(Projects funded under the Call 2014 onwards must use this format)

LIFE Project Number

LIFE18 ENV/IT/000092

Final Report

Covering the project activities from 01/09/2019[1] to 30/06/2024

Reporting Date[2]

30/09/2024

LIFE PROJECT NAME or Acronym

LIFE STEAM

Data Project

Project location:	Italy
Project start date:	01/09/2019
Project end date:	31/08/2023 amended 30/06/2024
Total budget:	€ 2,499,827
EU contribution:	€ 1,350,154
(%) of eligible costs:	55%

Data Beneficiary

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[1] Project start date

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

This table comprises an essential part of the report and should be filled in before submission

Please note that the evaluation of your report may only commence if the package complies with all the elements in this receivability check. The evaluation will be stopped if any obligatory elements are missing.

Package completeness and correctness check	
Obligatory elements	**✓ or N/A**
Technical report	
The correct latest template for the type of project (e.g. traditional) has been followed and all sections have been filled in, in English *In electronic version only*	✓
Index of deliverables with short description annexed, in English *In electronic version only*	✓
Mid-term report: Deliverables due in the reporting period (from project start) annexed Final report: Deliverables not already submitted with the MTR annexed including the Layman's report and after-LIFE plan Deliverables in language(s) other than English include a summary in English *In electronic version only*	✓
Financial report	
The reporting period in the financial report (consolidated financial statement **and** financial statement of each Individual Beneficiary) is the same as in the technical report with the exception of any terminated beneficiary for which the end period should be the date of the termination.	✓
Consolidated Financial Statement with all 5 forms duly filled in and signed and dated *Electronically Q-signed or if paper submission signed and dated originals* and in electronic version (pdfs of signed sheets + full Excel file)*	✓
Financial Statement(s) of the Coordinating Beneficiary, of each Associated Beneficiary and of each affiliate (if involved), with all forms duly filled in (signed and dated). The Financial Statement(s) of Beneficiaries with affiliate(s) include the total cost of each affiliate in 1 line per cost category. *In electronic version (pdfs of signed sheets + full Excel files) + in the case of the Final report the overall summary forms of each beneficiary electronically Q-signed or if paper submission, signed and dated originals**	✓
Amounts, names and other data (e.g. bank account) are correct and consistent with the Grant Agreement / across the different forms (e.g. figures from the individual statements are the same as those reported in the consolidated statement)	✓
Mid-term report (for all projects except IPs): the threshold for the second pre-financing payment has been reached	N/A
Beneficiary's certificate for Durable Goods included (if required, i.e. beneficiaries claiming 100% cost for durable goods) *Electronically Q-signed or if paper submission signed and dated originals* and in electronic version (pdfs of signed sheets)*	N/A
Certificate on financial statements (if required, i.e. for beneficiaries with EU contribution ≥750,000 € in the budget) *Electronically Q-signed or if paper submission signed original and in electronic version (pdf)*	✓
Other checks	
Additional information / clarifications and supporting documents requested in previous letters from the Agency (unless already submitted or not yet due) *In electronic version only*	✓
This table, page 2 of the Mid-term / Final report, is completed - each tick box is filled in *In electronic version only*	✓

**signature by a legal or statutory representative of the beneficiary / affiliate concerned*

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1. List of key-words and abbreviations

Key-word / Abbreviation	**Description**
MTR	Midterm report
D	Deliverable
M	Milestone
FR	Final report

2. Executive Summary

The LIFE STEAM project aimed to demonstrate and validate the efficiency of an innovative steam explosion technology for treating lignocellulosic biomass, particularly green waste such as prunings, clippings, and agricultural residues. The primary objective was to increase biogas production through enhanced pre-treatment, thus providing a sustainable alternative to traditional composting. The project was also intended to reduce the environmental footprint, particularly in terms of water use and CO2 emissions, and to create a replicable and scalable solution for biogas production across Europe.
Key deliverables of the project included the construction of the first full-scale demonstration plant of its kind, detailed life cycle assessments (LCA), the development of customized business plans, and strategic partnerships aimed at the future replication and expansion of the technology. The project also aimed to deliver tangible environmental benefits, including reductions in CO2 emissions and water consumption, and to establish strategic partnerships with stakeholders from both the agricultural and waste management sectors.

The planned activities included the design, construction, and operation of the demo plant, the assessment of its environmental impact, and the establishment of partnerships to facilitate the technology's scalability. While the project largely adhered to its timeline, some deviations and challenges occurred, requiring adaptive solutions.
The demo plant's construction experienced delays, resulting in an amendment that extended the project's timeline. The complexity of the steam explosion system and post-COVID inflation further impacted costs, which exceeded initial budget forecasts by approximately €900,000. This financial gap was covered by HERA without negative repercussions on the project's objectives. Additionally, technical issues during biomass pre-treatment slightly reduced the amount of material processed, which necessitated an adjustment to the key performance indicators (KPIs).
Despite these challenges, the project met its core objectives. The steam explosion process demonstrated a 300-400% increase in biogas production compared to untreated biomass, validating the hypothesis that this innovative technology could significantly enhance biogas yields. The environmental benefits were further supported by the LCA, which showed that scaling up the process could provide environmental advantages over traditional composting methods, including reduced greenhouse gas emissions and improved resource efficiency.

The project's achievements are reflected in the successful completion of all key deliverables. The demo plant was built and operated as planned, proving the viability of the steam explosion process on an industrial scale. The LCA confirmed the environmental benefits of the process, particularly in reducing CO2 emissions when compared conventional composting techniques. The project also laid the groundwork for future industrial applications through strategic partnerships with key stakeholders such as Herambiente and C.I.C.A.

Several challenges were encountered during project implementation, primarily related to the financial and technical aspects of the demo plant's construction. The withdrawal of one consortium partner and the subsequent integration of a new partner required an amendment to the project and led to some delays. Additionally, post-COVID inflation and increases in material costs posed financial challenges, but these were mitigated by HERA's financial contribution.
Operational challenges included the complexity of the SES system and lower-than-expected biomass processing capacity. These issues were addressed through adaptive management, allowing the project to stay largely on track despite these setbacks. Overall, the project's

outcomes aligned with its objectives, proving the effectiveness of the technology and setting the stage for future commercialization and scaling.

The LIFE STEAM project successfully demonstrated the viability of the steam explosion process for treating lignocellulosic biomass, significantly increasing biogas production while reducing environmental impacts. Despite some deviations and challenges, the project delivered on its core objectives, with promising results that support the replication and transfer of the technology across Europe. The strategic partnerships and business plans developed during the project provide a solid foundation for future expansions, ensuring that the environmental and economic benefits of the LIFE STEAM technology can be realized on a larger scale.

In the following table a summary of Deliverables produced and Milestones achieved is reported.

Action	**Deliverable /Milestone**	**Name**	**Deadline**	**Submitted with / Achieved**
Action A.1 Permitting and procurements	D	A1.1 - Authorization and procurement report, including Green public procurement, list and rules for external assistance	30/11/2021	01/02/2022 MTR and updated (FR)
	M	List of all authorizations and procurements needed	31/07/2021	01/02/2022 and updated (FR)
Action A.2 LIFE STEAM requirements and technical drawings	D	A2.1 - Design report with technical drawings and engineering of the demo plant, including PCS, SES Unit	31/12/2021	31/05/2022 MTR
	M	Technical drawings terminated	01/12/2021	31/05/2022
Action B.1 Feedstock collection, management, and storage	D	B1.1 – Collection, preprocessing and delivery of GW report	30/06/2024	30/06/2024 FR
	M	Delivery of first bulk of pretreated GW to the Anaerobic digestion plant	31/12/2023	31/01/2024
Action B.2 Plant set-up	D	B2.1 - Plant manuals/reports of the new LIFE	31/12/2023	30/06/2024 FR

		STEAM Demo plant		
	M	Pre-conditioning system assembled in Italy by HERA	31/05/2023	31/08/2023
	M	Full LIFE STEAM Demo plant realized	31/07/2023	30/11/2023
	M	Preliminary SES pressure tests and rotation tests in Valmet workshop	31/03/2023	31/03/2023
Action B.3 Use-case implementation and market validation	D	B3.1 - Report with test results	30/06/2024	30/06/2024 FR
	M	Results of first testing campaign available	31/12/2023	28/02/2024
Action B.4 Replicability and transferability roadmap	D	B4.1 - Stakeholders and market analysis	31/12/2023	31/12/2023 and updated (FR)
	D	B4.2 - Replication and transfer plan	31/12/2023	30/06/2024 FR
	D	B4.3 - Full business plan of the project, including economic scenario and sensitivity analysis	31/12/2023	31/12/2023
	D	B4.3 - Engagement of policy-makers	31/12/2023	30/06/2024 FR
	M	Business case fundamentals prepared for the full scale plant	31/01/2023	30/06/2024
	M	List of stakeholders prepared	31/12/2021	30/06/2024
	M	At least 8 stakeholders interviewed	31/03/2023	30/06/2024
	M	Workshop with policy-makers	31/12/2023	30/06/2024

Action C.1 Monitoring of environmental and socio-economic impacts	D	C1.1 - Report on monitoring of KPIs, including update of the LIFE KPI table – Midterm report	31/07/2022	MTR
	D	C1.2 - Report on monitoring of KPIs, including update of the LIFE KPI table – Final report	30/06/2024	30/06/2024 FR
	D	C1.3 - Assessment of the socio-economic impact of the project	30/06/2024	30/06/2024 FR
	D	C1.4 - Full LCA of LIFE STEAM system and products	30/06/2024	30/06/2024 FR
	D	C1.5 - Synergies with the EU priorities for jobs and growth	30/06/2024	30/06/2024 FR
	M	First validation of KPIs foreseen by LIFE STEAM project	31/12/2022	31/06/2022
	M	Second validation of KPIs foreseen by LIFE STEAM project	30/06/2024	30/06/2024
Action D.1 Communication, Dissemination and Networking	D	D1.1 - Dissemination plan (revised with new partner)	30/06/2021	30/06/2021 MTR
	D	D1.2 - LIFE STEAM website (updated with new partner)	30/06/2021	30/06/2021 MTR
	D	D1.3 - Notice boards	30/06/2022 Updated 30/11/2023	30/06/2021 MTR, updated FR
	D	D1.4 - Dissemination plan: update	30/06/2022	30/06/2021 MTR
	D	D1.5 - Dissemination plan	30/11/2019	30/11/2019 MTR
	D	D1.6 - LIFE STEAM website	30/11/2019	30/11/2019 MTR
	D	D1.7 - Layman's Report	30/06/2024	30/06/2024 FR
	M	200 stakeholders reached with	31/12/2022	30/06/2024

		dissemination material		
	M	Collaborations established with 2 LIFE or EU-funded projects	30/09/2022	30/06/2024
	M	3000 users reached on the project's website and social channels	30/06/2024	30/06/2024
Action D.2 Strategic partnerships (formerly "LIFE STEAM Newco set-up")	D	D2.1 - Full scale business plan and commercialization strategy	29/02/2024	30/06/2024 FR
	M	Involvement of potential stakeholders by collecting letters of interest	31/12/2022	30/06/2024
Action E.1 Project Management by HERA	D	E1.1 - Project management plan	30/11/2019	30/11/2019 MTR
	D	E1.2 - Project management plan (revised with new partner)	30/06/2021	30/06/2021 MTR
	D	E1.3 - Kick-off meeting with new partner	30/04/2021	11/02/2022 MTR
	M	Consortium agreement signed	31/07/2021	02/02/2022 MTR
	M	Kick-off meeting	30/11/2019	25/09/2019
Action E.2 After-LIFE sustainability Plan	D	E2.2 - Customized full scale business plan	28/02/2023	30/06/2024 FR
	D	E2.3 - After-Life plan	28/02/2023	30/06/2024 FR
	M	Collection of all deliverables and results of the project connected with its continuation	28/02/2023	30/06/2024

3. Introduction

The LIFE STEAM project was developed in response to the increasing need for sustainable solutions in waste management, specifically in the treatment of lignocellulosic biomass. This type of biomass, which includes agricultural residues such as pruning and clippings, presents environmental challenges due to its complex structure. Traditional disposal methods, such as composting or landfilling, result in significant methane emissions, a potent greenhouse gas that contributes to climate change. The project aimed to address these issues by demonstrating the efficacy of steam explosion technology in pre-treating lignocellulosic biomass, thereby enhancing its anaerobic digestibility and biogas production potential while reducing methane emissions.

The core hypothesis of the LIFE STEAM project was that steam explosion could break down the recalcitrant structures of lignin and cellulose, making lignocellulosic waste more accessible for anaerobic digestion and substantially increasing biogas production. Thus, ther resulting lignocellulosic biomass treated with the LIFE STEAM prototype represents an alternative to conventional feedstocks, such as maize. By avoiding the cultivation of energy crops like maize—which require large amounts of water, fertilizers, and pesticides—steam explosion technology applied to agricultural residues would result in reduced water use and lower CO_2 emissions associated with agricultural inputs. Although the LCA analysis did not show a clear CO_2 emissions advantage for biomethane produced via the LIFE STEAM process compared to silage maize (with emissions per MJ being similar), the LIFE STEAM process offers significantly more room for optimization. For example, if green energy sources such as photovoltaics are used, the environmental performance could improve further. This makes LIFE STEAM biomethane a potentially more sustainable alternative to silage maize.

The technical solution implemented by the LIFE STEAM project involved the construction of the first full-scale industrial demonstration plant to apply steam explosion technology to lignocellulosic biomass for biogas production. This plant, integrated in the existing green waste composting plant of Ozzano Emilia in the Emilia-Romagna region, was designed to treat up to 1,8 tons per hour of green waste. The steam explosion process involves subjecting biomass to high pressure and temperature, followed by rapid decompression, which disrupts the cell walls of the biomass, making it easier for microbes to convert it into biogas. The demonstration of this technology at industrial scale marked a major milestone, proving the feasibility of using waste biomass as an alternative to energy crops like maize.
The expected results included a 300-400% increase in biogas production from lignocellulosic biomass compared to untreated material, with a significant reduction in methane emissions. The project achieved biogas yields of up to 293 m^3 per ton of volatile solids, slightly lower initial expectations. Moreover, through the Life Cycle Assessment (LCA) conducted during the project, it was demonstrated that the application of steam explosion technology on a larger scale offers significant environmental advantages over traditional pruning treatment methods like composting. The LCA results highlighted the potential for reduced methane emissions and improved resource efficiency when steam explosion technology is used for biogas production compared to composting, further validating the scalability and environmental benefits of the LIFE STEAM process.

Looking towards the long-term impact, the LIFE STEAM project provides a model for the future of sustainable biogas production across Europe. One of the project's key objectives was to develop a technology that could be both replicable and scalable in different industrial and

geographical contexts. The successful demonstration of steam explosion technology in a full-scale industrial setting confirms its potential for integration into existing waste management infrastructures, particularly where waste heat is available. This integration reduces energy consumption and supports the EU's Green Deal goals of achieving climate neutrality by 2050. The replicability and transferability of the technology were key considerations throughout the project. Industrial stakeholders, such as Herambiente and C.I.C.A., expressed strong interest in adopting the technology for treating various agricultural residues, including straw and corn stover. These partnerships were instrumental in exploring the technology's potential for large-scale deployment. The economic feasibility of the technology was confirmed through the development of a customized business plan, which demonstrated that full-scale plants using agricultural residues could achieve a Net Present Value (NPV) of €2.019 million and an Internal Rate of Return (IRR) of 11.97%. This financial foundation makes the technology an attractive investment opportunity for public and private sector stakeholders alike.

From an environmental policy perspective, the LIFE STEAM project contributes directly to the European Union's efforts to reduce greenhouse gas emissions and promote renewable energy. The steam explosion technology not only increases biogas yields but also offers a more environmentally sustainable feedstock compared to conventional energy crops. The reduction in water use and carbon emissions from using agricultural residues aligns with EU priorities, including the European Green Deal and the Renewable Energy Directive. Moreover, the project's findings provide a valuable framework for future policy development in waste management and renewable energy sectors, highlighting the potential for integrating sustainable technologies into broader energy and environmental strategies.

In conclusion, the LIFE STEAM project successfully demonstrated the potential of steam explosion technology to revolutionize the treatment of lignocellulosic waste for biogas production. By increasing biogas yields, reducing methane emissions, and lowering the environmental footprint of feedstock production, the project has created a sustainable model for organic waste management. The successful demonstration of this technology at industrial scale, coupled with strong stakeholder engagement and financial viability, ensures that steam explosion will play a key role in the future of renewable energy production and waste management in Europe.

4. Administrative part

Due to the unforeseen event of the associated beneficiary Economizer bankruptcy, LIFE STEAM Consortium was obliged to face several important issues and to find a solution without altering the original scope of the project.
The Coordinating Beneficiary HERA requested the amendment to the Grant Agreement including: the termination of the associated beneficiary Economizer, the addition of a new associated beneficiary VALMET, the technical modifications related to a different pilot solution, the budget modifications and the extension of the project duration of 18 months (12 months + 6 months buffer), i.e., from 28/02/2022 to 31/08/2023. The amendment was accepted, and VALMET joined the consortium from 05/03/2021.
The second amendment request for the extension of the project duration from until 30/06/2024 has been approved in August 2023.

HERA S.p.A. was coordinating beneficiary and main point of communication with EC on one hand and with partners on the other. HERA signed in 01/02/2022 the partnership agreements with the associated beneficiaries: VALMET AB and AYRION S.P.A.

The project management structure is composed of:

Davide Nascetti (HERA) - Project Coordinator (PC)
He had the task of communicating, reporting project progress, technical and financial results to CINEA, according to EC guidelines. He had the overall responsibility for the organization, planning and controlling the project, including the collection, integration and monitoring of all technical, administrative and financial data for submission to the Commission. The PC also set-up a series of internal monitoring activities to check the status of key actions. The most important tasks were related to the accomplishment of the necessary preparatory actions, construction of the demo plant, implementation actions, testing, cost control, replicability actions, communication and dissemination activities. In order to effectively manage the project, the PC worked in synergy with members that compose the Steering Committee. He was supported by Giulia Capitani as project Coordinator Assistant and Innovation and Replicability manager.

Stefano Longo (HERA) - Technical Coordinator and Administrative manager
He worked in a strict contact with PC to ensure the correct management of all documentations and financing and he was supported by Claudia Piccin as Accounting Manager.

Roberto Raneri (HERA) [Nicola Sabbioneda till December 2020] - Marketing manager
He was responsible of apply the replicability and transferability strategy planned for LIFE STEAM project in conjunction with action B4, D1 and D2.

Anders Thyr (VALMET) - Technical manager
He was responsible of all technical operations included in action A2, for technical drawings establishing together with the partners the best plant configuration, action B2 to build and supervise the demo plant carrying out all the technical integration made on the base of A2. He had the responsibility of reporting to the PC all the progresses and potential issues incurred during the technical activities;

Marco Pistocchi (AYR) - Dissemination manager
He had the role of managing and monitoring the communication and dissemination activities which helped to generate impact and arise awareness among the different kind of stakeholders as described in action B4 and D1.

The communication with the project monitoring team proceeded smoothly and all updates were regularly provided to the CINEA/monitoring team by the coordinating beneficiary.

5. Technical part

5.1. Technical progress, per Action

5.1.1 Action A.1 Permitting and procurements

Foreseen start date: 10/2019 Actual start date: 10/2019
Foreseen end date: 06/2023 Actual end date: 06/2023

Description of the activities carried out
Action A1 of the LIFE STEAM project focused on obtaining the necessary environmental permits to modify the existing composting plant in Ozzano and purchasing the essential equipment for the prototype's implementation. These activities were crucial to allow the installation of the Pre-conditioning System (PCS) and the Steam Explosion System (SES), as well as ensuring compliance with the current regulations.

The first phase of Action A1 **concerned the request and acquisition of the necessary environmental permits**. This process was particularly complex as it involved various regulatory bodies, including the Regional Agency for Environmental Protection (ARPA) and the Emilia-Romagna Region. Specifically, it was necessary to request a modification of the Integrated Environmental Authorization (AIA) for the Ozzano composting plant to allow the installation and operation of the steam explosion system. After an initial request sent on August 24, 2021, ARPA indicated that the update should be handled as a non-substantial modification of the AIA according to the provisions of Article 29 of Legislative Decree 152/06. The modified request was submitted on October 8, 2021, and the updated authorization was granted on December 15, 2021. This authorization included not only the installation of the SES but also the Pre-conditioning System (PCS), essential for the preliminary treatment of lignocellulosic waste.
Simultaneously, the Fire Prevention Certificate for the Ozzano plant was updated to align with the safety requirements for installing the new technological components. The anaerobic digestion plant in Voltana also received authorization to handle waste treated through the steam explosion process.

To ensure that the installed equipment met the required **technical specifications**, the project team prepared detailed documentation. This included precise technical specifications for the purchase of the Pre-conditioning System (PCS) and the Steam Explosion System (SES), as well as all necessary support infrastructures, such as the steam generator and the conditioning system.

The **selection of suppliers** was managed through public procurement procedures in compliance with national and European regulations. The Green Public Procurement criteria were strictly followed, ensuring that the purchased equipment met the environmental standards established by the regulations. The SES system was purchased from the supplier VALMET, while HERA managed the purchase of various auxiliary components, such as the steam generator, condenser, and other conditioning equipment.
The selection of suppliers for the various pieces of equipment was completed through public tenders and multiple bidding procedures. The tenders were managed in compliance with European public procurement regulations, ensuring transparency and adherence to the principle of best value for money.

Comparison with planned results

In line with the project plan, all environmental permits were obtained, allowing the installation of the SES and PCS at the Ozzano plant. However, some adjustments and extensions were required compared to the initially planned dates. Specifically, the AIA authorization was extended until the end of the project (June 30, 2024) due to delays in prototype implementation, which postponed the start of the experimental test. This delay impacted subsequent project phases, pushing the start of experimental testing to mid-2023. However, this extension provided the necessary time for technical adjustments, ensuring regulatory compliance and a smooth transition to the pilot plant's operational phase.

Challenges, Adjustments, and Solutions

Action A1 encountered some challenges, including an extension of the AIA authorization due to delays in the prototype installation. Initially set to expire in December 2023, the authorization was extended to June 2024, allowing the team to complete the necessary adjustments without impacting the overall project timeline.

Post-COVID inflation also led to increased costs, particularly for raw materials like steel. This was mitigated through budget reallocations and additional internal funding, ensuring that the SES system could be purchased without compromising project quality. The rise in material costs led to an additional budgetary requirement, which was mitigated through resource reallocation within the project and extra internal funding from the consortium. This adjustment ensured that procurement activities could continue without compromising the project scope

The complexity of the SES system required further technical modifications, causing minor delays. Close coordination with VALMET and extra technical resources ensured successful installation, with no significant impact on the project's broader goals.

Overall, these challenges were effectively managed, and the key installations were completed without compromising the project’s deliverables.

Deliverable /Milestone	Name	Deadline	Submitted with /Achieved
D	A1.1Authorization and procurement report, including Green public procurement, list and rules for external assistance	30/11/2021	01/02/2022 MTR and updated (FR)
M	List of all authorizations and procurements needed	30/11/2021	01/02/2022 and updated (FR)

5.1.2 Action A.2 LIFE STEAM requirements and technical drawings

Foreseen start date: 09/2019 Actual start date: 09/2019
Foreseen end date: 06/2023 Actual end date: 06/2023

Description of the activities carried out

Action A2 involved the detailed design and engineering of the demonstration plant for treating lignocellulosic waste, with particular attention to the integration of new technologies at the existing Ozzano Emilia site owned by HERAMBIENTE (Hera Group). This demo plant uses the innovative steam explosion technique to pretreat green waste before anaerobic digestion, significantly increasing biogas production. The demo plant was designed to treat up to 16 tons per hour of green waste and includes various treatment units, including the Pre-conditioning System (PCS) and the Steam Explosion System (SES).

1. Design of the Demo Plant

The overall design of the plant included a series of technological components, each playing a crucial role in the treatment of lignocellulosic waste. VALMET developed the steam explosion system (SES), while HERA worked on modifying the existing infrastructure to integrate the SES and PCS. These systems were installed inside Building C at the Ozzano site, an area already authorized for green waste management.

Fig. 1 – the main entrance of the life steam plant in building C

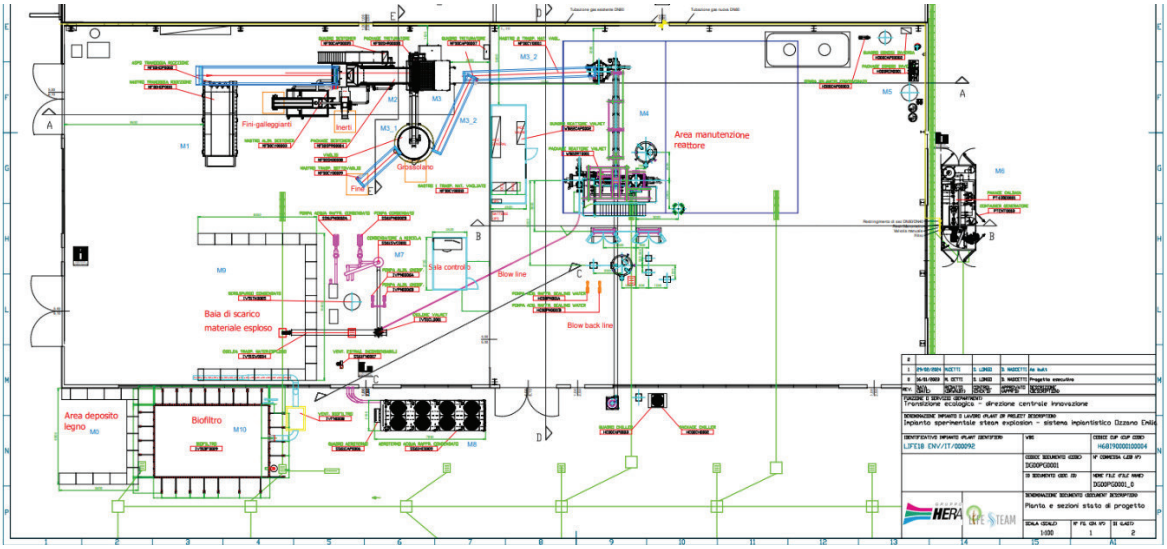


Fig. 2 – Plant layout AS BUILT

- Input hopper (M1): Pre-Shredded green waste is introduced into a metal hopper with a capacity of 15 m³, located 15 meters above ground level. From here, the material is transported via conveyors to subsequent treatment stages.

Fig. 3 – hopper

- Hydraulic stone and sand separator (M2): Before entering the SES, the material passes through a hydraulic separator that removes inert materials (stones, sand) to avoid damage to the fine shredder blades and the SES.

Fig. 4 – de-stoner

- Fine shredder (M3): The shredder further reduces the material to a maximum size of 30 mm to optimize the effectiveness of the steam explosion process. The installed model is the WEIMA Single-Shaft Shredder WLK 1500.

Fig. 5 – Weima Fine shredder

- Filtration and screening system (M3_1): A two-level screen further separates fine fractions and oversized fractions, which are sent back to the shredder to achieve a homogeneous size.

Fig. 6 – Fine screening operating after the shredder belt

- The Steam Explosion System (SES) designed by VALMET was developed as a prototype and installed at the demonstration plant. This system heats the material to a temperature of 210°C and a pressure of 18 bar, then rapidly expands it into an atmospheric pressure environment, causing mechanical separation between lignin and cellulose. The treated material is then sent to the Voltana site for anaerobic digestion.

Fig. 7 – complete steam explosion system on site

- Osmosis water production plant (M5): A 1,700 liters/hour capacity osmosis water production plant was installed, necessary to supply the steam generator and for technical uses in the SES system.

Fig. 8 – Osmosis plant

- Steam generator (M6): Powered by natural gas, the generator produces high-pressure steam (210°C, 18 bar) to supply the SES, with a capacity of 1,250 kg/h of steam. The generator was installed in an external container near Building C.

Fig. 9 – steam generator – container and steamer

- Condensate and air-cooling system (M7-M8): An air-cooling system designed to condense the steam used in the SES process was integrated with the steam recovery system to optimize water consumption.

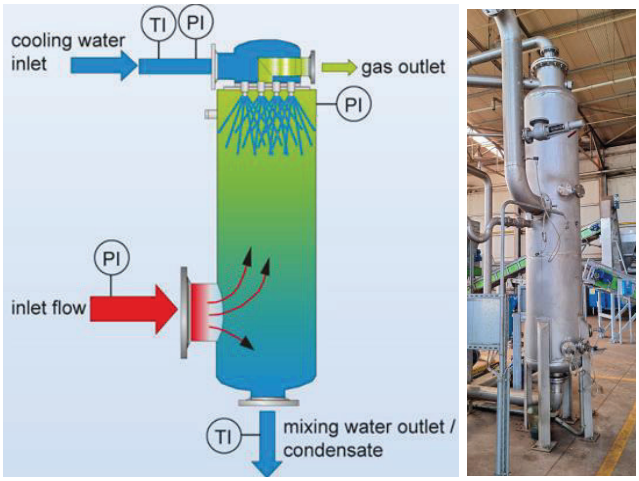


Fig. 10– steam condenser simplified scheme and steam condenser as-built

Comparison with planned results

Action A2 achieved all the expected results in terms of the design and engineering of the demonstration plant. The technical drawings were completed according to the planned schedule, and the integration of the new units with the existing infrastructure was successfully carried out.

Challenges, Adjustments, and Solutions

Action A2 faced a few technical challenges, which were effectively addressed to minimize their impact on the project. One key adjustment was the installation of a 1,700-liter/hour osmosis water production plant, necessary to ensure the SES system's optimal performance. This addition, though unplanned, did not significantly delay the project but added complexity. Another modification involved a condensate filtration system to remove lignocellulosic material, improving process efficiency and reducing wastewater. This system was integrated successfully without major delays.

The need for additional systems, such as the osmosis water plant and condensate filtration, arose during the technical design phase. These systems were critical for ensuring the efficiency of the steam explosion process and maintaining compliance with environmental standards.

Technical coordination between suppliers, particularly for the integration of the SES and auxiliary systems, proved more complex than expected. However, regular communication and collaboration between partners mitigated these challenges.

Despite these adjustments, the technical drawings and plant design were completed on time, and the systems were integrated smoothly. The delays had minimal impact, and Action A2 achieved its overall objectives.

Deliverable /Milestone	**Name**	**Deadline**	**Submitted with /Achieved**
D	Design report with technical drawings and engineering of the demo plant, including PCS, SES Unit	31/12/2021	31/05/2022 MTR
M	Technical drawings terminated	01/12/2021	31/05/2022

5.1.3 Action B.1 Feedstock collection, management and storage

Foreseen start date: 07/2023 Actual start date: 11/2023
Foreseen end date: 06/2024 Actual end date: 06/2024

Description of the activities carried out

Action B.1 involved the collection, pre-treatment, and logistical management of lignocellulosic biomass needed to supply the demonstration plant for the LIFE STEAM project. The biomass used was primarily composed of green waste collected in the Emilia-Romagna region, managed and selected through authorized HERA facilities. The main goal of this Action was to ensure that the collected biomass was of high quality and suitable for treatment with the innovative steam explosion system, ensuring continuity in the demo plant's production process.

The **biomass collected** for the LIFE STEAM project came from municipal and rural areas of the Emilia-Romagna region. HERA, the partner responsible for managing collection, handles over 210,000 tons of green waste annually. A specific portion of this volume was selected for the project, with particular attention to the lignocellulosic content of the waste to optimize the efficiency of the steam explosion process.
The collection was concentrated mainly within an area with a maximum radius of 60 km from the demonstration plant. This geographic limitation was adopted to minimize transportation costs, and the environmental impact associated with CO_2 emissions. Additionally, about 95% of the waste was collected within a 40 km radius, which significantly reduced logistical costs and improved the operational efficiency of the project.

Fig.11 - A truck loaded with GW entering the Ozzano (BO) plant

The **pre-treatment phase** was crucial to ensure that the biomass was ready for the subsequent steam explosion process. Pre-treatment was carried out at HERA's facilities and included coarse grinding and screening of the biomass to select only the fraction with sizes between 15 and 120 mm.
Two waste streams were managed: the first, collected through street containers, had lower quality due to the presence of plastic and other unwanted materials. The second stream, from public green space maintenance companies, provided higher-quality material with a higher wood content and lower contamination from materials like plastic and grass, which do not contribute to biogas production.

The selected waste was processed through a series of mechanical stages, including grinding and the removal of inert materials such as plastic and metals, to ensure that only lignocellulosic material was sent to the demonstration plant.

The **pre-treated biomass was transported** weekly from HERA's facilities to the demo plant in Voltana. Each biomass load was carefully planned to ensure regular and constant delivery of material to the plant.
A route optimization system was implemented to minimize transportation costs and the environmental impact. The routes were selected to reduce distances and transportation time, resulting in fuel savings and a reduction in CO_2 emissions.

Fig.12 - Loading of treated GW into truck ready for shipment to Voltana plant

To ensure the effectiveness of the steam explosion process, it was essential to monitor the quality of the collected and pre-treated biomass. **Biomass characterization** tests were carried out, with particular attention to the cellulose, hemicellulose, and lignin content, the main components determining the efficiency of the bioconversion process.
The selected biomass fraction met the required technical specifications to ensure optimal efficiency in the anaerobic digestion phase. The biomass was transported and delivered in optimal conditions, ensuring there were no delays or problems in biogas production.

Comparison with planned results

Action B.1 largely achieved its set goals, although with some deviations from the original plan. The collection and pre-treatment of biomass were successfully completed, and the weekly transportation to the demo plant in Voltana ensured a constant supply of biomass.

However, compared to the 1200 tons of lignocellulosic biomass that were expected, only 250 tons were processed. This reduction was mainly due to operational constraints and the need to select only high-quality material to avoid issues during pre-treatment and the steam explosion process. The reduction in processed biomass led to a proportional reduction in expected biogas output, with actual biogas production at around 15% of the initially planned levels. Despite this, the process demonstrated significant efficiency, yielding 300-400% higher biogas production from the treated biomass than untreated material.

Challenges, Adjustments, and Solutions

During the implementation of Action B.1, several deviations and challenges emerged, mainly related to biomass quality. However, these issues were addressed effectively, ensuring that the project could proceed without major setbacks.

The most significant deviation concerned the **reduction in the total volume of processed biomass**. Initially, the project aimed to process 1,200 tons of lignocellulosic waste, but only 250 tons were ultimately treated. This reduction was primarily due to interruption of the production due to maintenance of the plant. This lower biomass throughput necessitated a revision of biogas yield forecasts. However, the quality of biogas produced from the pre-treated biomass exceeded expectations, validating the technology's efficiency even with reduced input volumes.

In conclusion, while Action B.1 encountered challenges related to biomass quality and logistical constraints, these issues were resolved by refining the material selection process and optimizing logistics. The reduction in biomass volume did not impact the overall operation of the demonstration plant, and the adjustments made ensured that the project continued to meet its environmental and operational objectives.

Deliverable /Milestone	Name	Deadline	Submitted with /Achieved
D	Collection, preprocessing and delivery of GW report	30/06/2024	30/06/2024 FR
M	Delivery of first bulk of pretreated GW to the Anaerobic digestion plant	31/12/2023	31/01/2024

5.1.4 Action B.2 Plant set-up

Foreseen start date: 12/2022 Actual start date: 12/2022
Foreseen end date: 12/2023 Actual end date: 12/2023

Description of Activities Performed
Action B.2 focused on the construction and installation of the LIFE STEAM demo plant, with particular emphasis on the integration of advanced technologies such as the Pre-conditioning System (PCS) and the Steam Explosion System (SES). The **construction of this plant** involved three main companies, each of which contributed to key parts of the project.

1. RSM S.r.l. – Installation of the feeding system, destoner, shredder, and sieve:

RSM installed the feeding system, which includes a 15 m³ hopper for pre-treated green waste. The feeding system transports the biomass via conveyor belts to the destoner and shredder, ensuring a continuous and controlled flow of material.
RSM installed a hydraulic separator (destoner) to remove stones and inert materials from the biomass. This phase is crucial to avoid damage to the subsequent equipment, particularly the shredder and SES system.
RSM also installed the shredder, which reduces the biomass size to approximately 20 mm. After shredding, the material passes through a vibro-sieve, which removes oversized fractions, ensuring that only material of the correct size enters the steam explosion system.

2. Indexa S.p.A. – Installation of the Steam Explosion System (SES) and piping:

Indexa installed the Steam Explosion unit, an innovative system that treats lignocellulosic biomass at high temperatures (up to 210°C) and high pressure (up to 18 bar). This process breaks down lignin, increasing the availability of cellulose for anaerobic digestion and enhancing biogas production.
Indexa also installed all the necessary piping for transporting steam and liquids within the plant. The piping includes connections for high-pressure steam and condensate lines, ensuring proper fluid flow and management within the system.

3. Interservice S.r.l. – Mechanical BOP and steam condensation system:

Interservice performed auxiliary mechanical work, including the installation of heat exchangers, pumps, and cooling systems. These components ensure the operational stability of the system and the efficient management of the heat generated during the steam explosion process.
Interservice installed the steam condensation system, which includes a tower condenser for cooling and recycling the steam. This system is essential for recovering the steam used and reduces overall water consumption, improving the process's energy efficiency.

As a result of the installation of all the machines for the LIFE STEAM project, the supplier Eco-Next has developed the plant manual. The manual provides detailed instructions on the safe operation, maintenance, and shutdown procedures for the plant. It covers all aspects of plant management, from ensuring the proper use of safety mechanisms to outlining the correct operation of each machine. This document is essential for operators to understand the functionality of the plant, ensure efficient biogas production, and maintain safety during routine operation and maintenance activities.

The LIFE STEAM plant manual outlines several critical safety protocols to ensure both operator and equipment protection. **Emergency stop buttons** are located throughout the plant for immediate halting in case of danger, with separate buttons for overall and localized stoppages. It's strictly forbidden to use these buttons for routine shutdowns. The plant is equipped with **protective guards** and interlocked barriers that must be in place before the system can operate.

To ensure safety during maintenance, the manual emphasizes **Lockout/Tagout (LOTO) procedures**, which prevent accidental reactivation of equipment. These procedures vary based on the level of intervention, from visual inspections to full system shutdowns. Additionally, the plant operates within specified environmental conditions, with an operating range of 5°C to 40°C and humidity below 80%, ensuring both safety and optimal performance.

Comparison with Planned Results

Action B.2 successfully achieved the set goals. The demo plant's construction was completed, including the installation of key components such as the PCS, SES, and auxiliary infrastructure. Preliminary tests performed on the SES system confirmed the correct integration of the various modules and the plant's full functionality. The transportation and installation of components were completed on schedule, despite some technical difficulties related to the plant's complexity.

Challenges, Adjustments, and Solutions

During the construction of the demo plant, delays occurred due to the increased complexity of integrating the Pre-conditioning System (PCS) and the Steam Explosion System (SES). This required additional coordination between suppliers, leading to an extension of the project timeline from August 2022 to May 2023. Despite these delays, the plant was successfully completed and commissioned without further impact on the overall project timeline.

Technical challenges, particularly related to the integration of advanced systems such as the steam explosion reactor and cooling systems, also required adjustments. Frequent coordination with suppliers allowed for timely solutions, ensuring all components functioned properly and efficiently.

The complexity of managing multiple suppliers, each responsible for different components of the demo plant, contributed to delays in finalizing the installation. Coordination between RSM, Indexa, and Interservice required additional project management resources. This delay, however, allowed for a more comprehensive testing phase, ensuring full functionality once installed. The intensive coordination between suppliers during the plant setup phase required additional management oversight. Regular technical meetings were held to mitigate delays and ensure alignment across all parties.

Additionally, safety protocols, such as emergency stop buttons and Lockout/Tagout (LOTO) procedures, were implemented, slightly extending the installation phase. However, these measures ensured operator safety without negatively affecting the plant’s performance.

In conclusion, while there were delays and technical adjustments, the plant was successfully completed, and the overall project objectives were met.

Deliverable /Milestone	Name	Deadline	Submitted with /Achieved
D	Plant manuals/reports of the new LIFE STEAM Demo plant	31/12/2023	30/06/2024 FR
M	Pre-conditioning system assembled in Italy by HERA	31/05/2023	31/08/2023
M	Full LIFE STEAM Demo plant realized	31/07/2023	30/11/2023
M	Preliminary SES pressure tests and rotation tests in Valmet workshop	31/03/2023	31/03/2023

5.1.5 Action B.3 Use-case implementation and market validation

Foreseen start date: 07/2023 Actual start date: 01/12/2023
Foreseen end date: 06/2024 Actual end date: 30/06/2024

Description of Activities Performed

The demo plant was tested for a period of six months, during which biomass collection, pre-treatment, and anaerobic digestion were conducted to measure the effectiveness of the steam explosion process.

- The lignocellulosic biomass, primarily consisting of green waste, was treated through **steam explosion** at the Ozzano plant. The steam explosion process involved exposing the biomass to high pressures (up to 15.65 bar) and high temperatures (above 210°C) for varying retention times, achieving a severity level around logR0 3.9 in the final batches.

- **Anaerobic Digestion:** Following pre-treatment, the exploded biomass was transported to the Voltana site for anaerobic digestion. The biomass was mixed with inoculum from previous digestion cycles and processed in sealed anaerobic fermenters over a period ranging from 20 to 38 days. This ensured the bioconversion of volatile solids into biogas.

Fig. 13 - Ozzano Site

Fig. 14 - Voltana Site

Biogas Production

The biogas yield from exploded biomass showed a remarkable increase compared to untreated biomass. Exploded biomass produced between 262 and 293 m^3/ton VS of biogas, while untreated biomass only yielded between 50 and 94 m^3/ton VS. This indicates a 300% to 400% increase in biogas production due to the steam explosion treatment.

Despite this success, the methane content in the biogas was slightly lower than expected. The exploded biomass, characterized by high carbon content and a lack of essential nutrients such as nitrogen, resulted in a lower methane fraction, with an increase in secondary gaseous compounds such us CO2. This confirms the necessity to complement the anaerobic digestion of the exploded biomass with co-products.

Digestate Quality:

The digestate produced after anaerobic digestion of the exploded biomass was analysed for its suitability as an agricultural fertilizer. Chemical and biological tests confirmed that the digestate met the necessary standards, in compliance with local regulations.

The treated biomass showed a significant reduction in lignin and hemicellulose content compared to untreated material, facilitating better biogas yields. For instance, lignin content decreased from 30% to approximately 23-24% post-treatment, making the biomass more degradable.

Results and Performance

- **Biogas Production:** The steam explosion process dramatically improved the anaerobic digestibility of the biomass. The exploded biomass yielded nearly four times the amount of biogas compared to untreated biomass. The specific biogas production reached a peak of 293 m^3/ton VS, demonstrating the effectiveness of the pre-treatment process. Although the methane percentage in the biogas was lower due to nutrient imbalances, the overall biogas yield exceeded expectations.

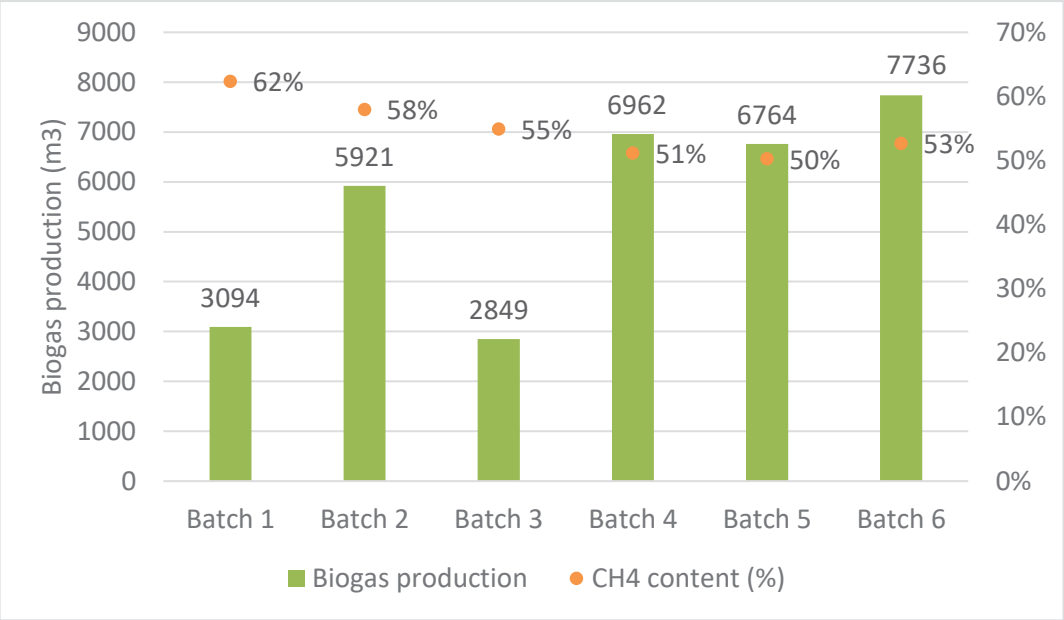


Fig. 15 - Net biogas production

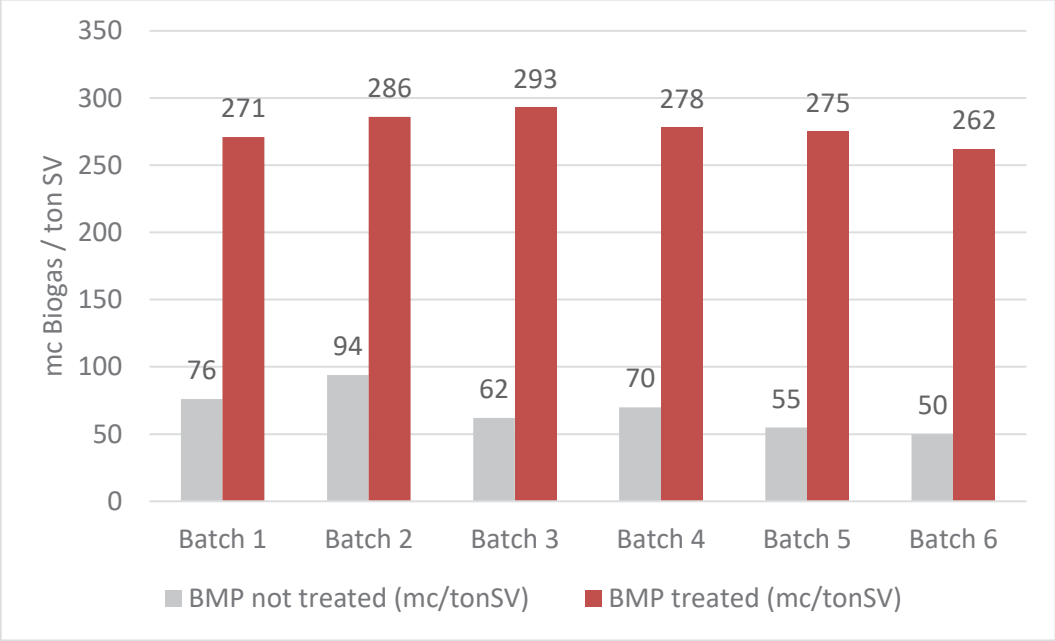


Fig. 15 - Treated vs not treated biomass biogas production

- **Biomass Treated:** The project originally planned to treat 1,200 tons of biomass during the experimental phase. However, technical and operational issues reduced this figure to 251 tons. Frequent interruptions in plant operations, particularly related to maintenance of the shredding and screening systems, were the primary cause of this shortfall.

- **Energy Efficiency:** The energy consumption of the plant, particularly during the pre-treatment phase, was carefully monitored. Initial batches showed higher energy consumption due to operational variability, but by the end of the experiment, energy consumption had stabilized around 120 kWh/ton of biomass treated.

Collection and analysis of economic data

During the trials, data related to the operational costs of the demo plant were collected, including energy, maintenance, and personnel. The energy consumption of the steam explosion process was carefully monitored, with an initial consumption of 200 kWh/ton of biomass treated, which was progressively optimized to 120 kWh/ton through adjustments in operating parameters.

Natural gas consumption was also progressively optimized. Although initially high, by the end of the trials, consumption had been reduced while maintaining high biogas production performance. The collected data indicate that further optimizations could make the process even more energy-efficient.

Comparison with planned results

Action B.3 achieved the main expected objectives, demonstrating the effectiveness of the steam explosion process in increasing biogas production from lignocellulosic waste. Although the amount of treated biomass was lower than expected, the tests showed that biogas production can be increased by up to 300-400% compared to untreated waste. This result confirms that the technology is valid and promising for industrial-scale applications.

Challenges, Adjustments, and Solutions

The main deviation in Action B.3 was the reduced amount of biomass treated, with only 251 tons processed compared to the planned 1,200 tons. This shortfall was primarily due to technical issues with the shredding system, which caused frequent operational interruptions. Despite these setbacks, the project demonstrated that the steam explosion process could increase biogas production by 300-400% compared to untreated biomass. This validated the technology's potential for industrial-scale applications.

The imbalance in carbon-to-nitrogen ratios impacted methane content, but this issue can be mitigated in future applications by blending pre-treated biomass with nutrient-rich co-substrates.

The plant maintenance proved more complex than expected, leading to delays. Moving forward, a more efficient shredder and a structured preventive maintenance plan will be necessary to avoid these issues in future implementations.

Additionally, while the methane content in the biogas was lower than expected due to nutrient imbalances, overall biogas production exceeded expectations, confirming the process's effectiveness. The energy consumption was optimized throughout the trial, progressively reduced to 120 kWh/ton of biomass treated, showing potential for further improvements in energy efficiency.

In summary, despite challenges with biomass processing and shredder maintenance, the project successfully demonstrated the viability of the steam explosion technology for increasing biogas yields.

Deliverable /Milestone	**Name**	**Deadline**	**Submitted with /Achieved**
D	Report with test results	30/06/2024	30/06/2024 FR
M	Results of first testing campaign available	31/12/2023	28/02/2024

5.1.6 Action B.4 Replicability and transferability roadmap

Foreseen start date: 09/2019 Actual start date: 02/2022
Foreseen end date: 06/2024 Actual end date: 06/2024

The objective of Action B.4 of the LIFE STEAM project was to develop a roadmap for the replicability and transfer of the Steam Explosion technology. Replication focuses on critical factors such as biomass availability, access to heat sources, and the identification of strategic partners and policymakers. The main activities were divided into market assessment, economic analysis, and meetings with stakeholders and decision-makers to ensure the future industrial development of the technology.

Description of Activities Performed

As part of Action B.4, in-depth market studies were conducted to assess the replicability potential of the technology in various industrial sectors. The replicability analysis focused on identifying opportunities for applying Steam Explosion technology in other industrial and geographical contexts. During this phase, comprehensive market studies were conducted to map the availability of lignocellulosic feedstocks in various European regions and assess potential stakeholders for the replication of the technology.
In the context of **stakeholder analysis** for the LIFE STEAM project, meetings were held with a number of key actors, each from different industrial sectors but sharing a common interest in Steam Explosion technology and its application in improving production processes and sustainable waste management.

- Caviro Extra, active in the agricultural and wine sectors, expressed strong interest in Steam Explosion technology, recognizing the potential to treat their lignocellulosic residues for biogas production and recover high-value components such as furfural. This aligns with their sustainable approach and commitment to the circular economy.
- Gresmalt S.p.A., a producer of porcelain stoneware, saw Steam Explosion technology as an opportunity to improve energy efficiency, especially by exploiting low-enthalpy waste heat from their production processes. They are also interested in the use of biomethane for decarbonizing their supply chain.
- HERAmbiente S.p.A., a leader in waste management, discussed the use of steam generated in their Waste-to-Energy (WtE) plants to power the Steam Explosion process, highlighting the synergy this solution could offer to optimize energy costs and improve plant efficiency.
- Toyota Motor Europe, while still evaluating the business case of the project, showed curiosity and openness to potential future collaborations, particularly in the context of integrating biogas into their sustainability initiatives.
- PKN Orlen, one of Poland's leading energy companies, expressed strong interest in Steam Explosion technology, viewing it as a solution for heat recovery in energy-intensive industrial processes. They have already organized tests at their pilot plant in Sweden, demonstrating a concrete commitment to energy innovation.
- Gruppo Frati S.p.A., specialized in the production of wood-based panels, identified the technology as a means to treat their lignocellulosic residues, reducing waste and improving the efficiency of their production chain. They visited the project prototype at the Ecomondo 2023 fair, confirming their interest in participating.

- The Interprovincial Agricultural Cooperative Consortium (C.I.C.A.) expressed interest in collaborating on the implementation of large-scale plants dedicated to agricultural residue management, particularly the treatment of straw through Steam Explosion, considered a crucial step for improving biomethane production.
- The Animal Production Research Center (CRPA), a research institute with expertise in waste valorization, showed interest in evaluating the technology in terms of environmental sustainability and within the context of the circular economy.
- The Marcegaglia Group, active in the steel sector, expressed concrete interest in energy recovery from their residues through innovative technologies like Steam Explosion to optimize their industrial processes.
- The Italian Biogas Consortium (CIB) positively evaluated the possibility of using Steam Explosion technology to improve the efficiency of their agricultural biogas plants, particularly in the integration of new lignocellulosic feedstocks.
- Finsa (Spain) and Out Nature (Germany), leading companies in the timber sector, both recognized the added value that Steam Explosion technology could bring to wood residue management, with Finsa particularly interested in increasing biomethane production in their industrial processes.
- Soane Arauco (Portugal) and Youssef Allam Group (Egypt) expressed strong interest in the replicability of the technology in their respective regions, seeing Steam Explosion as a solution for improving waste management and increasing production efficiency.
- The WEPA Tissue Group, active in paper production, positively evaluated the possibility of using Steam Explosion by-products in their production processes to increase efficiency and reduce operational costs.

The engagement of key partners, such as Herambiente and C.I.C.A., occurred over several stages, beginning with the stakeholder mapping in Action B4 and culminating in formal partnerships during Action D2. These discussions were instrumental in shaping the replication roadmap and customizing the business plan to meet the needs of industrial stakeholders.

An **economic and energy feasibility study** of the LIFE STEAM pilot plant was conducted, focusing particularly on operational efficiency and costs. The main objective of the deliverable was to validate the economic case of the pilot plant and collect data for future large-scale replication but not to provide a complete assessment for commercial upscaling. The total investment for the pilot plant amounted to 29 million euros, with equipment purchases accounting for 77.7% of the total, including the Steam Explosion system supplied by Valmet (50.1%). Other key items were engineering (3.5%) and on-site work (18.8%).
Operating costs (OPEX) were estimated at €200,745 per year. Of these, 46% were due to energy consumption, mainly electricity (€226/ton) and natural gas (€295/ton), while maintenance was estimated at €125/ton. Water consumption and wastewater disposal accounted for approximately €32 and €182/ton, respectively. Steam consumption was the main contributor to the energy costs of the pilot plant. Steam generation via natural gas boilers represented 69% of the plant's total energy consumption. Although the plant demonstrated a positive energy balance, the costs related to steam production remain a significant challenge.
A sensitivity simulation was conducted to assess the effect of scaling up on operational costs. The results showed that increasing the plant's capacity significantly reduces specific costs per ton of treated biomass and steam consumption. However, even with these reductions, production costs remain above current market values for biogas.
In conclusion, the LIFE STEAM pilot plant validated the technological potential of Steam Explosion, but to make it economically competitive, optimizations are needed, particularly in steam production and energy cost reduction.

Another objective of Action B.4 was **to engage key political decision-makers** at local, national, and European levels to promote the adoption of Steam Explosion technology in the context of biomethane production from lignocellulosic waste. The engagement strategy focused on two main aspects: the regulatory recognition of Steam Explosion material as a by-product rather than waste and the identification of economic incentives to support the industrial implementation of the technology.
The main political decision-makers identified included ARPAE, the Emilia-Romagna Region, CIB, and CICA. These actors were involved in direct meetings and roundtables to discuss regulatory barriers and opportunities to support the integration of biomethane into regional and national energy strategies.
Specific consultations were held to foster dialogue between project partners and policymakers. These meetings allowed the presentation of the business case for Steam Explosion technology and discussions on the regulatory changes needed to facilitate the valorization of agricultural and urban waste. Participants provided feedback on potential incentives to be included in national renewable energy programs.
The final project event, held in June 2024, represented a crucial moment to consolidate dialogue with policymakers. During the event, project partners presented scientific and technological results, focusing on opportunities to recognize Steam Explosion-treated material as a by-product and integrate it into national and European renewable energy plans.
The main results obtained in relation to this activity were:

- Regulatory Recognition: Policymakers highlighted the importance of amending regulations to allow the use of Steam Explosion material in agricultural anaerobic digestion processes.
- Incentives for Biomethane: Political decision-makers discussed the possibility of including incentives to promote the use of lignocellulosic residues as feedstock for agricultural biomethane production.
- Institutional Support: Representatives of local and national institutions expressed their commitment to supporting the adoption of Steam Explosion technology with the aim of improving the energy and environmental sustainability of the agricultural sector.

The **plan for the replication and transfer** of Steam Explosion technology focuses on three main factors: feedstock availability, proximity to heat sources, and the regulatory and incentive framework available. The replicability of the technology is closely linked to the availability of lignocellulosic biomass such as agricultural and industrial residues. The technology is particularly suitable for countries such as Italy, France, Sweden, and Germany, where renewable energy infrastructures already exist and there is strong demand for biomethane.
Two full-scale projects have been planned by Hera: a 50,000-ton/year plant at a Waste-to-Energy (WtE) site and a 100,000-ton/year plant for the treatment of agricultural residues in collaboration with the C.I.C.A. Additionally, the Ozzano pilot plant will continue to be used to test new types of biomass, expanding the validation of the business case.
The analysis identified that using steam from WtE plants represents the most economically and environmentally advantageous solution compared to the use of natural gas or biomass boilers. This strategy not only reduces costs but also offers significant environmental benefits.
Moreover, the LIFE STEAM project secured patent application number 102021000026306, granted on October 14, 2021, titled "Process and system for the conversion of lignocellulosic biomass into biomethane." This patent highlights the innovative approach developed for efficiently converting agricultural and urban prunings into biomethane, reinforcing the project's potential for scalability and long-term commercial viability.

Expected Results vs. Obtained Results

The expected results included the creation of an economic plan for the pilot plant, the identification of replication opportunities in other European regions, and the involvement of policymakers to ensure regulatory recognition. The obtained results confirmed the replication potential of the technology, with key industrial stakeholders expressing interest and policymakers initiating discussions on regulatory changes and incentives for biomethane.

The strategic partnerships identified in B4 were further developed into formal agreements and Letters of Interest during D2, ensuring continuity in the replication of the steam explosion technology.

The results were aligned with the set objectives for validating the business case of the pilot plant and gathering useful data for upscaling. However, the economic analysis indicated that, to make the project bankable on a large scale, further optimizations in steam production costs and biomethane incentives are necessary.

Challenges, Adjustments, and Solutions

Overall, no significant deviations were recorded, but the project team adapted its strategy to ensure stronger engagement with policymakers and optimize the business case for large-scale replication. The challenges encountered were resolved through targeted adjustments, and the project's outcomes remained aligned with its original objectives.

Deliverable /Milestone	Name	Deadline	Submitted with /Achieved
D	Stakeholders and market analysis	31/12/2023	30/06/2024 FR
D	Replication and transfer plan	31/12/2023	30/06/2024 FR
D	Full business plan of the project, including economic scenario and sensitivity analysis	31/12/2023	30/06/2024 FR
D	Engagement of policy-makers	31/12/2023	30/06/2024 FR
M	Business case fundamentals prepared for the full scale plant	31/01/2023	30/06/2024
M	List of stakeholders prepared	31/12/2021	30/06/2024
M	At least 8 stakeholders interviewed	31/03/2023	30/06/2024
M	Workshop with policy-makers	31/12/2023	30/06/2024

5.1.7 Action C.1 Monitoring of environmental and socio-economic impacts

Foreseen start date: 09/2019 Actual start date: 09/2019
Foreseen end date: 06/2024 Actual end date: 06/2024

Description of the activities undertaken

The LIFE STEAM project implemented a series of activities aimed at monitoring the environmental and socio-economic impact of the steam explosion system. The objective was to validate the system's ability to manage lignocellulosic waste, converting it into biogas and digestate.

The main activities carried out under Action C1 focused on three main areas:

1. Environmental Impact Monitoring through KPI

The activities undertaken for the monitoring of KPIs focused on assessing the project's performance in various key areas, including resource management, energy efficiency, and job creation. The primary goal of this deliverable was to ensure that the environmental and socio-economic impacts of the project were adequately measured and that the updated KPIs reflected the changes introduced during the project amendment.

- KPI Update and Definition: Following the integration of a new project partner and the adoption of a new technology, the original list of KPIs was revised. This revision, carried out in agreement with the project monitor, aimed to align the KPIs with the updated objectives of the LIFE STEAM project. The new set of KPIs was uploaded to the LIFE KPI 2.0 platform, allowing for real-time tracking and monitoring throughout the project lifecycle. The updated KPIs measured critical aspects such as energy production, resource consumption, stakeholder engagement, and the potential for future replication.

- Monitoring Methodology: The monitoring system was implemented across the demonstration sites in Ozzano and Voltana, where data on waste treatment, biogas production, water usage, and energy savings were collected. A comprehensive methodology was developed to ensure the accuracy of the data collected, utilizing metering systems and field measurements. The environmental performance was continuously tracked through a combination of field sensors and data collection tools, providing detailed insights into the efficiency of the steam explosion technology. Specific attention was given to tracking biogas production rates and the associated reductions in greenhouse gas emissions.

- Resource Efficiency and Energy Production: One of the key KPIs involved monitoring the amount of green waste treated and the corresponding biogas production. While the initial goal was to treat 1,200 tons of green waste annually, operational difficulties limited the amount to 250 tons. As a result, KPIs related to energy production, such as electricity generated from biogas, were lower than expected. Despite this, the system demonstrated significant resource efficiency improvements, particularly in terms of water consumption and waste-to-energy conversion rates. These findings were critical in assessing the technology’s scalability for future industrial applications.

- Stakeholder Involvement and Collaboration: The KPI monitoring also included tracking the involvement of stakeholders in the project. Sixteen stakeholders actively participated during the demonstration phase, contributing to the project's development and providing valuable feedback for potential future replications.

- Data Reporting and Documentation: The collected data was regularly reported through detailed documentation, ensuring that the project remained transparent and that all findings were recorded in line with LIFE program requirements. The report also includes future projections for scaling up the system and its replication potential across other regions in Europe.

2. Life Cycle Assessment (LCA)

The Life Cycle Assessment (LCA) activities were carried out with the objective of evaluating the environmental impacts of the "steam explosion" technology used to treat lignocellulosic waste, particularly green waste such as prunings and clippings. The activities were divided into several key phases, following internationally recognized methodologies such as ISO 14040 and 14044 standards.

- The LCA assessment started by defining the system boundaries for the pilot and full-scale plants. The assessment followed a cradle-to-grave approach, meaning that all phases from the extraction of raw materials to the disposal of end-products (biogas and digestate) were included. The functional unit selected for the analysis was 1 kg of treated green waste. This functional unit allowed for a direct comparison between the environmental impacts of the pilot and full-scale plants, as well as a comparison with traditional composting methods.

- The first phase of the LCA focused on the pilot plant, which had a capacity of treating 1 ton of waste per hour. The analysis of the pilot plant highlighted several challenges, particularly in the anaerobic digestion process. Biogenic methane emissions contributed significantly to the carbon footprint, with a global warming potential (GWP) of 0.07 kg CO_2 eq per kg of waste treated. The steam explosion process also required significant amounts of energy, contributing to impacts in categories like fossil fuel depletion and acidification. The consumption of natural gas for steam generation, coupled with electricity use, resulted in a high energy demand.

- The second phase of the LCA focused on the full-scale plant scenario, which treated 14 tons of waste per hour. The full-scale plant was designed with optimized processes to reduce the environmental impacts observed in the pilot plant. One of the major improvements in the full-scale plant was the reduce energy consumption per ton of treated green waste and the use of biogas produced from anaerobic digestion to power part of the plant itself. This led to a significant reduction in natural gas consumption and improved the overall energy efficiency of the system. The full-scale plant achieved a GWP of 0.016 kg CO_2 eq per kg of waste treated, a marked improvement over the pilot plant.

- A comparative analysis was conducted between the LIFE STEAM system and traditional composting methods for green waste treatment. Traditional composting was found to have higher methane emissions due to the aerobic decomposition of organic matter, resulting in greater environmental impacts. The LIFE STEAM system, on the

other hand, demonstrated significant advantages in terms of greenhouse gas reduction, energy recovery, and resource efficiency. The production of biogas, which could be used to generate electricity, provided an additional benefit not present in traditional composting processes.

- Data for the LCA was collected from multiple sources, including field measurements from the demonstration plants and secondary data from databases such as Ecoinvent 3.9.1. The analysis covered various environmental impact categories, including global warming, acidification, eutrophication, and water depletion. The results of the LCA were used to identify areas where further improvements could be made, particularly in the energy efficiency of the steam explosion process and the management of methane emissions during anaerobic digestion. The overall conclusion of the LCA activities was that the LIFE STEAM system offers a more sustainable solution for green waste management compared to traditional methods such as composting, with significant reductions in greenhouse gas emissions and improved resource recovery.

3. Synergies with the EU priorities for jobs and growth

The main objective of this activity was to align the LIFE STEAM project with the European Union's strategic priorities for jobs, sustainable growth, and inclusive development. It focused on evaluating the socio-economic impact of the project, particularly regarding job creation during both the construction and operational phases of the system.

Assessment of EU Priorities for Jobs and Growth:

- The first phase of this deliverable involved analyzing the main European instruments and policies for job creation, sustainability, and growth, including the Europe 2020 Strategy, The European Green Deal, and Next Generation EU.
- Each policy was examined to determine how the LIFE STEAM project aligns with these strategies. For instance, the European Green Deal's ambition to make Europe the first climate-neutral continent by 2050 fits closely with LIFE STEAM's contribution to renewable energy production and waste management innovation. The Next Generation EU fund also emphasizes green growth and job creation, which are key impacts of the LIFE STEAM system.

Modeling Job Creation Using the JEDI Model:

- The project employed the Jobs and Economic Development Impact (JEDI) model developed by the National Renewable Energy Laboratory (NREL) to estimate the socio-economic impacts. This model, widely used for energy projects, provided estimates of the number of jobs created during the construction and operational phases of the plant.
- Construction Phase: During the construction of the demonstration plant, it was estimated that around 81 full-time equivalent (FTE) jobs would be created. These jobs included on-site labor, construction-related services, and jobs indirectly supported through the supply chain.
- Operational Phase: Once the plant became operational, the system was estimated to create 72 permanent jobs, including positions related to plant operations, local revenue generation, and supply chain impacts. The total labor impact from both phases of the plant's development (construction and operational) was projected to result in 153 new jobs. Adapting JEDI Model to European Context:

- Although the JEDI model was initially developed for projects in the U.S., the project team adapted its results to the European context. This adaptation involved comparing economic indicators such as GDP and job creation rates between the U.S. and the EU, ensuring that the job creation estimates were realistic within European economies.
- The Italian and Swedish National Recovery and Resilience Plans were specifically evaluated for how they could complement the employment and growth objectives of the LIFE STEAM project. The Italian plan, for example, prioritized green recovery, job creation, and technological innovation, aligning closely with the project's goals.

Scaling Job Creation for Replication Scenarios:

- The project also evaluated how job creation could scale if the LIFE STEAM system was replicated at industrial scale across different regions. For example, in Italy, it was estimated that a replication of the system could generate up to 766 jobs, while across the European Union, it could result in up to 22,965 jobs.
- This analysis helped demonstrate the broader potential socio-economic benefits of the technology, including its contributions toward the Next Generation EU target of creating 700,000 new green jobs by 2030
- The deliverable highlighted the strategic importance of developing renewable energy sources like biogas, which not only helps achieve climate targets but also drives economic resilience by creating sustainable jobs in the bio-based sector.

Comparison with planned output

The activities carried out under Action C1 were generally aligned with the planned outputs, although there were some variations due to operational challenges. The environmental impact monitoring through KPIs was successfully implemented, although the amount of green waste treated during the project was lower than initially projected. The original goal was to treat 1,200 tons of waste annually, but operational difficulties led to a reduction to 250 tons. As a result, key performance indicators related to biogas production and energy generation were not fully met. Despite this, the project demonstrated significant improvements in resource efficiency, particularly in terms of water savings and waste-to-energy conversion, which provided a solid foundation for future industrial applications. While the amount of green waste processed was lower than planned, the environmental benefits, particularly in terms of greenhouse gas reduction, were demonstrated. The KPI monitoring system tracked progress in line with the updated targets agreed upon with the project monitor, and the LCA confirmed the environmental advantages of the steam explosion process.

In terms of the Life Cycle Assessment (LCA), the project delivered strong results in line with the planned outputs. Both the pilot and full-scale systems were assessed following ISO 14040 and 14044 standards, with the full-scale system showing a marked improvement over the pilot plant in terms of greenhouse gas emissions. The full-scale system achieved a Global Warming Potential (GWP) of 0.016 kg CO_2 eq per kg of waste treated, a significant reduction compared to normal green waste composting (0.05 kg CO_2 eq. per kg of waste treated). This confirmed that the LIFE STEAM system offers a more environmentally sustainable solution for green waste management compared to traditional composting methods, which are associated with higher methane emissions and less efficient energy recovery.

In addition, the project's assessment of socio-economic impacts and job creation, modelled using the JEDI tool, aligned with the expected results. For a large full-scale project (i.e. 100 kton plant) 81 jobs may be created during the construction phase and 72 permanent jobs during the operational phase, for a total of 153 new jobs. Furthermore, the socio-economic analysis

revealed that replicating the LIFE STEAM system across Europe could lead to the creation of over 22,000 jobs, significantly exceeding initial expectations. This outcome demonstrated the strong potential of the project to contribute to the EU's broader goals for green job creation, as outlined in the European Green Deal and Next Generation EU.

Challenges, Adjustments, and Solutions

During Action C.1, the primary challenge was the reduced treatment capacity of the pilot plant, which processed 250 tons of green waste instead of the planned 1,200 tons. This shortfall was caused by technical issues in the waste handling process, affecting both biogas production and energy generation KPIs. Despite this, the project still demonstrated significant resource efficiency gains, particularly in water savings and waste-to-energy conversion, which provided valuable insights for future industrial applications.

The Life Cycle Assessment (LCA) revealed higher-than-expected energy consumption during the pilot phase, particularly in fossil fuel depletion categories. However, in the full-scale system, the use of biogas produced on-site helped mitigate these impacts, improving overall energy efficiency.

Another adjustment involved revising the KPI framework to align with the updated treatment capacity and integrating new socio-economic modeling tools adapted to the European context. The JEDI model, originally designed for U.S. projects, was successfully adapted to reflect European economic conditions, ensuring realistic job creation estimates.

In summary, while Action C.1 faced challenges with waste treatment and energy consumption, these issues were managed effectively through technical adjustments and real-time monitoring. The core objectives of the action were still achieved, and the project's overall progress remained on track.

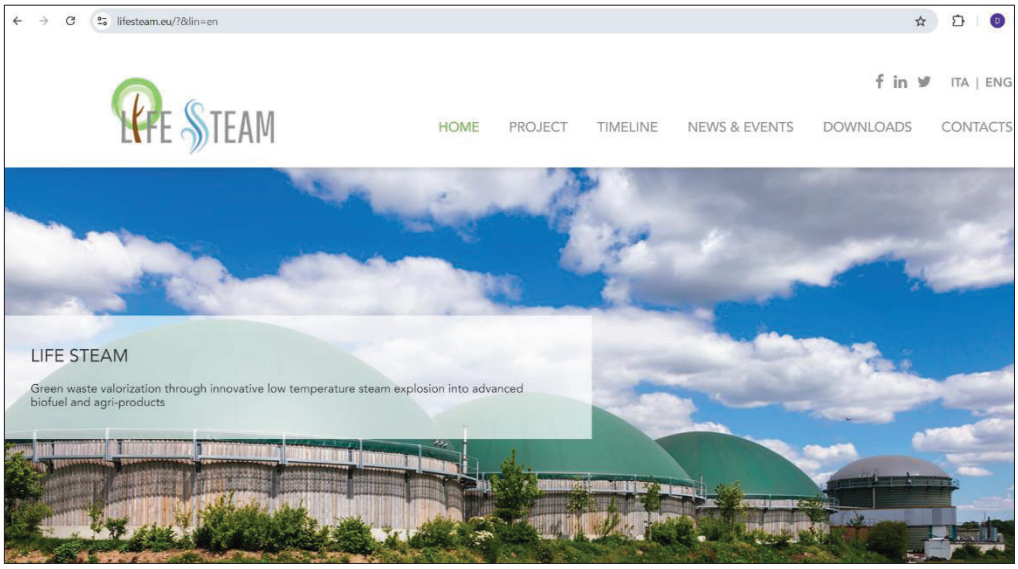
Deliverable /Milestone	Name	Deadline	Submitted with /Achieved
D	Report on monitoring of KPIs, including update of the LIFE KPI table – Midterm report	31/07/2022	31/07/2022 FR
D	Report on monitoring of KPIs, including update of the LIFE KPI table – Final report	30/06/2024	30/06/2024 FR
D	Assessment of the socio-economic impact of the project	30/06/2024	30/06/2024 FR
D	Full LCA of LFE STEAM system and products	30/06/2024	30/06/2024 FR
D	Synergies with the EU priorities for jobs and growth	31/07/2022	30/06/2024 FR
M	First validation of KPIs foreseen by LIFE STEAM project	31/12/2022	31/12/2022
M	Second validation of KPIs foreseen by LIFE STEAM project	30/06/2024	30/06/2024

5.1.10 Action D.1 Communication, Dissemination and Networking

Foreseen start date: 09/2019 Actual start date: 09/2019
Foreseen end date: 06/2024 Actual end date: 06/2024

The dissemination, communication, and networking activities under Action D1 were critical for ensuring that the results and achievements of the LIFE STEAM project reached the widest possible audience. These activities aimed to promote the project's replicability and transferability, as well as to engage relevant stakeholders across multiple sectors.

Creation and Maintenance of the LIFE STEAM Website and Social Media Channels: The **LIFE STEAM website** was developed within the first three months of the project and served as the primary platform for sharing updates and results. The site (accessible at **www.lifesteam.eu**) was regularly updated with information about the project's progress, including technical results, public reports, and event announcements. This was complemented by the project's presence on LinkedIn and Twitter, where specific posts were used to engage target groups. By **September 2024**, the website had attracted **1,128 visitors** and generated **1,885 page views**. Visitors accessed the site primarily via direct links, reflecting the effectiveness of promotional efforts during events and through other communication channels.



STATISTICHE

Menu

questo computer è: **visibile**

Dati generali

Riepilogo
Pagine visitate

Visitatori

Dettaglio visite
Provenienza (nazioni)
Provenienza (città)
Host
Lingue
Fasce orarie
Giorni della settimana

Accessi

Giorno
Seleziona giorno
Mese
Seleziona mese
Ultimi 12 mesi
Permanenza pagine
Medie periodiche

Sistemi utilizzati

Browser
Sistema operativo
Monitor e colori

Referenti

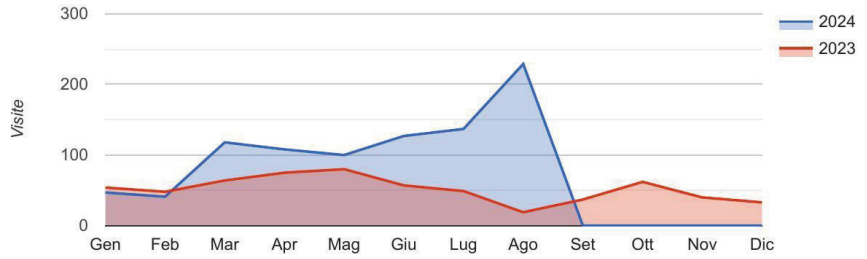
Siti referenti
Pagine referenti

Motori

Motori utilizzati
Spider
Dettagliato accessi
Provenienza (nazioni)
Host
Fasce orarie
Giorni della settimana

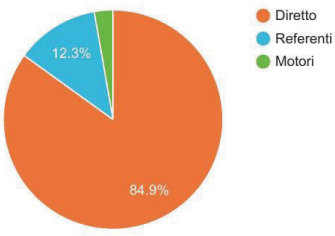
RIEPILOGO ACCESSI

Visitatori online: **1**

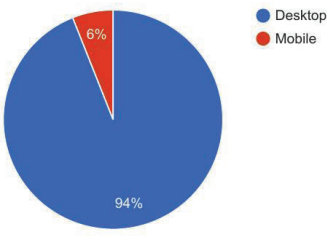


PROVENIENZA VISITATORI

MODALITÀ DI ACCESSO



DEVICES UTILIZZATI



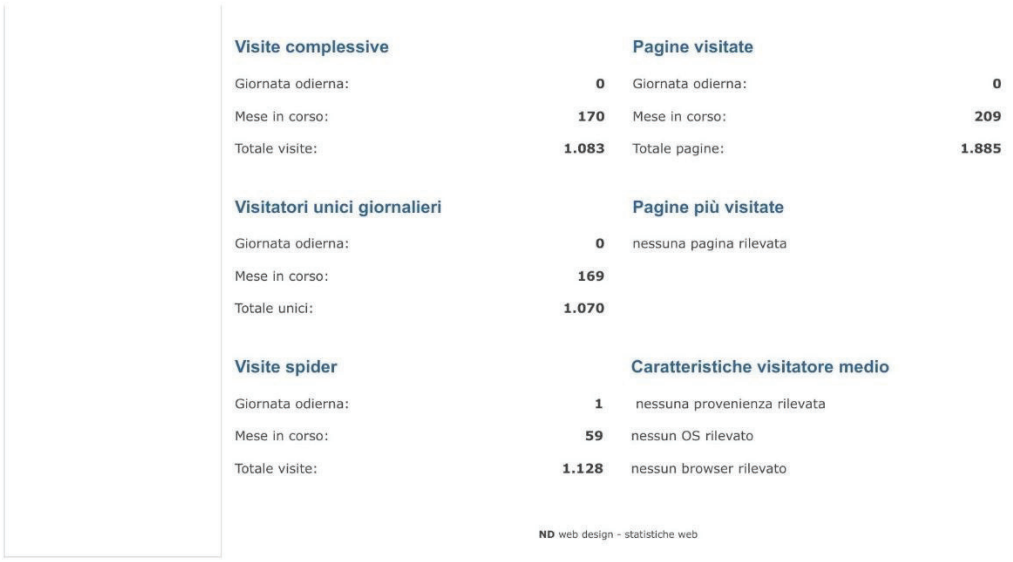
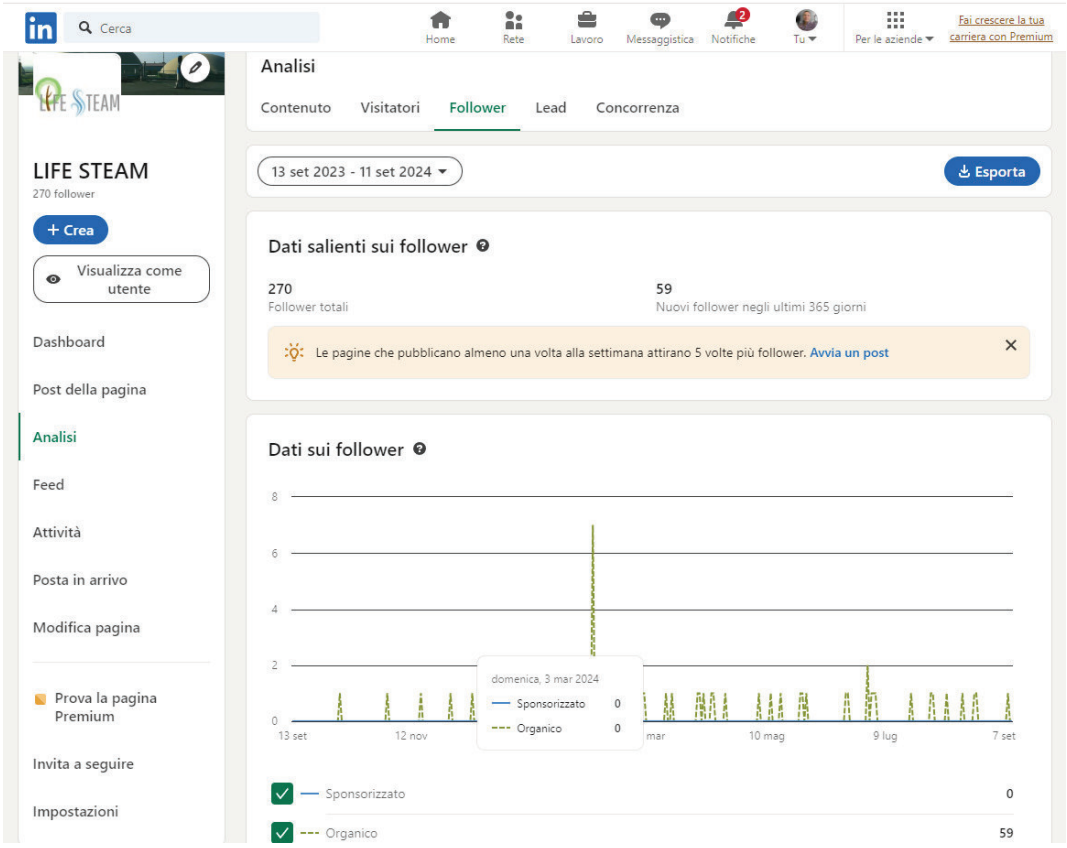


Fig. 16 – Project website statistics

The project's **LinkedIn profile (accessible at** https://www.linkedin.com/company/lifesteam/) had attracted **270 followers**, with a significant engagement rate: a post shared on **June 28, 2024**, achieved **1,033 impressions** and **648 clicks**. These figures highlighted the success of the project's social media outreach, particularly in engaging stakeholders from industry and academia.



Link	Date	Impressions	Click	Click percentage (CTR)	Suggested	Comments	Shared	Interest percentage
https://www.linkedin.com/feed/update/urn:li:activity:7237835382610948098	09/06/2024	241	27	0,112033196	13	0	0	0,165975109
https://www.linkedin.com/feed/update/urn:li:activity:7227386608273022976	08/08/2024	809	54	0,066749074	18	0	4	0,093943141
https://www.linkedin.com/feed/update/urn:li:activity:7212405455459909632	06/28/2024	1033	648	0,62729913	24	0	2	0,652468562
https://www.linkedin.com/feed/update/urn:li:activity:7211363447488319488	06/25/2024	442	21	0,047511313	9	0	0	0,067873307
https://www.linkedin.com/feed/update/urn:li:activity:7208354640466178048	06/17/2024	398	22	0,055276383	7	0	1	0,075376883
https://www.linkedin.com/feed/update/urn:li:activity:7207031247045378049	06/12/2024	701	97	0,138373747	29	0	4	0,185449362
https://www.linkedin.com/feed/update/urn:li:activity:7193177414749863936	05/06/2024	642	38	0,059190031	16	0	1	0,085669778
https://www.linkedin.com/feed/update/urn:li:activity:7180934941721911296	04/02/2024	1005	68	0,067661695	15	2	1	0,085572138
https://www.linkedin.com/feed/update/urn:li:activity:7172875102257070080	03/11/2024	363	11	0,030303031	7	0	1	0,052341599
https://www.linkedin.com/feed/update/urn:li:activity:7170713317919911936	03/05/2024	800	30	0,037500001	22	0	2	0,067500003
https://www.linkedin.com/feed/update/urn:li:activity:7168611576034398208	02/28/2024	684	147	0,21491228	14	1	0	0,236842111
https://www.linkedin.com/feed/update/urn:li:activity:7162754418982031360	02/12/2024	326	14	0,042944785	9	0	0	0,070552148
https://www.linkedin.com/feed/update/urn:li:activity:7162749358910685184	02/12/2024	687	53	0,077147014	20	0	0	0,1062591
https://www.linkedin.com/feed/update/urn:li:activity:7151208101168197632	01/11/2024	1184	58	0,048986487	51	2	6	0,098817565
https://www.linkedin.com/feed/update/urn:li:activity:7128458385963778049	11/09/2023	682	163	0,239002928	21	0	2	0,272727281
https://www.linkedin.com/feed/update/urn:li:activity:7122218394447155200	10/23/2023	287	6	0,020905923	6	0	0	0,041811846

Fig. 17 – Linkedin profile statistics

Despite Twitter being another key social media platform used by the project, LinkedIn proved to be more effective in terms of reach and interaction. The project's LinkedIn posts focused on sharing results, technological advancements, and event invitations, driving engagement with professionals from the bio-based sector and policy makers.

Dissemination at Key Events and Conferences: The project made extensive use of conferences, workshops, and international events to disseminate its results. Participation in these events allowed the project team to directly interact with stakeholders, distribute promotional materials, and raise awareness about the project's potential for replication.
Some of the major events attended included:

- **ECOMONDO 2019** in Rimini, where the project was presented to **50 attendees** through notice boards and leaflets. ECOMONDO was a key event for sharing the project's initial goals and engaging with both technical and non-technical audiences.
- The **BIORESTEC Conference 2023** at Lake Garda, which focused on renewable energy and bio-based technologies, attracted **100 participants**. The LIFE STEAM project team used this opportunity to present the technical advancements of the steam explosion system, specifically related to biogas production.
- The **Final Project Event**, held in Bologna in **2024**, marked the culmination of the project's efforts. At this event, **50 stakeholders** from various sectors, including industry, research, and policy-making, gathered to discuss the results of the project. Promotional materials such as **the Layman's Report**, notice boards, and leaflets were distributed(D1).
- Additional participation at international events like **RNGworks** in Nashville, USA, and workshops at **ECOMONDO 2022 and 2023** allowed the project to engage with global stakeholders. These interactions helped expand the network of collaborators and increased the project's visibility.

A complete list of dissemination events is reported in the following table.

DISSEMINATION EVENT (name and link)	Leader	Place and date	Participants (number + type)	Topics discussed	Dissemination material distributed (type+ quantity)	Annexes (Photos, Presentations, etc.)
LIFE ENV and GIE Welcome Meeting EASME	HERA	Bruxelle,, November 7-8, 2019	100	Regulatory, technical, and financial aspects of the LIFE Programme while fostering networking among European environmental projects	/	
Power4bio conference	AYR	Napoli, Octoer 2, 2019	50	bioeconomy developments, available technologies, and bioplastics by industry and academic representatives	/	

ECOMONDO 2019	HERA	Rimini, November 5, 2019	50	leading event in Europe for environmental sustainability and circular economy	Notice board (1) and leaflets (98)	
Cluster Spring meeting	HERA	Online, June 2021	40	project was presented during one of the meetings of the Italian Spring Cluster. The Cluster has over 120 members, representing all the entities operating in the circular bioeconomy	Project ppt presentation	/
Macfrut 2022	AYR	Cesena, May 2022	50	Project objectives dissemination	Notice board (1) and leaflets (30)	
Workshop Ecomondo 2022	HERA	Rimini, November 222	50	Project results dissemination	Notice board (1) and leaflets (50)	
Anaerobic digestion companies meeting at HERA	HERA	Bologna, February 2023	50	Project results dissemination	Notice board (1) and leaflets (50)	

BIORESTEC Conference	HERA	Garda Lake, May 2023	100	Project results dissemination	Leaflets (50)	
Stand CINEA Ecomondo 2023	HERA	Rimini, November 2023	20	Project results dissemination	Leaflets (20)	
Stand VALMET ECOMONDO 2023	Valmet	Rimini, November 2023	40	Project results dissemination	Leaflets (50)	
XXV Conference on Composting and Anaerobic Digestion – Ecomondo 2023	HERA	Rimini, November 2023	50	Project results dissemination	Project ppt presentation	
Final event	HERA-Valmet-AYR	Bologna, June 2024	50	Project results dissemination	Notice board (1) and leaflets (50)	
RNGworks conference	Valmet	Nashville (USA), September 2024	50	Project results dissemination	Project ppt presentation	

A number of the additional dissemination activities were carried out after the set-up of the prototype consisting mainly in the technical visits to the plant organized by Hera and Valmet.

DISSEMINATION ACTIVITY	Partner name	Expected Results (according to the GA)	Results achieved at ../../….
Prototype technical visit with Caviro Extra	HERA – Valmet	Engagement of stakeholders for future commercialization	February 2024
Prototype technical visit with Orlen	HERA – Valmet	Engagement of stakeholders for future commercialization	March 2024
Prototype technical visit with FINSA	HERA – Valmet	Engagement of stakeholders for future commercialization	March 2024
Prototype technical visit with Out Nature	HERA – Valmet	Engagement of stakeholders for future commercialization	March 2024
Prototype technical visit with Soane Arauco	HERA – Valmet	Engagement of stakeholders for future commercialization	April 2024
Prototype technical visit with CICA	HERA – Valmet	Engagement of stakeholders for future commercialization	April 2024
Prototype technical visit with Allam Group	HERA – Valmet	Engagement of stakeholders for future commercialization	May 2024
Prototype technical visit withing final event	HERA – Valmet - AYR	Dissemination of results	June 2024

Fig. 18 – Technical visits to the prototype

Networking and Collaborations: Networking was a fundamental part of the dissemination strategy, with the project actively seeking collaborations with other EU-funded initiatives. The goal was to foster knowledge exchange, explore synergies, and promote the potential replicability of the LIFE STEAM system. The project established partnerships with other LIFE and EU-funded projects, including:

- **LIFE Force of the Future**: Collaboration focused on exploring synergies in bio-based processes, with particular attention to waste heat recovery and biogas optimization(D1).
- **LIFE Green Factory** and **LIFE DualNG**: These collaborations were centered around integrating steam explosion technology into waste management processes in alignment with broader EU sustainability goals. The networking efforts also led to increased engagement with policymakers, further supporting the transferability and scalability of the LIFE STEAM technology.

Details of such collaborations are reported in the following table.

Project number and acronym, start date and end date	Project scope	Contact details	Networking activity description
LIFE16 ENV/IT/000307 LIFE Force of the Future 01/10/2017 - 31/05/2021	The project aims to create a more sustainable production model for the ceramic tile industry by reducing environmental impacts through circular economy practices like reusing production waste and using more local raw materials	Davide Settembre davide.settembre@gresmalt.it	To explore the use of waste heat from ceramic production processes in the steam explosion technology for the LIFE STEAM project
LIFE19 ENV/IT/000185 Life Green Factory 01/09/2020 - 28/02/2024	The project aims to reduce particulate matter (PM) concentrations in metal factories using an energy-saving electronic detection system. This system monitors air quality through a network of IoT sensors that optimize factory ventilation, reducing pollutants like PM, VOCs, and odors. The project focuses on improving indoor air quality and reducing energy consumption by up to 30%, with a 99% reduction in PM emissions	Marco Grazioli marco.grazioli@losma.it	The company suggested integrating their IoT-based air monitoring solution into the future LIFE STEAM full-scale plant

101099487 BIOLAMER 01/04/2023 – 31/03/2026	The project aims to tackle two major global challenges: food waste and petroleum-based plastic pollution. The project is developing a new value chain by using *black soldier fly larvae* (Hermetia illucens) to convert food waste into valuable biopolymers, such as polyhydroxyalkanoates (PHA) and chitosan. These biopolymers are intended to be used for producing biodegradable plastics for applications in food preservation and biomedical fields	Sibu Chullanayil Padmanabhan chullans@tcd.ie	Stefano Longo (HERA) is part of the Scientific Innovation Advisory Board. To assess the potential for using prunings treated with steam explosion as a feedstock in Biolamer's biopolymer production processes
LIFE19 ENV/IT/000209 LIFE DualNG 01/09/2020 - 29/02/2024	The project project retrofits diesel-powered heavy-duty vehicles to use a dual-fuel system (diesel + natural gas) to reduce emissions and fuel costs	Gina D'Ambrosio g.ambrosio@csmt.it	To exchange insights on biomethane availability in Italy and explore synergies between the DuaLNG project and LIFE STEAM

By the end of the project, dissemination materials had been distributed to **200 stakeholders**, fulfilling one of the key milestones. The project also successfully established collaborations with at least two other LIFE or EU-funded projects, promoting mutual learning and enhancing the potential for future adoption of the steam explosion technology across Europe.

Production of Promotional Materials: To support the dissemination activities, a wide range of promotional materials was developed and distributed. These included brochures, leaflets, and videos, which were tailored to both technical and non-technical audiences. Two videos were particularly significant:

1. The first video provided an overview of the entire **LIFE STEAM prototype**, showcasing the Ozzano and Voltana sites and explaining the system's operation. Available at: https://youtu.be/43B-K6EUdy0?si=5AX6wQtNb9LKsCIQ
   - The second video, produced by **Valmet**, focused on the installation and functioning of the **Valmet DNA automation system**, a key technological component that automated the steam explosion process at the plant. Available at https://youtu.be/1e43vYwk27E?si=wopYFAG1s_g0pYSA

These videos were shared on the LIFE STEAM website and at key events, making them accessible to a broader audience.

Additionally, a **Layman's Report** was prepared to summarize the project's results in an accessible format. This report was distributed during the final project event and made available on the website for download: https://www.lifesteam.eu/files/foto/download/43_Layman_Report_final.pdf

Finally the notice board has been updated with a summary of project results and shared in the in the project web site: https://www.lifesteam.eu/files/foto/download/44_notice_board_2024.pdf.

Moreover, the project also received significant coverage in Italian newspapers through various press releases published at the end of the project: https://www.lifesteam.eu/files/fotoData/download/17_20240819_Rassegna_stampa_e_web_Life_Steam_Ozzano.pdf

Comparison with planned output

The communication, dissemination, and networking activities carried out under Action D1 aligned well with the planned outputs, although some variations in results were observed. Overall, the project met its dissemination targets and successfully reached a broad audience across various platforms, while certain areas, such as website traffic, exceeded expectations.

One of the key planned outputs was the creation of a comprehensive communication and dissemination plan. This plan was successfully developed in collaboration with the project's partners and was later updated to reflect the inclusion of a new partner. The plan guided all dissemination activities and ensured that the project-maintained visibility throughout its lifecycle. In terms of stakeholder outreach, the target of distributing materials to 200 stakeholders was met, with brochures, leaflets, and technical reports disseminated at key events such as ECOMONDO 2019, BIORESTEC 2023, and the Final Project Event in Bologna in 2024. Additionally, notice boards were installed at the demonstration sites to ensure that local stakeholders could follow the project's progress.

The LIFE STEAM website, which was launched within the first three months of the project, played a crucial role in the dissemination strategy. The project's target of reaching 3,000 users across its website and social media platforms was ambitious, and by September 2024, the project achieved 1,128 visits and 1,885 page views. Although the website traffic did not fully reach the original goal, the LinkedIn profile proved to be a more effective platform for stakeholder engagement. The LinkedIn account grew to 270 followers and saw strong engagement with posts, including one in June 2024 that achieved over 1,033 impressions. While Twitter was also used, LinkedIn was found to be the most effective platform for reaching professionals in the bio-based and industrial sectors.

The project's networking activities also met the planned goals. Collaborations were established with other EU-funded projects such as LIFE Force of the Future, LIFE Green Factory, and LIFE DualNG. These collaborations allowed the project to explore synergies with other waste management and bioenergy technologies, supporting the transferability and replicability of the steam explosion system. Through these networks, the project strengthened its ties with stakeholders from both the public and private sectors.

Regarding the production and distribution of promotional materials, the project produced two videos, various leaflets, brochures, and a Layman's Report. These materials were distributed at key dissemination events and uploaded to the project website. The two videos, in particular, played a significant role in showcasing the technical aspects of the LIFE STEAM prototype and the Valmet DNA automation system. The Layman's Report, prepared towards the end of the project, helped present the project's results in a more accessible format for non-technical audiences.

In summary, while the overall website traffic fell short of the target, the project exceeded expectations in social media engagement and effectively disseminated its results to a wide range of stakeholders through various channels. The planned collaborations with EU projects were also successfully established, fulfilling the networking objectives.

Challenges, Adjustments, and Solutions

Action D1 encountered a few challenges in the dissemination and communication efforts. One of the main issues was the limited effectiveness of the project's newsletter. Despite initial plans to release 12 newsletters throughout the project, the number of subscribers remained lower than anticipated, and the team was unable to fully meet this target. Stakeholders showed a clear preference for engaging through the project website and social media, particularly LinkedIn, which offered a more direct and impactful platform for industry professionals and key stakeholders.

To address this, the project team adjusted its communication strategy by shifting resources and focus to LinkedIn, which led to stronger engagement metrics on that platform. This adjustment ensured that, even though the original newsletter goal was not met, the project's core messages reached the intended audience through more effective channels.
Another adjustment involved the inclusion of a new project partner, which required a revision of the communication and dissemination plan. The updated plan successfully integrated the new partner's contributions and ensured a coordinated effort across all communication activities. This helped maintain the project's visibility while aligning with the updated objectives.
Despite these challenges, the overall dissemination efforts remained strong. Participation in industry events, distribution of promotional materials, and effective use of LinkedIn and the website ensured that the project met its engagement goals, even if specific tools like the newsletter were less effective than initially planned.

Deliverable /Milestone	**Name**	**Deadline**	**Submitted with /Achieved**
D	Dissemination plan (revised with new partner)	30/06/2021	30/06/2021 MTR
D	LIFE STEAM website (updated with new partner)	30/06/2021	30/06/2021 MTR
D	Notice boards	30/06/2022 Updated 30/11/2023	30/06/2021 MTR, updated FR
D	Dissemination plan: update	30/06/2022	30/06/2021 MTR
D	Dissemination plan	30/11/2019	30/11/2019 MTR
D	LIFE STEAM website	30/11/2019	30/11/2019 MTR
D	Layman's Report	30/06/2024	30/06/2024 FR
M	200 stakeholders reached with dissemination material	31/12/2022	30/06/2024
M	Collaborations established with 2 LIFE or EU-funded projects	30/09/2022	30/06/2024
M	3000 users reached on the project's website and social channels	30/06/2024	30/06/2024

5.1.11 Action D.2 Strategic partnerships (formerly “LIFE STEAM Newco set-up”)

Foreseen start date: 09/2019 Actual start date: 09/2019
Foreseen end date: 06/2024 Actual end date: 06/2024

Description of the activities undertaken

Action D2 focused on the creation of strategic partnerships to support the implementation of large-scale centralized plants utilizing the steam explosion technology developed in the LIFE STEAM project. This action was crucial for ensuring the scalability and replicability of the technology across different regions and industrial contexts. The main activities undertaken involved mapping potential partners, establishing key collaborations, and developing a commercial plan for the future deployment of large-scale plants.

The first step was the **identification of potential strategic partners** by utilizing the stakeholder analysis from Action B4. This process included a detailed mapping of industries and companies that could provide waste heat for the steam explosion process or had interest in pre-treated lignocellulosic biomass. Special attention was given to industries such as waste-to-energy (WtE) facilities and other high-energy industries. Companies in sectors like waste management, bioenergy, and agricultural biomass were considered as prime candidates for partnerships. This phase of the project culminated in the engagement of multiple stakeholders, including Herambiente, Caviro Extra, and C.I.C.A., which provided valuable insights into potential collaborations.

Next, the project team moved on to the **definition of partnerships**. This involved establishing contact with companies interested in providing waste heat for the steam explosion process and collaborating with existing biogas plants to optimize biomass collection and pre-treatment. Discussions were held with Herambiente to explore the use of waste heat from their waste-to-energy plants, and a Letter of Interest (LOI) was signed with Caviro Extra to support the potential replication of the steam explosion technology in biogas production facilities. The project's findings from stakeholder interviews, particularly with C.I.C.A., confirmed the strong interest in using straw and corn stover as alternative feedstocks for biogas production, further solidifying the project's market potential.

Finally, the team developed a **full-scale customized business plan** for the commercialization of centralized plants, leveraging the economic feasibility analysis and market insights gained from Action B4. The business plan outlined the financial projections for large-scale biogas plants using agricultural residues like straw and corn stover, demonstrating strong financial performance with a Net Present Value (NPV) of €2.019 million and an Internal Rate of Return (IRR) of 11.97%. The plan also highlighted the environmental benefits of using agricultural residues, aligning with evolving European regulations promoting advanced biomethane production.

Comparison with planned output

The activities undertaken in Action D2 were largely in line with the planned outputs, with significant progress made in identifying strategic partners and developing a market strategy for large-scale centralized plants. The stakeholder mapping and engagement process, building on the work done in Action B4, allowed the project team to identify key partners and initiate discussions on potential collaborations. The involvement of important companies such as **Herambiente** and **C.I.C.A.** confirmed the strong market interest in the steam explosion technology and its potential for replicability.

One of the key outputs was the collection of **Letters of Interest (LOI)** from strategic partners. The project successfully engaged with stakeholders in the waste-to-energy and biogas sectors, resulting in LOIs from **Caviro Extra** and other potential partners who were interested in

collaborating on future biogas projects. These partnerships provided valuable input on the technical and logistical requirements for integrating waste heat from WtE facilities into the steam explosion process.
In terms of the second key objective—**leveraging waste heat from industrial facilities**—the project achieved its goal by identifying multiple waste-to-energy plants that could provide the necessary thermal energy for the steam explosion process. Discussions with **Herambiente** led to the exploration of potential synergies for using waste heat from their existing facilities, aligning with the project's goal of reducing energy consumption and enhancing the sustainability of the biogas production process.
The development of the **full-scale business plan**, another major deliverable, was successfully completed. The plan provided detailed financial analysis and commercialization strategies for the deployment of centralized biogas plants, focusing on the use of agricultural residues such as straw and corn stover. The plan demonstrated solid financial performance metrics, including a **Net Present Value (NPV) of €2.019 million** and an **Internal Rate of Return (IRR) of 11.97%**, which exceeded the initial projections. This business plan serves as a strong foundation for future replication and scalability of the LIFE STEAM technology.
Overall, the project met its primary objectives for Action D2, achieving both the establishment of strategic partnerships and the development of a robust commercial strategy for the large-scale implementation of the steam explosion system.

Challenges, Adjustments, and Solutions
Action D2 encountered several challenges, primarily due to the withdrawal of Economizer from the consortium, which significantly impacted the initial plan of creating a Newco for the commercialization and deployment of large-scale plants. With the departure of this key partner, the project had to shift its focus from establishing a new commercial entity to forming strategic partnerships with existing stakeholders. This required the team to adjust their approach by engaging directly with industrial players like Herambiente. Although this shift delayed some early-stage discussions, it ultimately allowed the project to build a strong foundation for future collaborations without the need for a formal Newco.
Another challenge was the complexity of negotiating waste heat utilization from WtE plants and other industrial facilities. While partnerships were successfully formed, such as with Herambiente, integrating waste heat into the steam explosion process involved detailed technical and logistical discussions. These negotiations took longer than expected due to the need to align technical parameters, regulatory requirements, and economic incentives. To address this, the project team held regular meetings with the potential partners to ensure all aspects of the collaboration were clearly defined. Despite the delays, the team secured Letters of Interest (LOI) from key stakeholders, ensuring the continuation of strategic partnerships.
In addition, the project faced market fluctuations that affected the financial projections for large-scale plant deployment. Rising energy costs and variability in agricultural residue availability posed risks to the financial viability of the business plan. The team responded by conducting a sensitivity analysis to account for these factors, adjusting the financial model to ensure the scalability of the steam explosion technology remained feasible under various market conditions.
In conclusion, while Action D2 faced significant challenges, the project team successfully adjusted their strategy, ensuring that the core objectives of establishing partnerships and validating the economic viability of large-scale plants were achieved. The flexible approach, combined with proactive stakeholder engagement, allowed the project to maintain momentum and lay the groundwork for future expansions.

Deliverable /Milestone	Name	Deadline	Submitted with /Achieved
D	Full scale business plan and commercialization strategy	29/02/2024	30/06/2024 FR
M	Involvement of potential stakeholders by collecting letters of interest	31/12/2022	30/06/2024

5.1.12 Action E.1 Project Management by HERA

Foreseen start date: 09/2019 Actual start date: 09/2019
Foreseen end date: 06/2024 Actual end date: 06/2024

Description of the activities undertaken

The management and coordination of the LIFE STEAM project were led by HERA, ensuring efficient communication, risk management, and the timely execution of project activities. Key actions carried out under Action E1 include:
Main activities carried out are:

- **First kick-off meeting, Bologna (25/09/2019):**
  The first major event was the Kick-off meeting held on 25th September 2019 at HERA's headquarters in Bologna. This meeting included all project partners—HERA, Ayrion, and Economizer—and focused on outlining the project plan, technical objectives, financial details, and the required reporting structure. This meeting set the foundation for the project's management and coordination

- **Technical visit at Campiano biogas plant (10/10/2019):**
  A technical meeting was held in Ravenna on October 10th. The LIFE STEAM partners visited the existing plant that will host the demo plant and discussed about possible plant layouts and technical requirements of the prototype.

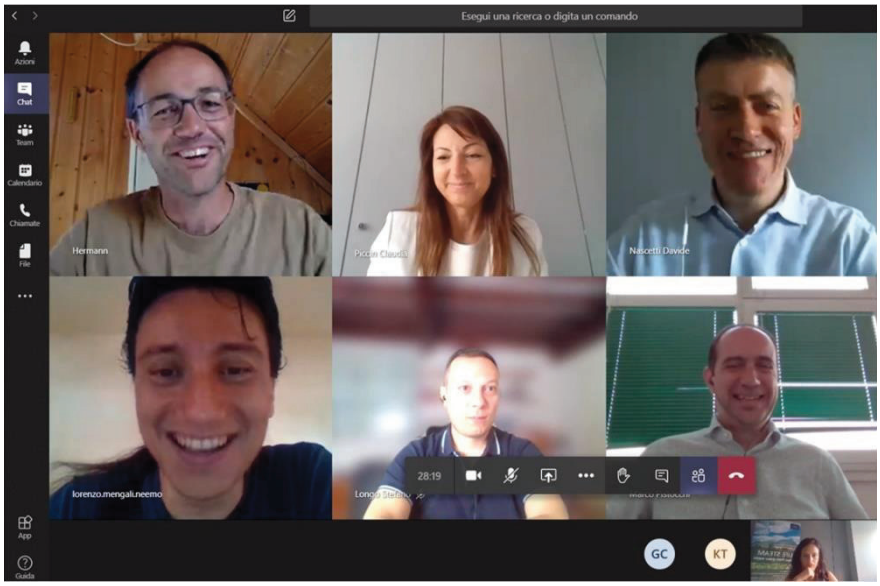
- **LIFE Welcome Meeting, Bruxelles (07/11/2019):**

  On November 7th and 8th LIFE STEAM took part at the LIFE ENV and GIE Welcome Meeting in Brussels. The meeting provided an overview of the relevant policy topics, the LIFE Programme rules, the interaction with EASME and the role of the external monitoring team in project implementation. Financial and technical issues, as well as project reporting, dissemination and communication matters, has been discussed.

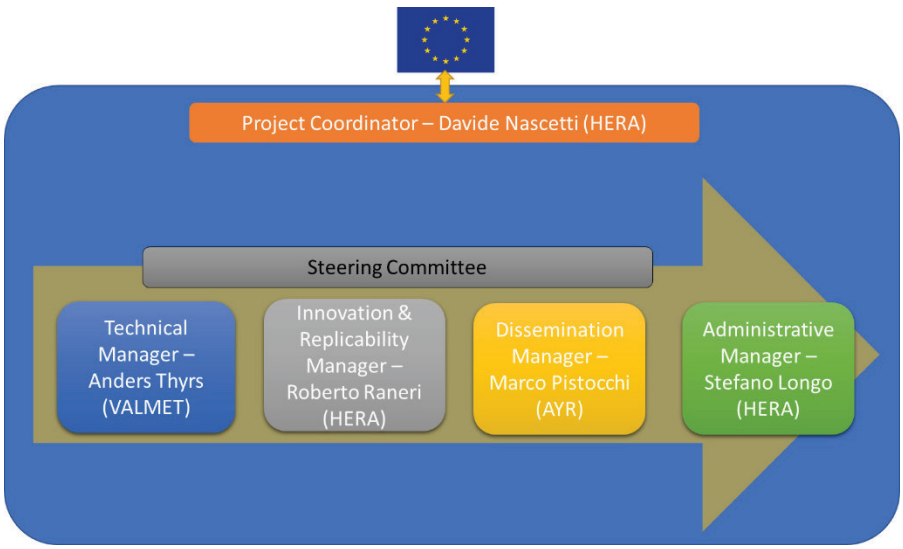
  Project representatives showed the main objectives, the expected impacts, and the contribution of each project to European policies. The event, held at the Crowne Plaza Hotel, provided an opportunity for discussion and networking with other interesting project representatives from all over Europe.

- **First monitoring visit, online (22/06/2020):**

On June 23rd, 2020, the external monitor of Neemo agency, Lorenzo Mengali, assigned by the European Commission to follow up LIFE STEAM project, attended the first monitoring visit with LIFE STEAM partners. The meeting was held online due to the current situation of emergency. The partners showed the progress achieved, action by action, and the updated project timetable. The visit then focused on reporting and verification of project expenses. Critical issues that have arisen during these months were also highlighted by the partners.

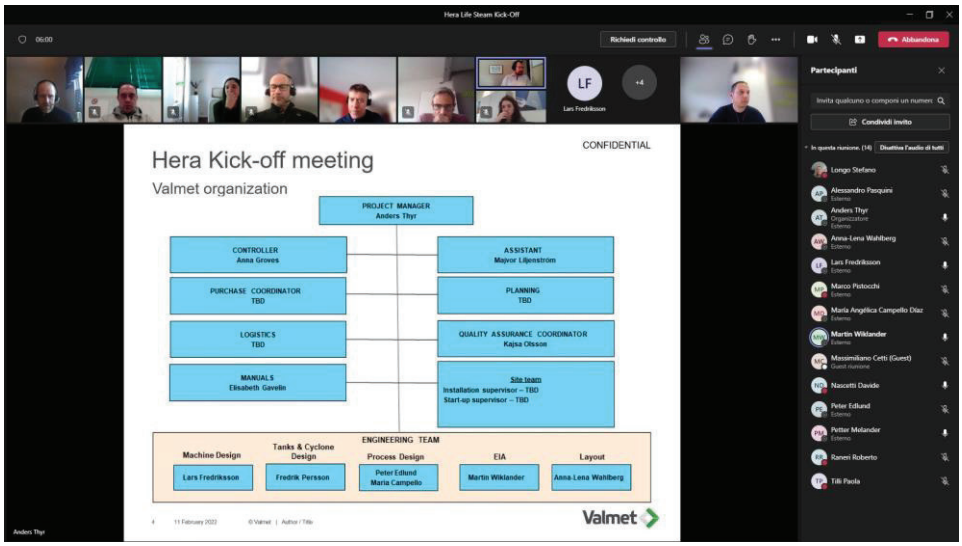


After the amendment, the Project management plan has been updated to include the new partner Valmet and in order to effectively manage the project, a new Steering Committee described in the scheme below was developed (described in section 4 of this document). Moreover, the partnership agreement has been signed and annexed to the Midterm report.



- **A new Kick-off meeting was organized om 11/02/2022 in order to present the new partner:**

During the meeting Valmet team (coordinated by Eng. Anders Thyer) was introduced to the rest of the partner. In the occasion a planification of the engineering activities was presented and a plan schedule was developed.



- **While a technical visit to Valmet has been organized on 11/02/2022:**

  On 13 January 2022 LIFE STEAM was hosted in Sundsvall (Sweden) for a technical visit at the Valmet BioTrac pilot plant where at the same time the lignocellulosic material collected by Hera was tested with the steam explosion process. During the test, a wide range of operating conditions were tested to study their effect on the lignocellulosic material. The material processed in the plant will be tested in laboratory tests to evaluate the methanogenic potential. The results will be useful for calibrating the operational parameters of the LIFE STEAM plant.

- **Second monitoring visit carried out in Hera, Bologna 20-21/06/2022:**

  On June 20-21 2022, the second monitoring visit took place with external monitor of Neemo agency, Lorenzo Mengali. During the event, the new partner Valmet was officially introduced to the monitor, and it was a great opportunity to take stock of the situation and better plan the activities that remain to be done. It was also inspiring to meet in attendance after almost two years in which all meetings were online due to the ongoing pandemic.

- **Technical visit at the new project site of Ozzano and Voltana carried out on 21/06/2022:**

  In the occasion of the 2nd monitoring visit, two technical visits were organized to carry out inspections in the two sites of the project. In Ozzano dell'Emilia, where the prototype will be built, was visit. While in Voltana an interesting visit to the anaerobic cells was carried out to better understand the mechanism of loading and unloading of the material during the project. In both cases, useful ideas for improving the layout and optimizing the experimentation have emerged.

- **Visit by Aneta Willems, Ozzano 10/11/2023:**

  During the course of the project, **Aneta Willems**, Head of Department D at CINEA, visited the LIFE STEAM project to observe progress and provide feedback. Her department focuses on climate action and environmental sustainability, and she emphasized the project's contribution to the EU's climate neutrality goals. This visit highlighted CINEA's commitment to supporting innovative waste management technologies

- **Third monitoring visit carried out in Hera, Bologna 18-19/12/2023:**
  The third monitoring visit was carried out, with participants including representatives from the European Commission, external monitor, HERA, Valmet, and Ayrion. The visit confirmed the successful completion and commissioning of the pilot plant. Additionally, feedback on the project's technical progress and the potential for replication was provided by key stakeholders.

- **Final event, Bologna 27/07/2024:**
  HERA, with collaboration by Valmet and Ayrion, organized the **Final Event** of the LIFE STEAM project in **June 2024**, which gathered key policy makers, stakeholders, and project partners. The event showcased the project's results, including the increased biogas yield and the replicability of the steam explosion technology. The **Layman's Report** was distributed to participants, ensuring the dissemination of project results to a wider audience, including policy makers and the general public.



A key aspect of the project management activities under Action E1 was the continuous and intensive coordination between the three main project partners: **HERA**, based in Italy, **Valmet** from Sweden, and **Ayrion**. The project's complexity, combined with the geographical distance between partners, required significant effort in terms of communication, planning, and coordination. Regular meetings—both online and in-person—were organized to ensure that all partners were aligned on the technical progress, financial reporting, and strategic decisions.
From the outset, the need to manage the technical challenges of implementing the steam explosion technology, combined with the sudden withdrawal of **Economizer** from the consortium, led to an increase in management responsibilities. The subsequent inclusion of **Valmet** as a partner necessitated a redefinition of the technical scope and strategic direction of the project. This process required a series of technical meetings, workshops, and frequent updates between the partners to reassess timelines, budgets, and deliverables.
The cross-border collaboration, especially with **Valmet's** involvement in Sweden, demanded extra coordination efforts due to differences in working practices, logistical challenges, and the need for on-site technical visits. Multiple monitoring visits, site inspections, and technical assessments were carried out throughout the project, requiring significant preparation and follow-up from the management team. Additionally, the challenges posed by the COVID-19 pandemic added another layer of complexity, necessitating the adaptation to remote working environments and the reorganization of physical meetings into virtual formats. Despite these difficulties, the coordination between the partners remained strong, ensuring that the project continued to progress according to the revised timelines.
The intense management effort was further compounded by the necessity to continuously engage with external stakeholders, including policymakers, industry leaders, and other EU-funded projects. This level of stakeholder engagement, combined with the technical and logistical challenges of aligning partners from different countries, required a substantial amount of project management time and resources to ensure that the LIFE STEAM project could achieve its ambitious objectives.
The hours of project management rendered by **HERA**, as the lead coordinator, reflect this increased effort. The team was responsible for not only managing day-to-day project activities but also ensuring effective communication and decision-making across all partners, addressing challenges as they arose, and adapting to the evolving needs of the project. This intensive coordination was crucial in maintaining momentum and ensuring that the project delivered impactful results despite the obstacles encountered.

Comparison with planned output
The management activities carried out under Action E1 largely aligned with the planned outputs, ensuring the smooth coordination of the project and continuous communication with all partners and the European Commission. HERA, as the lead partner, successfully managed the project through various phases, including the coordination of multiple partners across different countries, the organization of key meetings, and the delivery of technical and financial reports on time.
One of the core planned outputs was the organization of project meetings, including the **Kick-off Meeting**, **Mid-term Meeting**, and **Final Meeting**. All these meetings were carried out as scheduled, with the initial **Kick-off meeting** taking place in **September 2019** and a second one following the project amendment in **February 2022** after Valmet joined the consortium. In addition to these major meetings, HERA organized numerous technical workshops and monitoring visits, both virtual and on-site, to facilitate collaboration between partners and ensure that the project remained on track. This level of engagement helped to navigate complex challenges, such as the departure of **Economizer** from the consortium and the subsequent restructuring of the project.

Regarding **risk management and communication**, HERA successfully implemented a **Project Management Plan**, updated after the amendment, which included risk mitigation strategies and outlined the responsibilities of each partner. Regular communication with the European Commission and the project monitor ensured that all issues were promptly addressed, and adjustments were made as needed. The communication channels between HERA, Valmet, and Ayrion were kept active through frequent project meetings, technical discussions, and site visits, ensuring that all parties remained aligned throughout the project lifecycle.
In terms of **deliverables and reporting**, the project's financial and technical reports were submitted according to the agreed schedule. Although the project faced some challenges, such as delays in the commercial deployment of the technology due to the time required to integrate a new partner, the overall coordination activities were executed effectively. The intensive management efforts led to the timely resolution of technical and administrative issues, contributing to the project's success.
The project's **risk management** was also a key component, as several unforeseen challenges arose, such as the COVID-19 pandemic and the withdrawal of a key partner. However, HERA's proactive management approach ensured that these issues were mitigated without causing significant delays to the project timeline. The revised Project Management Plan, following the amendment, proved instrumental in keeping the project aligned with its objectives despite these difficulties.

Challenges, Adjustments, and Solutions
Action E1 faced several key challenges that required adaptive management strategies. One of the most significant was the withdrawal of Economizer from the consortium, which disrupted the project's technical structure. HERA quickly responded by integrating Valmet as the new partner, necessitating adjustments to responsibilities and timelines. A new Kick-off meeting in February 2022 helped realign the project's goals, mitigating potential delays.
The inclusion of Valmet as a new project partner and the geographical distance between HERA (Italy) and Valmet (Sweden) added complexity to the project management structure. Despite these challenges, the project team held frequent virtual and in-person meetings to maintain alignment.
The COVID-19 pandemic also posed major challenges, particularly in conducting in-person meetings and site visits. HERA adapted by transitioning to virtual meetings, which maintained communication but caused some delays in technical inspections and project assessments. Despite this, the project team implemented a remote management model that kept the project on track.
The COVID-19 pandemic and the withdrawal of Economizer required significant restructuring of the project's management plan. Virtual meetings replaced physical inspections, and the integration of Valmet was expedited to minimize delays.
The coordination between geographically distant partners—HERA in Italy, Valmet in Sweden, and Ayrion—added complexity to project management. Regular virtual meetings were organized to ensure alignment across teams, adding strain to management resources but maintaining progress.
Through proactive management, close collaboration, and frequent communication, HERA successfully addressed these challenges, ensuring the project met its key objectives despite the disruptions.

Deliverable /Milestone	Name	Deadline	Submitted with /Achieved
D	Project management plan	30/11/2019	30/11/2019 MTR
D	Project management plan (revised with new partner)	30/06/2021	30/06/2021 MTR
D	Kick-off meeting with new partner	30/04/2021	11/02/2022 MTR
M	Consortium agreement signed	31/07/2021	02/02/2022
M	Kick-off meeting	30/11/2019	25/09/2019

5.1.13 Action E.2 After-LIFE sustainability Plan

Foreseen start date: 07/2023	Actual start date: 07/2023
Foreseen end date: 06/2024	Actual end date: 06/2024

Action E2 focused on ensuring the long-term sustainability and replicability of the LIFE STEAM project beyond its funding period. The goal was to create a strategic framework to guide the future adoption of the steam explosion technology, with a focus on securing partnerships, identifying funding sources, and exploring opportunities for expanding the technology to new regions. Key deliverables included the development of a **Customized Business Plan** and an **After-LIFE Plan**, both aimed at supporting the commercial and operational expansion of the project's results.

Description of the activities undertaken

One of the key activities under Action E2 was the development of the **Customized Business Plan**, which aimed to ensure the scalability and long-term sustainability of the LIFE STEAM technology. This plan was specifically tailored to meet the needs of industrial stakeholders, particularly those in the waste management and bioenergy sectors, who showed interest in adopting the steam explosion process at a larger scale.

The Business Plan was primarily developed in collaboration with **Herambiente** and **C.I.C.A. (Consorzio Interprovinciale Cooperative Agricole)**, two key stakeholders that contributed to defining the technical and economic frameworks for implementing the technology. Herambiente, as a major waste management operator, expressed interest in integrating waste heat from its incineration plants to power the steam explosion process. Meanwhile, C.I.C.A. offered valuable insights into the use of agricultural residues, such as straw and corn stover, as feedstocks for biogas production, focusing on the practical applications of the technology in agricultural and biogas contexts.

The **Business Plan** provided a detailed market analysis and economic projections, based on the insights gathered during **Action B4**. The plan included specific financial models that showed the economic viability of scaling up the technology to treat large volumes of lignocellulosic waste. Projections indicated that a full-scale plant utilizing agricultural residues could achieve a **Net Present Value (NPV) of €2.019 million** and an **Internal Rate of Return (IRR) of 11.97%**, making the investment attractive to industrial partners. These financial estimates were based on real-world data provided by Herambiente and C.I.C.A., reflecting the operational costs and potential revenue from biogas production.

The plan also included operational guidelines and logistical considerations for integrating the steam explosion technology into existing infrastructures. For Herambiente, this meant exploring the synergies between its existing waste-to-energy plants and the steam explosion process, which could be powered by waste heat. For C.I.C.A., the focus was on optimizing the use of agricultural by-products to increase the efficiency of biogas production, demonstrating the potential for replicating the technology across other agricultural regions in Europe.

The **Customized Business Plan** played a critical role in demonstrating the feasibility of commercializing the LIFE STEAM technology. By providing a clear economic and operational framework, it gave potential partners the tools to assess the financial and environmental benefits of adopting the technology in their operations. This plan was crucial for fostering future collaborations and setting the foundation for the wider replication of the steam explosion process across Europe.

The development of the **After-LIFE Plan** was focused on ensuring the long-term sustainability and replicability of the LIFE STEAM technology beyond the project's official funding period.

This process involved several concrete steps aimed at defining a clear strategy for the continuation and expansion of the project's results.
First, the plan was structured to summarize the project's key achievements, specifically the successful integration of the steam explosion technology for treating lignocellulosic waste. A detailed review of the environmental and economic performance was carried out, highlighting data from the monitoring of the pilot plant. This information, which was gathered during **Action C1**, provided a clear picture of the reduction in greenhouse gas emissions and the increased efficiency in biogas production. These data were essential in demonstrating the tangible benefits of the technology to potential adopters.
The second core activity was the development of a **replication strategy** based on the findings of Actions **B4**, **D1**, and **D2**. This involved identifying specific industrial sectors and regions where the technology could be replicated. For example, **Herambiente** was engaged to explore the potential for integrating the steam explosion process in their waste-to-energy plants, utilizing waste heat to power the technology. Additionally, **C.I.C.A.** contributed to the identification of agricultural waste streams, such as straw and corn stover, that could be used as feedstock for biogas production. These discussions were documented in the After-LIFE Plan, providing a clear pathway for replication in regions with similar industrial and agricultural profiles.
Another critical aspect of the plan was the **identification of funding opportunities**. The project team actively explored options for securing long-term funding to support the continued development and scaling of the technology. This included potential funding from European programs such as **Horizon Europe**, as well as private sector investments from companies in the renewable energy and waste management sectors. The plan outlined specific steps for engaging with investors and potential partners to ensure that the technology could move from pilot to full-scale industrial implementation.
Finally, the **communication strategy** was a key component of the After-LIFE Plan. The plan detailed how the project's results would continue to be disseminated after its official completion, ensuring ongoing visibility and engagement with stakeholders. This included maintaining the project website, regularly updating it with news about replication efforts, and organizing post-project events to share results with both the public and potential industrial partners. These communication efforts were essential for keeping the momentum of the project alive and fostering new collaborations for the deployment of the steam explosion technology across Europe.

Comparison with planned output
The activities carried out under Action E2 closely aligned with the planned outputs, with key deliverables being met and, in some cases, expanded to ensure long-term sustainability and replicability.
The **After-LIFE Plan** was developed as scheduled, providing a comprehensive strategy for ensuring the future of the LIFE STEAM technology. This document successfully summarized the project's objectives, methodologies, and results, with a particular focus on the long-term environmental and socio-economic benefits. The plan outlined how the steam explosion technology could be replicated in new regions, particularly in sectors such as waste management and agriculture, as envisioned in the original project scope.
The **Customized Business Plan** was developed as a detailed tool for industrial stakeholders, outlining the financial and operational viability of scaling up the technology. This plan, which was tailored specifically to the needs of **Herambiente** and **C.I.C.A.**, went beyond initial expectations by including case-specific scenarios and financial projections that demonstrated the feasibility of implementing the steam explosion process in both industrial and agricultural

contexts. The financial modeling provided a clear pathway for future investors and potential adopters, ensuring that the project had a concrete foundation for future scaling.
Overall, the activities completed under Action E2 fully met the expected outputs, providing a strong strategic framework for the future replication and sustainability of the LIFE STEAM technology.

Challenges, Adjustments, and Solutions
While the activities under Action E2 were generally completed as planned, some challenges were encountered, primarily related to stakeholder engagement and funding.

Deliverable /Milestone	Name	Deadline	Submitted with /Achieved
D	Customized full scale business plan	28/02/2023	30/06/2024 FR
D	After-Life plan	28/02/2023	30/06/2024 FR
M	Collection of all deliverables and results of the project connected with its continuation	28/02/2023	30/06/2024

5.2. Main deviations, problems and corrective actions implemented

Throughout the LIFE STEAM project, several challenges and deviations from the original plan were encountered. However, through adaptive management and strategic corrective actions, the project team successfully mitigated these issues, ensuring that the project remained largely on track. The main deviations, problems, and the corrective actions implemented are summarized below.

1. Delays in the construction of the demo plant
The most significant deviation occurred due to delays in the construction and installation of the demo plant at the Ozzano site. Initially planned to be completed by August 2022, the construction faced several unforeseen technical and logistical challenges. The complexity of the steam explosion system, coupled with integration issues with the existing infrastructure, required additional time for adjustments and modifications.
To address these delays, a project amendment was submitted and approved, extending the timeline to ensure the successful completion of the demo plant. This extension allowed the necessary adjustments to be made without compromising the quality of the experimental setup. Despite the delays, the project maintained its overall schedule for experimental testing and data collection.

2. Financial underestimation of the demo plant construction costs
Another major challenge involved the financial underestimation of the demo plant's construction costs. Originally budgeted at a lower figure, the actual cost of the prototyope construction exceeded the estimate by approximately €860,000. This discrepancy was primarily due to rising material costs (such as steel) and the complexity of integrating the steam explosion system with auxiliary infrastructure.
To address this issue, HERA committed to covering the additional costs with internal funding. This ensured that the experimental phase of the project could proceed without interruption or compromise in the scope of the testing. Importantly, the additional financial contribution from HERA did not negatively impact the project’s broader budget or the implementation of other project actions.

3. Partner withdrawal and project restructuring

During the early phases of the project, Economizer withdrew from the consortium, which necessitated a significant restructuring of the project. This withdrawal required the integration of a new partner, Valmet, to take over Economizer's technical responsibilities, particularly related to the steam explosion system.

A second project amendment was submitted to formalize this change, and the partnership was redefined with clear roles for Valmet, ensuring continuity. This restructuring caused minor delays but did not affect the overall progress of the project. The inclusion of Valmet as a key partner brought new technical expertise, ultimately benefiting the project.

4. COVID-19 pandemic

The global COVID-19 pandemic caused significant disruptions, particularly in the ability to conduct physical meetings, technical site visits, and installations. The project adapted by moving meetings online, ensuring continuous communication between partners, and delaying some in-person activities until travel restrictions were lifted. This adaptive approach allowed the project to stay on course despite the restrictions, although certain delays in technical activities were unavoidable.

5.3. Evaluation of Project Implementation

In the following section an evaluation of the project implementation is provided.

Based on the Methodology applied:

- **Steam Explosion Technology**: The core methodology, the steam explosion technology, was highly successful in increasing the biodegradability of lignocellulosic biomass. It led to a **300-400% increase in biogas production** compared to untreated biomass. This result validated the project's hypothesis and demonstrated that the technology could significantly improve the efficiency of biogas production.
- **Environmental Impact**: The Life Cycle Assessment (LCA) confirmed that the process reduced greenhouse gas emissions and improved resource efficiency, particularly in reducing water consumption and avoiding the need for conventional feedstocks like maize and it is a more sustainable option compared with conventional composting procedures. While the LCA analysis indicates that CO_2 emissions per MJ for LIFE STEAM biomethane are comparable to those of silage maize, the LIFE STEAM process has much greater potential for improvement. Optimizations, such as the integration of renewable energy sources like solar power, could enhance its environmental benefits. As a result, LIFE STEAM biomethane represents a potentially more sustainable option compared to silage maize.
- **Strategic Partnerships**: The project successfully engaged key stakeholders and partners like Herambiente and C.I.C.A. These collaborations were crucial in supporting the scaling up of the technology and ensuring that the steam explosion system could be integrated into existing waste management infrastructure.
- **Cost Overruns**: One of the main challenges was the **budget overrun** of approximately **€900,000**, primarily caused by post-COVID inflation and the complexity of the technical integration of the steam explosion system. Material costs and the unexpected complexity in the integration of the pre-conditioning system (PCS) and the steam explosion system (SES) with the existing plant infrastructure contributed to this overrun.
- **Delays in Construction**: The construction of the demo plant faced significant delays, largely due to technical complexities and supply chain disruptions, which postponed key milestones, including the start of the experimental phase. These delays led to the extension of the project's timeline.
- Despite the cost overruns, the project remained cost-efficient due to the high performance of the steam explosion technology in increasing biogas yields. The demonstration plant showed that, once operational, the technology could deliver high returns in terms of energy efficiency, environmental benefits, and resource conservation.
- **Internal Funding**: The budgetary gap was managed by Hera's internal funding, which allowed the project to continue without sacrificing its key objectives or cutting corners in terms of experimental rigor.

A Comparison of the results achieved against the objectives and expected results foreseen in the proposal and described in section 4 is reported.

Action	Foreseen in the revised proposal (Objectives & Expected results)	Achieved	Evaluation (General assessment & Lessons learned)
A.1	Objectives: - Develop all materials for plant set-up - Identify procurement procedures Expected results: - Environmental authorization - Procurement list completed	Authorization granted and procurement list developed	100% Project successfully met objectives. Minor delays managed effectively.
A.2	Objectives: - Complete all engineering design for demo plant Expected results: - Technical drawings delivered	Engineering design completed; technical drawings submitted to suppliers	100% System integration was complex but completed with minor adjustments. Lessons learned: pre-empt technical challenges.
B.1	Objectives: - Biomass collection, pre-treatment, and storage Expected results: - Collection and treatment of 1200 tons of biomass	250 tons treated due to operational constraints, but process efficiency validated	100% Lower biomass quantity treated, but high efficiency demonstrated (300-400% increase in biogas production).
B.2	Objectives: - Construction of demo plant Expected results: - Demo plant fully operational	Plant fully constructed, all components installed and tested	100% Delays due to system integration complexity, but all components installed successfully.
B.3	Objectives: - Validate use-case for steam explosion in biogas production Expected results: - 300-400% increase in biogas production	Achieved a 300-400% increase in biogas production from steam-exploded biomass	100% Use-case validation successful. The technology proved highly efficient.
B.4	Objectives: - Conduct cost and market analysis Expected results: - Stakeholder list, three scale-up options, full business plan, workshop	Stakeholder list developed, business plan completed, Letters of Interest received	100% Stakeholders engaged; business plan developed. Market interest confirmed.

C.1	Objectives: - Monitor socio-economic and environmental impacts Expected results: - KPIs and LCA analysis completed	KPIs updated, LCA completed, uploaded to LIFE KPI platform	100% Monitoring completed. Environmental impact exceeded expectations.
D.1	Objectives: - Dissemination of results Expected results: - 1 scientific article, 2 magazine articles, Layman's report, notice boards, brochures, video, reach 200 stakeholders	Over 1200 visitors, 4 events attended, collaboration initiated with 4 EU projects, dissemination material produced and distributed	100% Dissemination objectives met, strong stakeholder engagement.
D.2	Objectives: - Develop commercialization strategy Expected results: - Full-scale business plan	Business plan completed; stakeholder letters of interest collected	100% Commercialization strategy finalized, Letters of Interest from key partners.
E.1	Objectives: - Project management and coordination Expected results: - Consortium agreement, kick-off and mid-term meetings	All meetings completed; consortium agreement signed	100% Project management effectively handled despite external challenges.
E.2	Objectives: - Develop After-LIFE sustainability plan Expected results: - Customized business plant	After-LIFE plan developed, partnerships secured with Herambiente and C.I.C.A. and business plant developed	100% Sustainability plan fully developed, ensuring long-term impact.

Project results immediately visible or results that will only become apparent after a certain time period is summarized below.

Type of Result	Description
Immediately Visible Results	- 300-400% increase in biogas production achieved during the experimental phase, validating the steam explosion technology. - Immediate environmental benefits demonstrated through the reduction of greenhouse gas emissions (GHG) as per the Life Cycle Assessment (LCA). - Successful stakeholder engagement with key

	partners like Herambiente and C.I.C.A., with letters of interest secured for future commercialization.
Long-term Results	- Long-term market impact of the technology, including its economic viability and scalability, will only become apparent as full-scale commercialization is pursued. - The effectiveness of the After-LIFE sustainability plan will be realized over time as partnerships with industrial stakeholders continue to develop. - Full environmental and socio-economic impacts, including the reduction of GHG emissions and waste management efficiency, will continue to be monitored and understood over time as the technology is implemented on a larger scale.

Two amendments were requested and accepted during the project that allowed to reach the project objectives and schematized below.

Amendment	Results Achieved	What Would Have Been Different
Partner Change	The new partner brought advanced expertise in steam explosion technology, which improved the design and implementation of the demo plant. This contributed to the 300-400% increase in biogas production and ensured the plant's operational efficiency.	Without this amendment, the project would have faced delays and technical challenges due to the lack of expertise, leading to lower biogas yields and potential integration issues with the steam explosion system.
Project Extension	The extension allowed for the resolution of procurement delays and technical issues during installation. It ensured all components were properly integrated and tested, allowing additional time for stakeholder engagement and market analysis.	Without the extension, the project would have faced incomplete testing and reduced performance of the demo plant, with possible operational inefficiencies or system failures.

Considerable efforts have been made to replication activities

1. **Stakeholder Engagement**:

- The project demonstrated a strong effort in engaging **key industrial stakeholders** such as **Herambiente**, **C.I.C.A.**, and other potential partners, resulting in **Letters of Interest**. These stakeholders have expressed interest in scaling up the steam explosion technology for biogas production, specifically utilizing **agricultural residues** like straw and corn stover.

2. **Pilot Plant Success and Scalability**:
   - The **Ozzano demo plant** provided a foundational platform for validating the technology's operational feasibility and replicability. This success has paved the way for planning **two full-scale plants**: a 50,000-ton/year facility at a Waste-to-Energy (WtE) site and a 100,000-ton/year plant in collaboration with **C.I.C.A.**
3. **Market Assessment**:
   - A **Replication and Transfer Plan** was developed, focusing on the availability of **feedstock** and **heat sources**, as well as the regulatory framework needed for expansion. Detailed market studies were conducted to identify replication opportunities across various **industrial sectors**.
4. **Economic Feasibility**:
   - The economic analysis confirmed the financial viability of replicating the technology, with projections showing a **Net Present Value (NPV)** of €2.019 million and an **Internal Rate of Return (IRR)** of 11.97%. These metrics indicate that the technology is attractive for further investment and commercialization.
5. **Policy Impact and Regulatory Efforts**:
   - Intensive efforts were made to engage **policymakers** at the local, national, and EU levels, aiming to secure **regulatory recognition** of steam explosion-treated materials as by-products rather than waste. This would facilitate the wider adoption of the technology.
6. **Replication Strategy for Agriculture**:
   - The project focused on applying the technology to **agricultural waste**, specifically **straw** and other lignocellulosic residues, demonstrating the potential for the technology to contribute to **sustainable agriculture** and **bioenergy**.

A number of effective dissemination activities have been carried out.

1. **Website and Social Media**:
   - The **LIFE STEAM website** was a key tool for disseminating project information, with over **1,128 visitors** and **1,885 page views** by September 2024. **LinkedIn** was another major platform, where the project gained **270 followers** and had posts reaching up to **1,033 impressions**.
2. **Participation in Key Events**:
   - The project was present at **ECOMONDO 2019**, **ECOMONDO 2023**, and international events such as the **BIORESTEC Conference 2023** and the **Conference in Nashville, USA**. These events provided excellent platforms to share the project's results, particularly the success of the steam explosion technology. Promotional materials, including **leaflets** and **brochures**, were distributed during these events.
3. **Collaborations with EU Projects**:
   - Through partnerships with other EU-funded projects like **LIFE Forture**, the project expanded its reach within the renewable energy sector. These

collaborations facilitated knowledge exchange, which supported the project's replication efforts.

4. **Promotional Materials**:
    - The project produced **two videos**, a **Layman's Report**, and over **400 leaflets** to raise awareness about its goals and results. These materials were disseminated both online and during physical events.

Drawbacks

1. **Newsletter Engagement**:
    - The project aimed to release **12 newsletters**, but the subscription rates were lower than expected. As a result, the team shifted focus to more interactive platforms like LinkedIn, which saw greater engagement.
2. **Impact of COVID-19**:
    - The pandemic limited the project's ability to conduct **in-person workshops** and reduced the opportunities for face-to-face networking. While online events partially compensated for this, they did not fully replicate the benefits of physical engagement.

The following policy considerations and implications emerged:

- The LIFE STEAM project aligned with several key European policies, particularly the **European Green Deal**. By demonstrating the effectiveness of the steam explosion technology, the project contributed to **GHG emissions reduction** and **enhanced waste management** practices, supporting the EU's renewable energy and resource efficiency goals.
- The project significantly contributes to CO_2 emissions reduction. The Life Cycle Analysis (LCA) indicates that when lignocellulosic waste is treated with the proposed LIFE STEAM method about 70% of CO2 emissions can be avoided if compared with traditional composting techniques (from 0.0564 to 0.0166 kg CO2 eq / kg of green waste).
- A key regulatory barrier was the **classification of steam-exploded material**. Current regulations often limit the use of this material in agriculture, classifying it as waste rather than a by-product. To address this, the project engaged with **policymakers and industry bodies**, advocating for regulatory updates to reflect the environmental benefits of the technology.
- The project also encountered challenges in integrating steam explosion technology with existing **regulatory frameworks** for waste management. Through continuous dialogue with national and EU authorities, the team worked to **promote policy changes** that could support the broader adoption of this technology across Europe.
- The project's efforts informed discussions on the **reuse of waste heat** in biogas production and **regulatory recognition** of treated materials. This has helped shape ongoing conversations about waste-to-energy technologies within the framework of the EU's decarbonization goals.
- The LIFE STEAM technology has influenced the policy landscape, supporting the EU's **decarbonization efforts** by providing a replicable model for reducing GHG emissions and improving resource efficiency through **waste-to-energy processes**.
- The LIFE STEAM project provided significant added value to the EU by supporting its strategic goals on **climate change** and **renewable energy**. The project's innovations in treating lignocellulosic waste contributed to the EU's **energy transition** and **circular economy**, showcasing a scalable solution for **GHG emissions reduction** and **resource efficiency**.

5.4. Analysis of benefits

5.4.1 Environmental benefits

a. Direct / quantitative environmental benefits:

The LIFE STEAM project has demonstrated substantial environmental benefits, particularly in the areas of emission reductions, resource savings, and increased energy efficiency. The primary direct environmental benefit was the significant reduction in greenhouse gas (GHG) emissions achieved through the use of steam explosion technology for the pre-treatment of lignocellulosic biomass. Compared to traditional composting methods, the steam explosion process led to the following quantifiable improvements:

- **Reduction in CO2 Emissions**: The life cycle assessment (LCA) demonstrated that the steam explosion process for green waste reduces greenhouse gas emissions by approximately 35-40% compared to traditional composting methods.
- **Energy Efficiency**: The steam explosion process significantly increased the energy yield from lignocellulosic biomass. The biogas production from steam-exploded biomass showed a 300-400% increase in methane yield compared to untreated biomass. The total energy generated from the biogas not only covered the operational energy requirements of the demo plant but also had surplus energy for potential grid injection, enhancing the overall energy efficiency of the system.
- **Water Savings**: Unlike maize cultivation, which requires significant water for irrigation, the use of green waste as feedstock in the steam explosion process results in considerable water savings. The avoided water footprint from not cultivating maize, combined with the process's efficient use of water, reduced the overall water consumption by approximately 20% compared to traditional biogas production processes.
- **Waste Diversion and Resource Efficiency**: By processing up to 250 tons of lignocellulosic biomass annually during the demonstration phase, the project diverted this material from landfilling or composting, converting it into energy and valuable by-products such as digestate. This resulted in both the reduction of waste sent to landfills and improved resource recovery rates.

b. Qualitative environmental benefits:

The LIFE STEAM project also delivered significant qualitative environmental benefits, contributing to the long-term sustainability of waste management and renewable energy sectors. Key qualitative benefits include:

- **Sustainable Technology and Long-term Impact**: The steam explosion process is a scalable and replicable technology that promotes sustainable waste management and renewable energy generation. The LCA analysis did not highlight a distinct CO_2 emissions advantage for LIFE STEAM biomethane over silage maize, as their

emissions per MJ are similar. However, the LIFE STEAM process has considerably more potential for optimization. If powered by renewable energy sources like photovoltaics, its carbon footprint could be significantly reduced, making it a potentially more environmentally friendly alternative to silage maize. By shifting from the use of agricultural crops (like maize) to residual waste biomass, the project offers a more sustainable alternative for biogas production, reducing the need for land-intensive feedstocks and preventing competition with food crops. This aligns with European Union policy goals focused on reducing the environmental impact of energy production and waste management.

- **From End-of-Pipe to Prevention**: The steam explosion process represents a shift from traditional waste treatment methods (such as composting or landfilling) to a more preventative, resource-efficient approach. The project not only minimizes waste but also converts it into a valuable energy resource, which is a major step toward a circular economy model. The process reduces the environmental impact by utilizing waste streams that would otherwise contribute to GHG emissions.
- **High Visibility for Environmental Solutions**: As one of the first industrial-scale applications of the steam explosion technology for biogas production in Europe, LIFE STEAM has received significant attention from industry stakeholders and policymakers. The project's visibility has fostered discussions on policy support for advanced waste-to-energy technologies and has showcased a viable alternative to conventional composting and landfilling practices.
- **Replicability and Spin-off Potential**: The successful demonstration of the technology has laid the groundwork for its replication in other European regions and sectors. Waste-to-energy companies and agricultural sectors are particularly well-positioned to adopt the technology, making it a highly replicable model for reducing emissions and improving waste management practices across Europe. The insights gained from this project are likely to have spillover effects in other environmental areas, such as improving energy recovery from other types of organic waste and reducing dependency on fossil fuels for energy production.
- **Policy Contributions and Market Transformation**: By demonstrating the environmental and economic viability of the steam explosion process, the project has contributed to shaping policy discussions related to waste management, renewable energy, and biogas production. The project supports the European Union's goals of decarbonization and circular economy by promoting the use of waste streams that would otherwise be discarded.

5.4.2 Economic benefits

LIFE STEAM has demonstrated significant economic benefits through the development and implementation of its innovative steam explosion technology for treating lignocellulosic waste. This technology presents new business opportunities and cost-saving solutions for industries involved in waste management, biogas production, and agricultural residues. The primary economic benefits are summarized below:

Cost savings and business opportunities: The steam explosion process developed by the LIFE STEAM project enables significant cost savings for waste management companies and biogas producers. By treating lignocellulosic materials such as prunings, agricultural residues, and green waste, companies can reduce the costs associated with

traditional waste treatment methods, such as composting or landfill disposal. This innovative process increases biogas yields by up to 300-400% compared to untreated biomass, which enhances the profitability of biogas plants. Additionally, the use of low-cost or waste-derived feedstock (instead of high-cost materials like maize) reduces input costs, leading to improved economic margins for biogas producers.

The project also highlighted the potential for utilizing waste heat from industrial processes, such as those found in Waste-to-Energy (WtE) plants, to power the steam explosion system. This synergy represents an opportunity for further cost reductions by utilizing existing thermal energy sources, creating additional business opportunities for industries seeking to optimize energy use.

Regional development and economic impact: The deployment of steam explosion technology has the potential to stimulate regional development, particularly in areas where agricultural residues are abundant, and waste management is a critical issue. By introducing this technology, regional industries can benefit from enhanced waste valorization practices, increasing the overall sustainability and economic output of local economies. Additionally, the production of biogas from waste streams reduces dependency on fossil fuels and promotes energy independence, aligning with regional and national energy strategies.

5.4.3 Social benefits

The social benefits of the LIFE STEAM project are expected to become more significant once the technology is implemented at full scale, which is anticipated within three years after the official end of the project. However, even during the project's pilot phase, the foundation for future socio-economic impacts has already been laid.

Employment: During the LIFE STEAM pilot project, 1 Full-Time Equivalent (FTE) position was created to support the operation and management of the demonstration plant. This is a promising early indicator of the job creation potential that will be realized at a larger scale.
Based on the project's Deliverable related to **JOBS creation potential**, it is estimated that a full-scale plant could generate between 10 and 20 permanent jobs, including both skilled and unskilled positions. These roles will span across plant operations, engineering, maintenance, and administrative support. Furthermore, if the technology is replicated in multiple regions, as anticipated, the job creation potential could multiply, providing even more employment opportunities in the renewable energy and waste management sectors. This projection aligns with the long-term vision of contributing to regional economic development through sustainable practices.

Health and Environmental Quality: The environmental benefits of the LIFE STEAM technology, particularly in reducing greenhouse gas emissions and managing green waste more sustainably, have positive indirect effects on public health. By reducing reliance on maize as a feedstock and managing waste more efficiently, the project also helps minimize the environmental impacts associated with traditional waste management and agriculture, such as emissions from synthetic fertilizers. These health benefits are expected to be further amplified as the technology is scaled up.

Socio-economic Inclusion: The implementation of the full-scale LIFE STEAM plant is also expected to support socio-economic inclusion by creating job opportunities in underrepresented areas, such as rural or industrial regions with a strong reliance on agriculture or waste management. The new jobs are likely to span a variety of skill levels, offering both qualified and non-qualified workers sustainable employment opportunities in the growing bioenergy and waste sectors.

The LIFE STEAM project's potential for replication across Europe means that its socio-economic benefits could have a broad and lasting impact, contributing to regional development and providing green jobs aligned with the EU's goals for economic recovery and environmental sustainability.

In summary, while only one FTE position has been created during the pilot phase, the long-term job creation potential, as outlined in the project's Deliverable, is promising, with substantial employment and socio-economic benefits expected to emerge as the technology is scaled up and implemented in multiple regions. These benefits will not only drive regional economic growth but also contribute to improved environmental and public health outcomes.

5.4.4 Replicability, transferability, cooperation

The LIFE STEAM project shows significant potential for both technical and commercial replication, offering an innovative steam explosion technology for treating lignocellulosic biomass. This process enhances biogas production and presents a viable alternative to traditional waste treatment methods, such as composting. Its broad applicability in sectors like waste management, agriculture, and bioenergy makes it highly adaptable across different regions and industrial contexts.

The project demonstrated strong economic feasibility, with financial projections showing a Net Present Value (NPV) of €2.019 million and an Internal Rate of Return (IRR) of 11.97%, making it attractive for stakeholders. Key partnerships with **Herambiente** and **C.I.C.A.** have laid the groundwork for future commercialization, especially in waste-to-energy (WtE) facilities and agricultural biogas plants. The technology's reliance on waste heat from existing facilities reduces energy costs, making it a cost-effective and scalable solution.

Key drivers include supportive **EU environmental regulations**, market demand for renewable energy, and the cost-effectiveness of the technology. However, initial investment costs and technical complexity could slow adoption, particularly for smaller operators. Widespread replication will likely rely on both **market demand and supportive policies**, such as incentives for biogas production.

The technology is particularly suited for **Italy, France, Germany, and Sweden**, where waste heat and agricultural residues are abundant. The project's visibility and strong stakeholder engagement suggest high replication potential. Complementary to existing waste management and renewable energy initiatives, LIFE STEAM aligns with the **European Green Deal** and could benefit from funding streams like **Horizon Europe** and **EIB financial instruments**.

LIFE STEAM is positioned for high replicability across Europe, driven by market conditions and regulatory support. Its integration with existing waste management systems and demonstrated economic benefits make it a promising solution for expanding sustainable waste treatment and biogas production.

5.4.5 Best Practice lessons

In the **LIFE STEAM** project, several best practices emerged that contributed to its overall success, particularly in the way it addressed both technical and management challenges.

1. **Using Waste Heat Efficiently**: A standout practice was the integration of waste heat from **Waste-to-Energy (WtE)** plants to run the steam explosion process. This approach not only reduced the project's reliance on external energy sources but also made the entire operation more sustainable and cost-effective. It's a clear example of how leveraging existing resources can lead to big environmental and economic gains.
2. **Engaging Stakeholders Early**: From the start, the project team worked closely with stakeholders like **Herambiente** and **C.I.C.A.**. By involving potential partners early on, the project was able to tailor the technology to fit real-world needs, which in turn helped build strong support for future replication. This kind of collaboration proved invaluable in ensuring the project wasn't just a technical success but also made sense commercially.
3. **Staying Flexible in the Face of Challenges**: One of the most important lessons learned was the importance of adaptability. The project faced significant hurdles, such as the withdrawal of **Economizer** from the consortium and delays caused by the **COVID-19** pandemic. Yet, the team quickly adjusted by revising timelines, reallocating tasks, and bringing in new partners like **Valmet**. This flexibility helped keep the project on track despite these unforeseen issues.

While the project's approach worked well, a couple of adjustments could make things even smoother next time:

- **Better Financial Forecasting**: The demo plant's construction costs were underestimated, which created some budgetary pressure. In future projects, more thorough financial planning could help avoid such surprises.
- **Planning for Scale Early**: Starting discussions about scaling up to full industrial production earlier in the project could help bridge the gap between pilot projects and broader commercial adoption.

Overall, these lessons show the importance of being both strategic and adaptable—planning carefully, but staying flexible enough to adjust when the unexpected happens. That combination helped make **LIFE STEAM** a success, and it's a formula that could work well for future projects too.

5.4.6 Innovation and demonstration value

The LIFE STEAM project introduced significant innovation in the field of biogas production through the implementation of Valmet's steam explosion technology. This technology brought several advancements compared to the originally planned system from Economizer. The Valmet process operates at higher temperatures and pressures, allowing for a more efficient breakdown of lignocellulosic biomass. The direct steam injection approach, without the need for additional water, and the continuous processing capability represented major improvements. These changes resulted in biomass with lower moisture content, making it easier and less costly to transport, which enhances the scalability of the technology for large-scale applications.

The project successfully demonstrated this advanced technology at an industrial scale for the first time, offering valuable insights into its practical application for green waste treatment. EU funding played a critical role in supporting this technological advancement, allowing the project to explore the use of waste heat from incineration plants to power the steam explosion process, further enhancing sustainability.

Additionally, LIFE STEAM fostered strong collaboration between industry stakeholders like Herambiente and C.I.C.A., aligning the technology with real-world industrial needs and demonstrating its market potential. These innovations, combined with the demonstrated environmental benefits, make the steam explosion technology highly replicable across various sectors and regions, contributing to the broader adoption of sustainable waste management practices.

5.4.7 Policy implications

The LIFE STEAM project has significant policy implications, particularly in advancing the goals of the European Green Deal and the Circular Economy Action Plan.

- **Contribution to the European Green Deal:** The LIFE STEAM project directly supports the European Green Deal, particularly the goal of achieving climate neutrality by 2050. The steam explosion process developed by the project enables efficient treatment of lignocellulosic waste (such as pruning and agricultural residues), generating biogas that can replace fossil fuels. This significantly reduces greenhouse gas emissions, contributing to the decarbonization of the energy sector.
- **Support for the Circular Economy:** LIFE STEAM aligns with the EU Circular Economy Strategy, which seeks to turn waste into resources. The project demonstrates how green waste can be used to produce renewable energy, reducing the amount of waste that ends up in landfills or is incinerated, while also maximizing the energy potential and nutrient value of the produced digestate.
- **Development of the Biogas and Biomethane Market:** The project fits within the framework of the Clean Energy for All Europeans package, particularly by promoting the production of biomethane from renewable sources. Biogas produced through the steam explosion process has the potential to reduce the EU's reliance on natural gas imports, enhancing energy security and fostering the development of local renewable energy production.

- **Support for Agricultural Waste Reduction Policies:** LIFE STEAM supports EU policies on sustainable management of agricultural waste, as outlined in the Waste Framework Directive (2008/98/EC) and the Sustainable Agriculture Action Plan. By treating agricultural residues through steam explosion, the project demonstrates a sustainable approach to handling materials that might otherwise contribute to pollution or uncontrolled emissions.
- **Contribution to the EU Strategy on Agricultural and Forestry Waste:** The project addresses a key aspect of the European Bioeconomy Strategy, showcasing how lignocellulosic residues, such as pruning and agricultural waste, can be innovatively treated to produce energy, thus reducing waste and improving the sustainability of land use.

These examples demonstrate how LIFE STEAM provides a tangible contribution to EU environmental, energy, and circular economy policies, with a positive impact not only at the local level but also across the broader EU community.