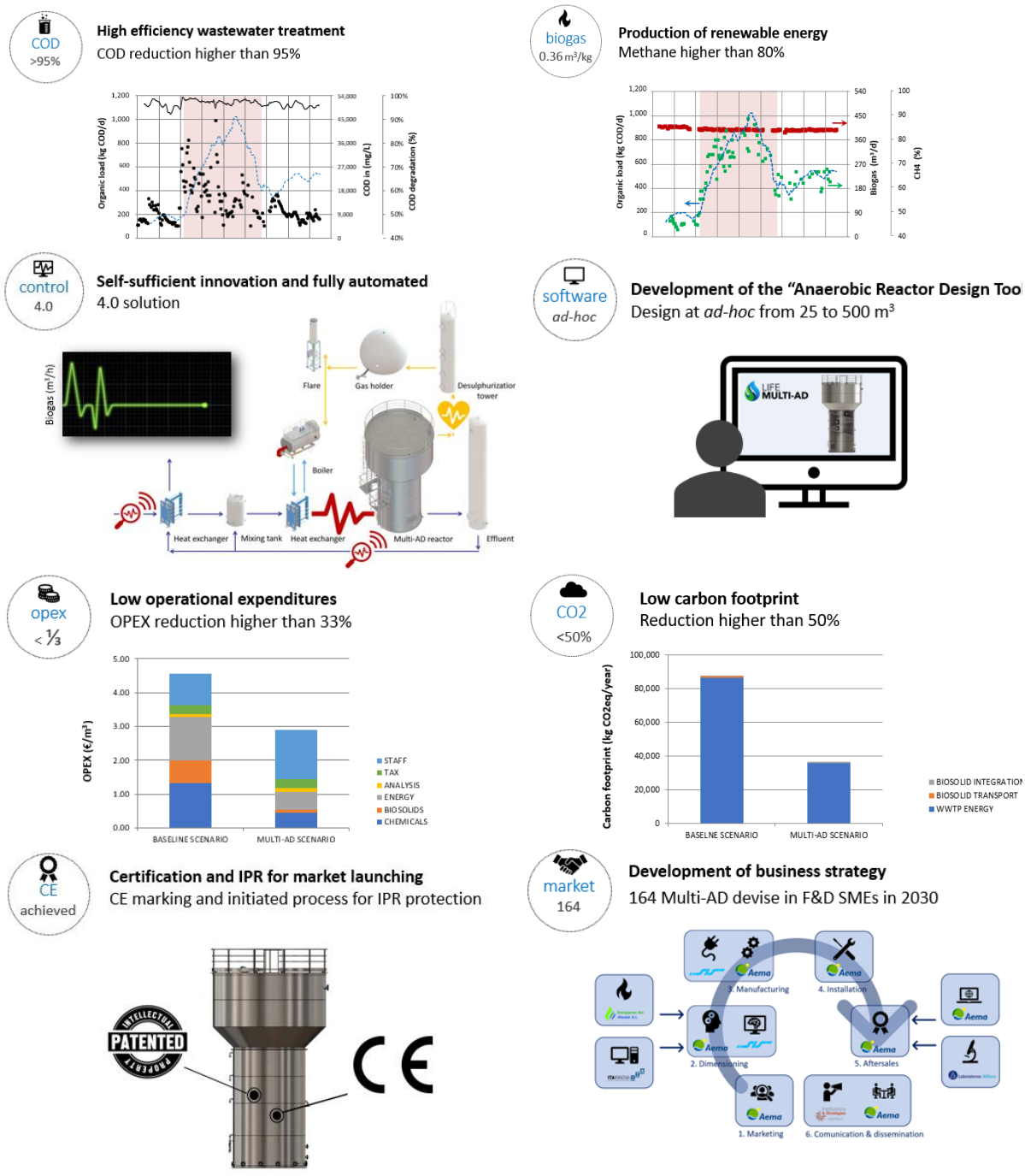
It should be noted that the multidisciplinary team that forms the international consortium found synergies between the different groups, which enriched the decision making and project development. Since the end of 2020, each month a general meeting held, and all the partners present to the others their progress or problems found. These meetings allowed all the project beneficiaries to increase their technical knowledge in other disciplines, allowing the generation of discussion in the different subjects, very profitable.

These meetings let the constant flow of information allowed achieving the objectives of the project. Furthermore, the monthly gathering was a team building activity and therefore it was considered that one of the most important advantages was the creation of a robust and motivated team, which allowed continuing successfully reaching the execution of all actions. In addition, specific meetings were held in each action, including collaboration between all partners in actions B, C and D.

6.3.2. Results

The implementation of LIFE Multi-AD project achieved the following 10 milestones:





The results expected for each action were analysed by comparison with the results achieved within the reporting period as shown Table 13.

Table 13. Results achieved are compared against the objectives and expected results foreseen in the proposal.

Action	Foreseen in the revised proposal	Achieved	Evaluation
B1: Fluid dynamic analysis	*Objectives:* To fix the main dimensions of the industrial scale Multi-AD rector. *Expected results:* Proposal for designing a new 100 m^3 digester Validation of CFD model using data from the existing 100 L prototype.	Fully 100%	Definition of requirements done. System description and experimental data done. CFD model definition, validation and analysis for scaling-up done. Design proposal for a 100 m^3 digester done. Selection of scale-up criteria done. Final proposal for the 100 m^3 digester done. *Deliverables:* **D1.** "Presentation describing the CFD model and its validation" submitted. **D2.** "Report describing the CFD model and scaling-up criteria" submitted.
B2: Control system development	*Objectives:* To design and develop an advanced control system that will optimise MultiAD's operation by adjusting the controllable outputs' variables. *Expected results:* Functional SCADA system for Multi-AD industrial unit.	Fully 100%	Definition of monitored parameters done. Advanced control system: P&ID done. Control system strategy done. Control system architecture done. *Deliverables:* **D3.** "Control system specification" submitted. **D4.** "PLC control logic and electrical cabinet" submitted. **D5.** "Control system testing results" submitted.
B3: Design and construction of the 100 m^3 Multi-AD demo unit	*Objectives:* To design and build a technological solution based on the first industrial scale Multi-AD device. *Expected results:* Feasible reactor design. Construction of the 100m^3 Multi-AD demo unit. FAT for process control.	Fully 100%	Reactor scaling-up done. Process diagram flow designed. Multi-AD reactor manufactured. Peripheral equipment of Multi-AD technological solution designed and manufactured. Civil work done. Multi-AD technological solution implemented. Control system implemented. *Deliverables:* **D6.** "Drawings and components of the 100 m^3 Multi-AD demo unit" submitted. **D7.** "Report on the construction of the 100 m^3 Multi-AD demo unit" submitted. **D8.** "Drawings and components of the 100 m^3 Multi-AD demo unit" submitted.

Table 13. Results achieved are compared against the objectives and expected results foreseen in the proposal (continued from previous page).

Action	Foreseen in the revised proposal	Achieved	Evaluation
B4: Demo experience in real environment	*Objectives:* To validate in real industrial environment the 100 m^3 Multi-AD demo unit. *Expected results:* Adaptation of granular sludge and anaerobic reaction running stable. The 100 m^3 demo unit reaches expected performance values.	Fully 100%	Starting-up the 100 m^3 demo unit done. Running of testing procedures done. Re-design and optimisation of the scale-up done. Validation of final design done. *Deliverables:* **D9.** "Start-up of the 100 m^3 demo unit installed" submitted. **D10.** "Report with conclusions from testing the 100 m^3 demo unit at the winery" submitted. **D11.** "Report on optimisation of the Multi-AD's design and control system" submitted.
B5: Anaerobic reactor design tool	*Objectives:* To develop a design tool that can be used to pre-design and optimise new Muti-AD devices. *Expected results:* ROM for the digester to be available for control optimisation and for the design tool. Anaerobic reactor design tool.	Fully 100%	Definition of standard plant design done. Definition of control and instrumentation requirements done. System simulation definition done. Multi-physics models done. Reactor real-time model done. Data-driven improvement of the real-time model done. Implementation done. Updating 100 L prototype and data collection done. GUI and cloud service developed. *Deliverables:* **D12.** "System models for template plants defined jointly by AEMA and ITAINNOVA" submitted. **D13.** "Web-based application and GUI" submitted.
B6: Market launching preparation	*Objectives:* To perform the development business strategy and take care of the regulatory and knowledge protection tasks. *Expected results:* Business plan.	Fully 100%	Commercialization strategy done. Preparatory steps for commercialisation done. IPR management submitted. Acquisition of necessary certification done. *Deliverables:* **D14.** "ROI for Multi-AD clients" submitted. **D15.** "Business plan" submitted. **D16.** "Replicability and transferability plan" submitted. **D17.** "IPR management actions and certifications" submitted.

Table 13. Results achieved are compared against the objectives and expected results foreseen in the proposal (continued from previous page).

Action	Foreseen in the revised proposal	Achieved	Evaluation
C1: Monitoring of the impact of the actions	*Objectives:* To take care of regulatory monitoring the compliance of the developments in Multi-AD. *Expected results:* Reports on the monitoring of the impact of the action successfully finished. Update of the KPI webtool	Fully 100%	Parameters to specify the baseline determined. A list of indicators has been performed. Update of the KPI 50% completed (up to midterm report). Monitoring of the project`s technical impacts completed. Assessment of socioeconomic impact done. Assessment of environmental impact done. *Deliverables:* **D18.** "First report on the monitoring of the impact of the actions" submitted. **D19.** "Second report on the monitoring of the impact of the actions" submitted. **D20.** "Third report on the monitoring of the impact of the actions" submitted
D1: Dissemination and communication	*Objectives:* To provide to LIFE Multi-AD with sufficient tool and resources to perform a successful communication activity and reach a wide dissemination of the project's activities. *Expected results:* Publishing of the project's dedicated website.	Fully 100%	Dissemination and communication plan done. Dissemination material done (*i.e.*, webpage, Twitter, Facebook, LinkedIn, leaflet, roll-up and poster). Participation on thematic conference done (*i.e.*, 30 events). Reaching relevant stakeholder 33% completed (*i.e.*, more than 100 providers, more than 80 customers and 5 technological platforms). Communication activities completed (*i.e.*, 3 press release and 58 news published, 2 technical workshops and 5 local events were organised). *Deliverables:* **D21.** "Dissemination and communication: report of planned activities" submitted. **D22.** "Mid-term report on completed and planned Dissemination and communication" submitted. **D23.** "Short report containing main highlights of technology relevant for policy makers" submitted. **D24.** "Dissemination and communication materials produced including notice boards, layman's report and website" submitted. **D25.** "Report stating the events or media reached for multiplying the project's impact" submitted. **D26.** "After-LIFE dissemination and communication plan" submitted.

Table 13. Results achieved are compared against the objectives and expected results foreseen in the proposal (continued from previous page).

Action	Foreseen in the revised proposal	Achieved	Evaluation
E1: Project management	*Objectives:* To ensure appropriate management and coordination. *Expected results:* Successful completion of the project	Fully 100%d	Consortium Agreement signed. Grant Agreement commitment signed. 6 progress meetings done. 5 general assembly done. Monthly meetings by online-meetings. Risk management completed Implementation of Green Procurement done. Progress report submitted. Mid-term submitted. Progress report submitted Final report submitted *Deliverables:* **D27.** "LIFE Multi-AD project guidelines to implement Green Procurement" submitted. **D28.** "Report on LIFE Multi-AD's Project Management" submitted.

6.3.3. Results visibility

Results visibility were extended from the initial on due to 1:1 scale in the industrial environment and "close-to-the market" project. This way, the LIFE Multi-AD demonstrative facility involved more collaborators and suppliers than a smaller scale prototype and subsequently, the visibility of the project and its results were augmented. Moreover, as the demonstrative character of the demo plant reinforced to achieve sounder results, a real interest of the stakeholders was detected in the interactions, meeting and visits.

In this line, the visibility of the results is expected to continue active after LIFE Multi-AD project. The consortium commitment to come to agreements for future steps and the interest about the initiative from several stakeholders points out this framework for the near future.

Specifically, the results of actions carried out in the project may be considered as visible. For instance, the progress in the building up activities led to progressive changes on site, with more and more elements designed, built, received and installed (B3 "Design and construction of the 100 m^3 Multi-AD demo unit"). The pictures in Figure 22-23 show a moment of this visible work.

The results of this action B3 together with others regarding the prototype design (B1 "Fluid dynamic analysis") and control system development (B2 "Control system development"), all of them being used in the demonstration phase (B4 "Demo experience in real environment), were visible in the second half of the project.

The results visibility of Action B5 "Anaerobic reactor design tool" and B6 "Market launching preparation" were achieved at the end of the project with Anaerobic Reactor Design Tool and Business Plan, respectively. Both products help catalyse replicability and transferability of Multi-AD technological solutions after the LIFE project.

Finally, other results regarding other types of actions such as communication and dissemination were continually visible along project life as well as after-life.

6.3.4. Amendment impact on results achieved

The new configuration of the Consortium approved by the Commission was proved not only as necessary as one partner left the project (*i.e.*, PURAL) but also as effective, since the contribution of the new partner EGA satisfied the expectations and made interesting contributions to the progress of the project such as biogas line design or administrative and financial management. In case the new Consortium structure had not been agreed, the feasibility of the project would have compromised and thus, the results obtained up to the date had not been produced.

The change of localisation of the LIFE Multi-AD demo unit could be called a success. AGE Winery is part of Pernod Ricard Winemakers, which is the wholly owned wine subsidiary of French wine and spirits producer Pernod Ricard, one of the largest alcoholic beverage companies in the world. More precisely, in Spain winemaker, the company has six wineries, distributed across four Designation of Origin (AGE, Campo Viejo and Ysios in Rioja; Tarsus, in Ribera del Duero; Aura, in Rueda; and Vinícola Navarra, in Navarra). Therefore, Pernod Ricard could assist in the future replicability of LIFE Multi-AD technological solution.

Furthermore, Pernod Ricard is a global leader in sustainability. In fact, it has recently unveiled its 2030 sustainability and responsible roadmap, consisting of eight goals which are aligned to the United Nations' Sustainable Development Goals. These include reducing its carbon footprint by 50% and committing to sustainable water sourcing, goals number 6 and 7, which match very well with the main aim of LIFE Multi-AD technological solution.

Finally, the implementation of the LIFE Multi-AD project faced, compared with the original schedule, some challenges related to the design and construction of the pilot plant. As a result, unavoidable extra efforts and time devoted to tackle these exceptional circumstances, with the aim of avoiding hazards and risks in the operation of the plant.

The circumstances faced in the implementation of the project, directly or indirectly related to the COVID pandemic, were *a)* exceptional, *b)* unforeseeable and *c)* demanding enough not to be covered by the original buffer time considered for contingencies in the project schedule. The delays in these critical actions made necessary to postpone the end of the activities 16 months, in order to ensure that the viability and results of the project were maintained.

This second amendment enabled the consortium to carry out a robust demonstration phase. The prototype ran 24 hours a day, 365 days, treating more than 10,000 m^3 in two different campaigns: Harvest (from August to November) and Non-harvest season (from December to July). This fact allowed assessment of Multi-AD reactors on the different production stages which was considered key for a F&D industry such as the winery.

6.3.5. Results of the replication efforts

No project replication was developed along with the project. In fact, the project produced the results that will allow us to demonstrate the feasibility of the LIFE Multi-AD technological solution after the corresponding replication. In fact, the consortium created a Replicability and Transferability plan in order to facilitate the deployment of Multi-AD on a wide scale, cross-border and trans-sectorial.

However, it is important to highlight that the demo unit will continue to operate in AGE Winery at the end of the project demonstrating the technical, economic and environmental feasibility of the Multi-AD technology. The main objective of this action is to carry out a process of continuous improvement of the facility to improve the design and maintenance service in future Multi-AD plants.

Multi-AD device will treat all of the wastewater from the winery, as well as could treat other effluent from surrounding industries during off-season periods in order to maximise the treatment capacity of the anaerobic system. Furthermore, Multi-AD will be an innovation hub for anaerobic processes. Specifically, future R&D initiatives will be requested to increase the efficiency and effectiveness of the installation (*e.g.*, coupling of digital twins and solar panels), specialised training in anaerobic processes for plant managers and operators will be performed, new equipment and instrumentation will be tested and validated for installation in other Multi-AD plants. In addition, the plant in operation may be visited by future clients to facilitate the sales process in order to accelerate technology replication.

6.3.6. Effectiveness of the dissemination and major drawbacks

The impact of the dissemination activities (Action D “Dissemination and communication”) above-described, mainly events, generated high expectations to stakeholders. Dissemination actions made it possible to receive contacts from diverse profiles: collaborators in other projects, researchers, etc. Figure 63 shows some achievements:

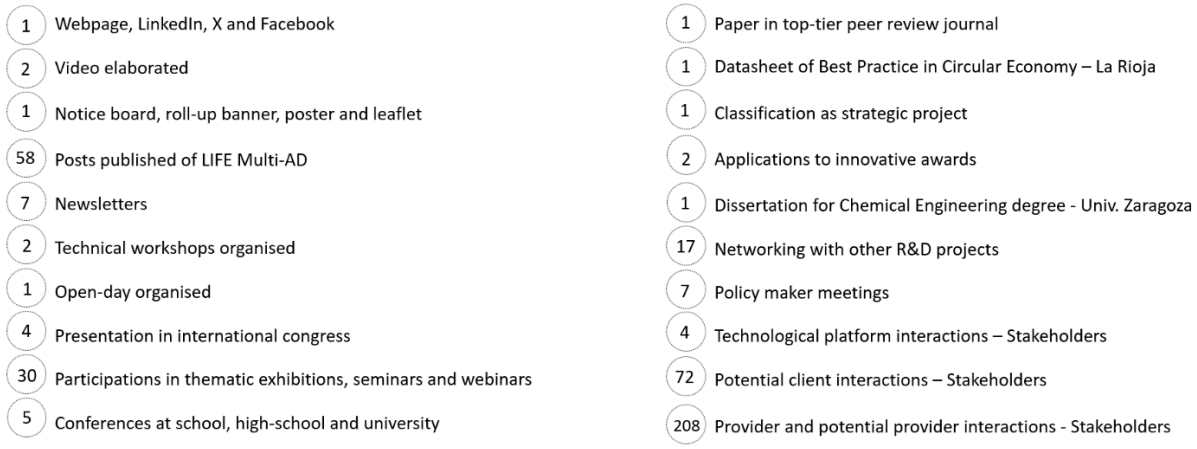


Figure 63. Data on achievements as a result of LIFE Multi-AD project communication and dissemination.

COVID-19 pandemic was considered the main drawback of the communication and dissemination action. This extraordinary situation limited the number of congresses and fairs. This challenge was met

by networking online. In addition, the consortium agreed in scheduling these activities in a twofold way. Actions during 2018-2020 were scheduled in a more generalist way (low-profile) through blogs, webs and social media. The consortium focused on reaching the attention to the problems addressed in the project.

Actions during 2021-23 were scheduled in a more specific way (high-profile) through specialised press, as well as congress and event. Therefore, the consortium focused on disseminating the results during the last part of the project.

6.3.7. Policy impact

The LIFE Multi-AD project will contribute to achieve the European objectives by helping the implementation of several concerned regulations. In fact, LIFE Multi-AD project is relevant for different policy areas:

Integrated Prevention Pollution and Control

LIFE Multi-AD project developed a wastewater treatment technology to consider in the determination of Best Available Technique (BAT) across Food, Drink and Milk (FDM) sector, as well as Slaughterhouses and Animal by-products Industries according to Industrial Emissions Directive 2010/75/EU Integrated Pollution Prevention and Control (IPPC).

Thus, Multi-AD can be considered the only technical alternative for agri-food SMEs, in line with the fact that BAT anaerobic reactor such as Up-flow Anaerobic Sludge Blanket (UASB), Expanded Granular Sludge Bed (EGSB) or Internal Circulation (IC) reactor are already implemented in large F&D industries.

LIFE Multi-AD project demonstrated the technical, economic and environmental capability of an innovative technology to degrade biodegradable organic compounds present in wastewater of F&D SMEs at industrial scale. Multi-AD technological solution is capable, on the one hand, to treat industrial effluent with high organic load before aerobic treatment, as well as to valorise the pollution by means of energy recovery from methanisation.

Therefore, LIFE Multi-AD reactor, as anaerobic treatment, is identified as one of the techniques, whose appropriate combination should be used by FDM Slaughterhouse and Animal by-product industries in order to reduce emission to water according to Commission Implementing Decision (EU) 2019/2031 establishing BAT conclusion under Directive 2010/75/EU.

Water

LIFE Multi-AD project will contribute to ensuring the safe and efficient use of water resources, to have a resource-efficient-industrial sector in the whole EU. The implementation of this eco-innovative technology, will promote the compliance with the EU Water Framework Directive (2000/60/EC) and the aims set by EIP-Water, providing to European F&D SMEs a cutting-edge solution aligned with the global aims set in the Europe 2020 Strategy.

Moreover, LIFE Multi-AD project achievements are aligned with the EC new circular economy action plan adopted in March 2020. LIFE Multi-AD technological solution will contribute to the EU's transition to a circular economy that will reduce pressure on natural resources: low use of resource (*i.e.*, chemical compounds and energy) and low generation of waste (*i.e.*, sludge). This fact has been demonstrated by the inclusion of LIFE Multi-AD in the guide of Best Practice in Circular Economy of La Rioja.

On the other hand, LIFE Multi-AD technological solution, as anaerobic treatment, is very effective in removing biodegradable organic compounds, leaving mineralised compounds like ammonium, phosphate or sulphide in the effluents. These nutrients could be valorised by means of fertigation techniques, reusing water for agricultural irrigation in areas surrounding of the industry such as vineyards. Water reuse could potentially reduce the need for supplemental applications of mineral fertiliser as proposed in Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirement for water reuse.

Finally, the replicability of Multi-AD technological solutions will lead to decentralised wastewater treatment in F&D industries. This fact will minimise the pressure on urban WWTP that usually receives these kinds of raw effluents with high concentration of biodegradable organic matter from SMEs. Therefore, Multi-AD technology will facilitate compliance with the new urban wastewater treatment directive, which significantly decreases the discharge limits for physic-chemical parameters in relation to Directive 91/271/EEC concerning urban waste-water treatment.

Sludge

The achievements of LIFE Multi-AD project fit the needs set in the baseline scenario resulting from the assessments on sewage sludge management carried out by the DG Environment of the EC in the process engaged for the revision of Directive 86/278/CEE, on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. LIFE Multi-AD is coherent with the Roadmap to a Resource Efficient Europe regarding the objective of turning waste into a resource.

LIFE Multi-AD technological solution, being an anaerobic process, minimises sludge production and therefore facilitates the application of new legislation on sustainable soil nutrition: Spanish Royal Decree 1051/2022, which establishing standards for sustainable nutrition in agricultural soils. It is important to emphasize that this Spanish legislation limits the agricultural application of sewage sludge.

Climate neutrality

LIFE Multi-AD project achievements are properly aligned with the European Commission strategic long-term vision for climate neutrality by 2050. The strategy shows how Europe can lead the way to climate neutrality by investing in realistic technological solutions and aligning action in key areas such as industrial polity.

According to Food Drink Europe “European F&D manufacturing accounts for approximately 1.5% of total EU GHG emissions”. LIFE Multi-AD, thanks mainly to lower energy consumption, has lower carbon foot print than aerobic system and therefore, it will contribute to reducing net GHG emission by at least 55% by 2030, compared to 1990 levels, as well as the 2050 climate neutrality goal.

Digitalization

The achievements of LIFE Multi-AD are aligned with the future new Industry law of Spain (replace to Law 21/1992), which will cover areas of major relevance such as climate carbon neutrality and circular economy, digital transformation, industrial safety and quality, or the governance model.

This future legislation is based on the Industrial Policy Spain 2030, which identified the main challenges facing the manufacturing industry: the digital transformation based on data in the field of industry and services; strengthening its weight in the Spanish economy and increasing the size of industrial companies; improving efficiency in the management of water, waste, energy and resources, emissions and renewable energies within the framework of the circular economy.

Thus, LIFE Multi-AD technology, a self-sufficient and full automated solution based on concept as Industry 4.0 and IoT, increase digitalisation in the manufacturing industry by enabling the redeployment of human resources to higher value-added positions. Moreover, the advanced operational control of LIFE Multi-AD allows, under continuous operation, for robust process with low operational costs. This fact increase reduces the environmental costs of industries, increasing their competitiveness.

6.4. Analysis of benefits

6.4.1. Environmental benefits

The F&D industry is the largest manufacturing sector in the EU, which is characterised by being composed mainly by SMEs (>99%). Water is an essential part of the industrial processes in this sector. Thus, several operations required the usage of water such as regular operations, cleaning procedures, ingredient/additive or cooling. As a result of this fact, the F&D industry discharges a high volume of wastewater, which contains high biodegradable organic matter which results in significant environmental pressure. Nowadays, wastewater treatment of SMEs belonging to the F&D sector is usually done by aerobic process. Due to the typical process selection, aerobic biological treatment,

relative energy consumption is high. Moreover, due to typical on- or near- site disposal of biosolids without biogas recovery, there is little or no opportunity for carbon emission offset.

LIFE Multi-AD allows SMEs of the F&B sector to treat in an environmentally friendly way their wastewater effluents, significantly reducing the production of sludge and residues, and allowing a better valorisation of by-products, and biogas. This will result in better treated wastewater to return to the environment, with minimal need for energy, and generation of biogas rich in methane to be used in the industries.

Water

The LIFE Multi-AD project is based on anaerobic process, which is considered one of the most sustainable alternatives for wastewater treatment. LIFE Multi-AD technological solution can be considered as the solution to accomplish an optimal treatment of wastewater generated by the F&D industry, in terms of energy cost (57% less energy), use of hazard reagents (100% reduction in the generation of liquid oxygen and 74%, 54% and 89% reduction in the need of urea, phosphoric acid and polyelectrolyte) and sludge to manage (89% less amount of sludge is generated than in aerobic digesters).

Moreover, anaerobic treatment itself is very effective in removing biodegradable organic compounds, leaving mineralised compounds like ammonium, phosphate or sulphide in the effluents. These nutrients could be valorised by means of fertigation techniques, reusing water for agricultural irrigation in areas outside of the industry. Thus, water reuse could potentially reduce the need for supplemental applications of mineral fertiliser.

Green House Emission

LIFE Multi-AD project can be considered a climate-related project as well, since it reduces by 59% the CO_2 emissions and by 57% the energy requirements for wastewater treatment of each industry that implements our system. This reduction is achieved by the combination of two key facts:

- Unlike aerobic reactors, Multi-AD does not need high-energy demanding air blowers (50-75% of the energy consumed in the WWTP of the F&D sector is associated with the air blowers).
- The generation of methane-rich gas during the process, provides a source of energy to *i*) operate the Multi-AD reactor (*i.e.*, net use of energy from renewable energy sources) and *ii*) convert other operations with the industry (*e.g.*, boiling or heating).

Since 99% of the EU27 F&D industries are SMEs (our target users) – that currently depend on either aerobic reactor – the LIFE Multi-AD project has a huge potential to reduce the F&D CO_2 emissions throughout the whole EU and therefore, contribute to climate-change mitigation.

Sludge

The LIFE Multi-AD project brings other important environmental benefits that arise mainly from the fact that with Multi-AD 89% less amount of sludge is generated. Moreover, it is important to note that anaerobic sludge is well stabilised. Sludge management has become one of the most critical issues for the wastewater industry worldwide, due to the very fast increase in sludge production resulting from increasing numbers of new WWTPs, more industries and more inhabitants connected to existing sewerage systems and upgrading of existing facilities to meet stricter discharge criteria.

6.4.2. Economic benefits

The F&D industry is a major contribution to Europe's economy. The industry maintains the characteristics of a stable, resilient and robust sector. The EU F&D industry generated a turnover of €1,121 billion, a value added of 1.9% of EU gross and it employs 4.6 million people (2022). Furthermore, the F&D industry is a highly water-intensive sector worldwide as it was mentioned before. In fact, the volumes of wastewater derived from F&D sector produces roughly 2.17 million m^3/d of wastewater in Europe according to the technical magazine Industrial WaterWorld. Moreover, wastewater in F&D industry contain high organic matter, could reach up to 50 kg COD/m^3, which results a significant environment pressure.

SMEs belonging to the F&D sector usually treat their wastewater by means of aerobic reactors present

either in their own industrial WWTP or in centralised urban WWTP. Aerobic process involves high energy costs ( ). One main factor that makes this process expensive is the system's high oxygen needs, which is applied through the activated sludge by air blowing machinery. This aeration process represents between 50 to 75% of the operational costs of an industrial WWTP. Besides, during the treatment process, it is generated an excess of sludge whose management leads to extra costs ( ).

These factors, point at LIFE Multi-AD technology as the solution to accomplish an optimal treatment of the wastewater generated by the F&D industry, in terms of energy costs (no aeration is needed), and sludge to manage (about 99% less amount of sludge is generated than in aerobic digesters), which implies huge savings. Moreover, LIFE Multi-AD technological solution generates abundant biogas ( ). This self-generated renewable energy is 84% methane-rich ( ), as well as may be used partially (60-65%) for operating the anaerobic reactor and partially (35-40% surplus) for other operations (*e.g.*, boiling or heating) in the industry.

In particular, an F&D industry that has to treat around 100 m^3/day of wastewater such as AGE Winery, compared to its current aerobic reactor, LIFE Multi-AD technological solution will mean:

- energy savings
- sludge saving

Moreover, the LIFE Multi-AD project offers a technological solution to F&D industries that are not on the market of wastewater treatment services. LIFE Multi-AD technology suited for SMES, since high-rate anaerobic reactors already on the market (*e.g.*, UASB, EGSB or IC) are optimised for large enterprises (>1,000 m^3/d, being 2,500 m^3 a standard capacity) where economies of scale make vast technology investment affordable. In contrast, the F&D sector, dominated by SMEs, does not discharge enough organic load for existing anaerobic reactors to prove economically viable.

This is the reason why LIFE Multi-AD is a ground-breaking technology: the consortium has been able to obtain a technology to bridge this gap on the market. Our target are SMEs that does not generate enough wastewater volume to justify the investment in large investment in large-scale anaerobic reactors, very expensive (around 1 M€) due to large volume (>1,000 m^3). LIFE Multi-AD brings them a great business opportunity, since they will be able to implement anaerobic reactor at affordable prices: average selling price € for 100 m^3 Multi-AD reactor.

Business plan estimates that 164 Multi-AD devices could be theoretically up taken by the European market in within seven years post-project, generating a total sales volume of million. This number of reactors represents 0.06% of the total number of F&B SMEs in Europe. Most of Multi-AD reactors could be installed in medium companies (*i.e.*, 135 devises), which means 2.21% of enterprises of this size (50-249 person employed). Those data show that economic potential of Multi-AD technological solution is very promising since there is still a large market share to penetrate.

Commercial benefits will be higher than million during the period 2024-2030. The profit could achieve €, value from which it is necessary to deduct the proportional cost of IPR ( ). It is important to emphasize that the consortium could achieve a return on investment (ROI) of 1,125% in 2030. Considering a consortium investment in LIFE Multi-AD project € ( ) ROI value would be less than three years.

6.4.3. Social benefits

The execution of the LIFE Multi-AD project has positive effects on the local economy and EU population as a whole.

An important social effect of this LIFE Multi-AD project is the great improvement of the environmental performance of the industries that implement this system. F&D industries are a main source of biodegradable organic pollution in the European water basins. Therefore, LIFE Multi-AD technology implementation has a positive effect on the perception that the consumers have about them. This positive

image could be even monetised by the industries in the future through marketing campaigns, seals of excellence or generally a good image of the involved industries.

Another social effect is concerning green jobs creation. Increase of the hired staff for the execution and design of the proposed facilities for the project and its extrapolation to other parts of the EU which will stimulate the labour market related to industrial WWTP where technology would be implemented within EU. The consortium calculates that, as stated in the financial forecast, it will need to reinforce AEMA's manufacturing capacity, and during the first five years present in the market, it might need about 200 new personnel.

This fact is especially important taking in to account that AEMA is localised in Alfaro, town with fewer 10,000 inhabitants, where the main economic activity is farming. Economic promotion of different industrial sectors related with the implementation of the project (*e.g.*, engineering, parts distributor, transporters, researchers, computer scientists, electric operator or machinery rent) is a major social impact.

Finally, the last significant effect of LIFE Multi-AD includes the social awareness about wastewater treatment into the general public in new technologies of energy self-sufficient industrial processes. The consortium carried out 5 conferences in schools, colleges and universities where more than 100 people between the ages of 8 and 25 participated in order to increase social impact of LIFE Multi-AD. In fact, during the local events, it was explained the integral water cycle, how it is anthropogenically modified, as well as how technologies such as Multi-AD are developed so that this alternation does not affect water resource quality.

6.4.4. Replicability, transferability, cooperation

LIFE Muti-AD technological solution is replicable and transferable throughout almost all EU SMEs belonging to the F&D industries such as winery, brewing, soft drinks, dairy, sugar manufacture as well as vegetable, fish and meat processing. In order to make sure that our repercussions reach its maximum possible, the project elaborated a "Replicability and Transferability Plan". The consortium defined a schedule, in which the three first stages are key in order to achieve the replication and transferability of Multi-AD technological solutions.

The aim of the LIFE Multi-AD project was to assure that the technological solution hereby developed is widely incorporated by EU's F&D industry production processes. To do so the consortium has put the commercialisation focus not only in Spain, but also in other EU countries. The consortium has outlined *i*) a business plan for launching to the market the Multi-AD reactor, and *ii*) a commercialization plan split in five stages through which we will broaden the scope of the Multi-AD system by reaching different countries and F&D subsectors.

As a measure for assuring replicability and transferability to all relevant F&D subsectors, the consortium will perform once the project is finished, more end-user 100 L pilot tests in other industries different that wineries and vegetable processing industries. This action is, on the one hand, aimed at gathering data for fine-tuning the "Anaerobic digester design tool", and on the other, aimed at fostering the massive adoption of this wastewater treatment solution by the F&D European industries, which is as well directly linked with our aim of launching to the market this product.

Another measure for rapid replicability and transferability is a process of continuous technology improvement. Thus, the consortium will request new demonstration projects with the aim of incorporating new technological packages ([redacted]) to Multi-AD that improve its competitiveness or that facilitate its transferability to other sectors. The programs to which it is planned to apply are Technical Assistance – Replication – Nature & Biodiversity and Circular Economy & Quality of LIFE (LIFE-2024-TA-R-NAT-ENV) or New circular solutions and decentralised approaches for water and wastewater management (HORIZON-CL6-2024-CircBio-02-4-two-stage).

Since LIFE Multi-AD is a close-to-the-market project, the consortium elaborated technology's market positioning, supply chain, competitors and economic feasibility. In this line, the consortium considers as well as "preparatory steps for commercialisation" the whole range of activities and tasks that will be

performed under Action D "Dissemination and Communication ", since they will raise awareness of this ground-breaking technology. Among this cited action, particular interest has reached relevant stakeholders for multiplying the project's impact.

Technological platform such as Croatian Competitiveness Cluster for Food Processing Sector, Food+i Cluster or National technology platform for F&D industry or Wine Technological Platform (PTV). In fact, PTV included LIFE Multi-AD project in its 3rd Strategic Innovation Plan, as well as awards AD-Wine project, precursor project of LIFE Multi-AD, as Innovation Awards 2019.

6.4.5. Best practice lessons

LIFE Multi-AD developed a wastewater treatment technique to consider in the determination of BAT across the FDM sector according to Industrial Emissions Directive 2010/75/EU IPPC such as UASB, EGSB or IC reactor.

Furthermore, the project applied as innovative technology within the innovation observatory of Institut Cerdá, as well as ODS awards of Fundación Rafael del Pino. Both private foundations help identify, analyse and disseminate disruptive technology to potential stakeholders. They carry out a public recognition, appearing in the report of the Observatory of Innovation in Mass Consumption 2023 (Institut Cerdá) or on the website and social networks of the UN Global Compact Spain and the Rafael del Pino Foundation.

Finally, LIFE Multi-AD technological solution was classified as one of the Best Practices in Circular Economy by La Rioja Government (Figure 64). This fact is very important since, as good practices, could be used as an example of success stories for other industries, as well as will include in the guideline in circular economy that the Spanish government will be drafting in the coming years.

Figure 64. Datasheet of Best Practice in Circular Economy. LIFE Multi-AD.

6.4.6. Innovative and demonstration value

The LIFE Multi-AD project is in full accordance with the specific objectives for the Environment and Resource efficiency priority area in the LIFE call. The aforementioned project is aimed at developing, testing and demonstrating the potential of an innovative wastewater treatment technology for the F&D industry, consisting of a multiphase anaerobic reactor optimised for the SMEs' small volumes and composition.

The implementation of 100 m^3 Multi-AD reactor at 1:1 industrial-scale in a real environment (*i.e.* AGE Winery) allowed identifying operational problems and technical constraints. The innovative technology to be implemented includes a high performance multiphase anaerobic reactor with two coupled cylinders with different widths.

The first one, by three deflectors, is divided in four chambers in which the four steps of anaerobic reactions are carried out by various microbial communities generating methane-rich biogas. Each of these chambers acts as an independent reactor where the whole biological process takes place. Globally, Multi-AD acts as an ensemble of reactors in series, placed after each other, that each of them maintains the environmental factors close to the microorganisms' comfort range. Multi-phase configuration allows a stepwise conversion, chamber by chamber, in line with the design purpose of a multi-stage reactor, where each chamber behaves as CSTR. This fact may indicate that a Multi-AD reactor is capable of achieving better degradation rates for the same volume than a conventional anaerobic reactor such as UASB. The second one is the three-phase separator that leads to retention of a larger sludge mass, which means that the mean solids retention time is increased, a fundamental operational parameter of anaerobic reactor.

However, the main innovation of Multi-AD reactor resides in its scalability of anaerobic wastewater process to low working volumes, ranging 25 to 500 m^3. This working volume are suited for SMEs, since current anaerobic reactors are only a cost-effective solution for large volumes (its average capacity is 2,500 m^3) while Multi-AD device is specifically designed to treat lower volumes. Besides, medium and small anaerobic reactors currently available in the market are only suitable for the biological treatment of solid fractions and high solid liquids such as manure, sewage sludge, food waste or crop residues. Given the lack of anaerobic systems adopted to treat low wastewater volumes, medium-sized companies can only implement aerobic systems, which are high energy-demanding and produce significant amounts of sludge (associated disposal costs).

The fact that the Multi-AD reactor is fully automatized with advanced control goes along with the Industry 4.0 concept, since the technological solution uses a great number of sensors and deploys intelligent computing machines among other technologies. An advanced control system was designed and developed in order to optimise Multi-AD reactor performance by adjusting the controllable output variables such as temperature, pH, total solids, ORP, COD and biogas. The control logic was developed using a "cause-effect" approach that allows the innovative solution at constant organic load by means of a mass balance over the Multi-AD reactor.

The architecture to carry out the monitoring and control of Multi-AD technology allows unattended and fully automated operation. Equipment and instrumentation of the demo unit were connected to the power and automation-control panel. Therefore, the advanced control system maximises the stability of the anaerobic process, and makes it robust towards changes in the wastewater composition or operational conditions.

On the other hand, LIFE Multi-AD project developed a design tool that can be used to design the *ad-hoc* devices and set their technical characteristics depending on each F&D industry conditions and constraints. Software is based on a database that includes detailed description of the units installed in F&D industries, including the characteristics of the equipment and their operational conditions.

Therefore, LIFE Multi-AD project will have two main innovative outputs:

- The first output is the demonstration of the capability of a 100 m^3 Multi-AD reactor to treat more than 10,000 m^3 of wastewater with different compositions (since we will operate in harvesting season and non-harvesting season). The consortium optimised the reactor's processing parameters (operating temperature, pH, recirculation flows of liquid and gas, hydraulic retention time -HRT-) with the implementation of an advanced control system based on logic rules, and the biogas recovery device.
- The second output is the "Anaerobic reactor design tool". With this software, we will be able to mock-up *ad-hoc* the requirements and constraints for the installation of this wastewater management system in other kinds of F&D Industry. This adaptation is in line with the replicability and transferability wanted in the LIFE call, and will help us attain our ultimate aim:

to be able to broaden Multi-AD's applicability throughout the whole European F&D sector, and to launch to the market a cost-effective and eco-innovative wastewater treatment solution adapted for the particular constraints of SMEs.

6.4.7. Policy implication

Water quality remains an issue across Europe, with implications for public and environmental health and biodiversity. Pollution (*i.e.*, excess nutrients, pesticides, toxic substances or waste discharges, among other) is still a top priority and a concern for all water users and the need to supply clean water in sufficient quantity for use at a reasonable cost remains a challenge EU wide (EU Water Framework Directive 2000/60/EC). According to the European Innovation Partnership (EIP) on water Europe must have safe, available and affordable water supply and wastewater treatment for all water in place, based on sustainable management of the water resources and most innovative, competitive and cost-effective solutions.

It must also be stressed how important it is for the competitiveness of Europe, that such problems can be solved with a permanent concern of all stakeholders (regulators included) to optimise solutions' cost-effectiveness. That does not mean lowering environmental or public health standards. It means proper risk identification and assessment, definition of best technologies and practices, and development of tools and technologies to keep costs as low as possible.

In fact, the EU has recently established the wastewater techniques, whose appropriate combination allows achieving the BAT in order to reduce pollutant emission to water (Commission Implementing Decision (EU) 2019/2031). Thus, the cited European Decision establishes BAT conclusions for FDM industries under Directive 2010/75/EU, identifying among wastewater techniques the anaerobic treatment as a process generally applied to biodegradable organic compounds.

In this line, the Best Available Techniques (BAT) Reference Document (BREF) for the FDM industry, published by the EC pursuant to Article 13 of the Directive 2010/75/EU, describes several anaerobic treatment techniques: UASB, Anaerobic contact process, Anaerobic lagoons, Anaerobic filters, EGSB, Fluidized and expanded bed and IC reactor.

Therefore, the main objective of the LIFE Multi-AD project fits with the needs of implementing in F&D industry a technology to degrade biodegradable organic compounds in order to achieve a BAT to reduce emissions to water. Multi-AD technological solution is capable of pre-treatment of wastewater with high COD load before aerobic treatment, as well as energy recovery from methanisation. Therefore, innovative technology Multi-AD could be part of the new version of the BREF document.

In order to engage policy makers, the consortium prepared a report specifically aimed at highlighting the relevant benefits of LIFE Multi-AD and its contribution to improve the sustainability and competitiveness of European F&D sector (*i.e.*, Layman's Report) as well as Procedure: safety in biogas plants to emphasise the need for proper design, construction and operation of anaerobic treatment systems. The consortium identified the following organisms: EIP, European Environmental Agency (EEA), European Integrated Pollution Prevention and Control Bureau (EIPPCB) or Food & Drink Europe (FDE).

In addition, the consortium invited local and regional policy makers and other stakeholders to show demonstrations of the LIFE Multi-AD operating system once the demo unit is installed in AGE Winery. The La Rioja Counselling of Sustainability and Ecological Transition and regional sanitation entities such as Consorcio de Aguas y Residuos de La Rioja, EPSAR (Valencia Region) or ESAMUR (Murcia Region) are among the invited public organisations.

It is important to emphasise that LIFE Multi-AD project contributes to achieve European Objectives by helping the implementation of several concerned strategies and regulations, cited above:

- **Industrial Emissions Directive 2010/75/EU Integrated Pollution Prevention and Control (IPPC)**. The LIFE Multi-AD technological should be considered as a best available technique (BAT) in order to reduce pollutant emission to water by F&D SMEs.

- **Water Framework Directive, Directive 2000/60/EC**. To protect continental surface, transitional and coastal waters. LIFE Multi-AD technology biodegrades organic compounds, reducing pollution in the European water basins.

- **First Circular Economy Action Plan of EC**. LIFE Multi-AD project objectives are properly aligned with the EC new circular economy action plan adopted in March 2020. The LIFE Multi-AD technological solution will contribute to the EU's transition to a circular economy that will reduce pressure on natural resources.

- **Regulation 2020/741 on minimum requirements for water reuse**. LIFE Multi-AD technological solution generated an effluent characterised by a high concentration of nutrients. These nutrients could be valorised by means of fertigation techniques, reusing water for agricultural irrigation in areas outside of the industry.

- **Urban Wastewater Directive 91/271/ECC**. This Council Directive aims to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors.

- **European Commission Directive 86/278/EEC** on the use of sludge in agriculture. LIFE Multi-AD generated an established sludge that could be used for agricultural application.

- **Spanish Royal Decree 1051/2022** which establishes standards for sustainable nutrition in agricultural soils and makes the agricultural application of sewage sludge more restrictive.

- **EC strategic long-term vision for climate neutrality by 2050**. LIFE Multi-AD technological solution will contribute to the 2050 climate neutrality goal, as well as help to the Commission's zero-pollution ambition.

- **Preliminary Draft Spanish Law on Industry**. LIFE Multi-AD technology increases digitalisation in the manufacturing industry, reduces environmental costs and therefore, rises companies competitiveness.

7. Key Project-level Indicators

The specific indicators are shown in the following tables of indicators: environmental (Table 15) and socio-economic impact (Table 16). In order to assess environmental impact, baseline scenario was stabilised taking into account that LIFE Multi-AD technological solution will be replicated in fifty-six industrial WWTP and a demo unit remains in operation in AGE Winery (Deliverable **D15** "Business Plan").

Three WWTP from a representative SMEs of F&D industry, together the prototype, were selected: [redacted], a winery localised [redacted], [redacted], a dairy [redacted], and [redacted] a canned vegetable industry [redacted] (Table 17). Moreover, it is assumed that 1 in 4 WWTP will change aerobic system by Multi-AD technological solution.

Table 17. Scenarios established in order to assess the environmental impact of the LIFE Multi-AD project.

Industry		Base scenario	End of the project	5 years beyond
Industrial WWTP	Aerobic reactor	56+1*	56	0
	Multi-AD	0	0	14
	Multi-AD + Aerobic reactor	0	1	42+1
Total		57	57	57

* demo unit installed at AGE Winery (Fuenmayor, SPAIN).

More information about data of indicator evaluated is in KPI excel file (Annex 4) and Deliverable **D20** "Third report on the monitoring of the impact of the actions"

Table 15. List of KIP used to assess the environmental impact of the LIFE Multi-AD project.

Indicator	Description	At the beginning	At the end	5 years beyond	Unit	Comments
Project area	Partial reduction of specific pressure	0	3.51	536.55	ha	One of drivers to install Multi-AD in WWTP of F&D SMEs is that anaerobic process carries out the valorisation of organic matter. In aerobic systems, organic matter is eliminated thanks to a high biomass growth rate; the organic matter is transformed into CO2 (45%) and biological sludge (45%). On the other hand, in anaerobic systems the organic matter is mainly transformed into biogas (75-80%), with the generation of anaerobic granular sludge being very small (=<5%), due among other reasons to the fact that the growth rate is very small. The lower generation of sludge means less use of the land for its management (agricultural application). Taking these premises into account, the reduction of environmental pressure was calculated by quantifying the lowest use of land footprint for its application.
Waste management	Partial reduction of specific pressure	0.00	210.87	32,192.73	tonne/year	
Water - Point source pollution	EEA_3133-03-7 CODCr	946.37	942.96	194.41	tonne/year	The indicator evaluated reduction of the impact of point source pollution by organic matter to water bodies, measured as a Chemical Organic Demand (COD). This fact is due to the Multi-AD can achieve improved discharge from wastewater treatment plants, when it replaces the aerobic in wastewater treatment plant discharge, or increase the removal rate of the aerobic system when the Multi-AD is installed as pre-treatment.
Resource efficiency - consumption	Diesel	486.20	483.48	60.76	MWh/year	The indicator evaluated diesel consumption derived from the transport and integration of the sludge generated in the aerobic process. The integration of Multi-AD technology reduces sludge production and therefore fuel consumption.
Resource efficiency - consumption	Electric	18,281.00	18,138.62	6,052.85	MWh/year	The indicator evaluated energy consumption derived from wastewater treatment. Aerobic system has high-energy demanding due to air blowers (50-75% of the energy consumed in the WWTP is associated with the air blowers). In anaerobic system, degradation of organic matter is in the absence of oxygen. In addition, energy savings are derived from the lower sludge production.

Table 15. List of KIP used to assess the environmental impact of LIFE Multi-AD project (continued from the previous page).

Indicator	Description	At the beginning	At the end	5 years beyond	Unit	Comments
Resource efficiency – renewable production	-	0	299.96	40,296.32	MWh/year	The indicator evaluated thermal energy production by anaerobic process. In anaerobic systems the organic matter is mainly transformed into biogas (75-80%). Biogas has high methane content (84%) and is valorised in a boiler in order to obtain thermal energy.
Chemical	Substance in ECHA list released	3,218.27	3,177.99	70.18	tonne/year	The indicator evaluated considers four chemical compounds. Liquid oxygen EC number 231-956-9. Reduction due to anaerobic degradation of organic matter (in absence of oxygen). Urea. EC number 200-315-5. Reduction due to anaerobic degradation needs a ratio COD/N - 1000/5, whereas aerobic treatment the ratio is 200/5. Orthophosporic acid. EC number: 231-633-2. Reduction due to anaerobic treatment needs a ratio COD/N - 1000/1, whereas aerobic system the ratio is 200/1. Cationic polyacrylamide (polyelectrolyte). EC number: 938-790-2. Reduction due to less sludge generation as it is a chemical used in sludge dehydration.
Climate change mitigation – CO2 emission	Unspecific private	5,050.56	5,009.82	2,898.37	tonne/year	The indicator evaluated emission of CO_2 a Green House Gas. Anaerobic processes such as the LIFE Multi-AD technological solution is a more environmentally friendly wastewater treatment technology because it uses less energy directly and indirectly (*i.e.*, produces less sludge, which does not need to be managed). It was considered m^3 as unit in order to assess footprint reduction per volume of treated wastewater.
	Unspecific private	1.600	1.596	0.918	kg CO_2/m^3	

Table 16. List of KIP used to assess the socio-economic impact of LIFE Multi-AD project.

Indicator	Description	At the beginning	At the end	5 Years beyond	Unit	Comments
Humans influenced by the project	Persons who may have been influenced via dissemination	0	14,315	22,190	persons	People who may have been influenced via dissemination or awareness raising LIFE Multi-AD project-actions includes: *i)* 75% of total employees of Multi-AD beneficiaries (AEMA-169, ITAINNOVA-291, SIS-31, EGA-5 and I&-3): 374, *ii)* 25% of total AEMA visits where LIFE Multi-AD roll-up banner is located in the hall (5 visits per week: 1,255 visit): 314; *iii)* Professional interactions (4 technological platform, 7 policy makers, 7 NGOs, 2 private foundations, 103 providers, 105 potential providers, 16 competitors, 72 potential consumers): 316; *iv)* 25% of members of technological platform contacted (576 members), *i.e.*, amplification of the scope: 144; *v)* Reached audience in person events (12,619): 6,692 (53%); *vi)* 25% reached audience online (25,903 user webpage and social media impressions): 6,476
Governance	Involvement of NGOs and other stakeholder	0	4	9	number	4 entities have participated directly in project activities: *i)* FER and AUXRIOJA included us in the program of the day "Strengthening the wine value chain. Sustainability in the wine sector and the role of the auxiliary industry" organized by both on June 2; *ii)* PTV included the LIFE Multi-AD project in the 3rd Strategic Innovation Plan and organized the seminar on reuse and regeneration where anaerobic technology was shown, *iii)* Pole de Competitvie participated as active listers in bilateral meetings of LIFE Multi-AD project.

Table 16. List of KIP used to assess the socio-economic impact of LIFE Multi-AD project (continued from previous page)

Indicator	Description	At the beginning	At the end	5 Years beyond	Unit	Comments
Information and awareness	Website	0	14,094	21,384	visits	Users of the website according to the Google Analytic report shown in the Annex to Deliverable 25 "Report stating the events or media reached for multiplying the Project`s".
Information and awareness	Print media	0	1	3	number	1 Published press release (Multi-AD: a new reactor tailor-made for SME, published in Tercer Milenio nº 797 of Heraldo de Aragon).
Information and awareness	Number of different publications made (Journal/conference)	0	8	12	number	1 Scientific publication of project results in peer review journal. A practical approach for biochemical modelling in the CFD evaluation of novel anaerobic digester concepts for biogas production published in Processes 2023, 11(10), 2851, 4 book abstract congress (14th World Congress in Computational Mechanics and ECCOMAS Congress; 15th International Bioenergy Congress; 6th IWA International Conference on eco-Technologies for Wastewater Treatment; 16th International Bioenergy Congress), 1 datasheet of Best Practice in Circular Economy, 1 Dissertation of Chemical Engineering Degree and 1 occurrence at 3rd Strategic Innovation Plan (Special R&D Project 2017-2019).
Information and awareness	Number of different displayed informed created	0	7	15	number	The LIFE Multi-AD consortium organised 2 technical workshop (one of them technology showroom - open-day) and 5 local events in school, high-school and universities.
Information and awareness	Other media (video/leaflets)	0	3	5	number	It was made 2 videos (2-minute video summarising the project and 5-minute video that presents project objectives and shows in detail the final prototype and its performance in an entertaining way) and 1 leaflet. These media can be downloaded at LIFE Multi-AD webpage.
Information and awareness	Displayed information (poster, information boards)	0	7	9	number	Roll-up (x1), poster (x4), notice boards (x2) of the LIFE Multi-AD project were made during the project. All displayed information can be downloaded at LIFE Multi-AD webpage.

Table 16. List of KIP used to assess the socio-economic impact of LIFE Multi-AD project (continued from previous page)

Indicator	Description	At the beginning	At the end	5 years beyond	Unit	Comments
Capacity building	Networking – professionals	0	18	23	number	18 R&D projects networked with the project coordinated by technological centre (e.g., CARTIFF, CTIC CITA, AINIA, CEIT, CIEMAT or CETAQUA), universities (*i.e.*, University of Santiago) institutes (*i.e.*, Benaki Phytopathological Institute), competitors (*e.g.*, DAM, FACSA or GLOBAL OMMNIUM)
Jobs	Jobs	0	3	200	number	FTEs were calculated taking into account total hours of people contracted for LIFE Multi-AD: [redacted] (AEMA) 545h, [redacted] (AEMA) 1,855h, [redacted] (AEMA) 1,491h, [redacted] (ITAINNOVA) 4,499h, [redacted] (ITAINNOVA) 2,698h and [redacted] (ITAINNOVA) 6,678h. Total hour was divided was divided by the years of project duration (4.83) and the average productive hours of a year (1,760h) in order to obtain FTE.
Contribution to economic growth	Running cost	0	2,266,187	35,321,496	€	This indicator was calculated taking into account at the end of the project total costs incurred. Beyond 5 years, it was calculated adding to the expenses attributed to the project ([redacted]) the expenses of building 56 new Multi-AD ([redacted]).
Contribution to economic growth	Revenue expected in case of continuation	-	-	36,728,121	€	This indicator was calculated taking into account revenue expected for 56 new Multi-AD plants according to Business Plan. The consortium hopes to sell 56 Multi-AD planta with a medium revenue of [redacted]€.

Table 16. List of KIP used to assess the socio-economic impact of LIFE Multi-AD project (continued from previous page)

Indicator	Description	At the beginning	At the end	5 Years beyond	Unit	Comments
Contribution to economic growth	Future funding	-	-	2,000,000	€	It was calculated taking into account the development of two new demonstration projects that will catalyse the replication and transferability of Multi-AD technology. The consortium will request new demonstration projects with the aim of incorporating new technological packages (e.g., hybrid solar panels or digital twins) to Multi-AD that improve its competitiveness or that facilitate its transferability to other sectors. The programs to which it is planned to apply are Technical Assistance – Replication – Nature & Biodiversity and Circular Economy & Quality of LIFE (LIFE-2024-TA-R-NAT-ENV) or New circular solutions and decentralised approaches for water and wastewater management (HORIZON-CL6-2024-CircBio-02-4-two-stage). Budget for the LIFE Multi-AD consortium will be around 1M€ per project: *i)* LIFE programme: 600,000€ grant and 400,000€ own contribution; *ii)* H2020 programme: 700,000€ grant and 300,000€ own contribution.

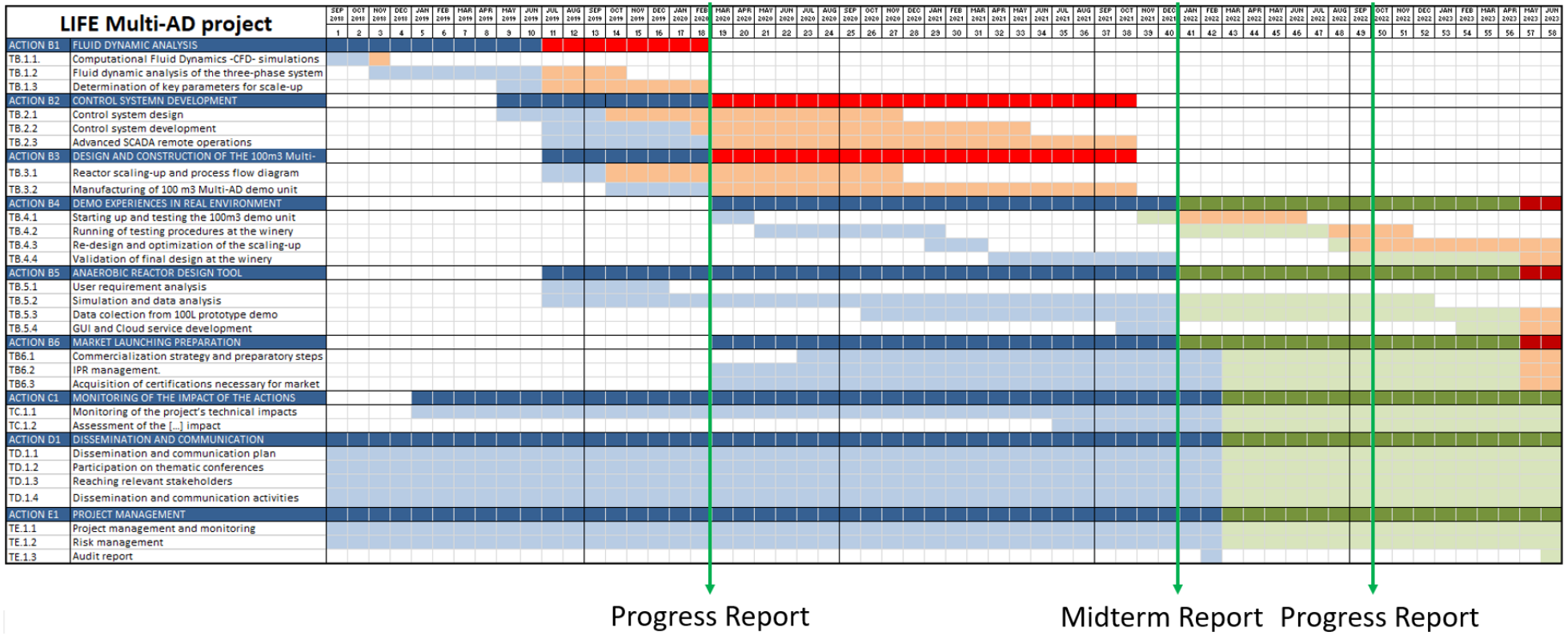


Figure 65. Gantt chart of LIFE Multi-AD project blue cells represent the time schedule, red cells show delays in the execution of the project and green cells show prolongation requested.