Ref. Ares(2021)6729241 - 02/11/2021

2021.09.01
Version 1
689229

Deliverable 6.7

Report on demonstration sites installation and performances

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 689229.

DECISIVE

A DECENTRALISED MANAGEMENT SCHEME FOR INNOVATIVE VALORISATION OF URBAN BIOWASTE

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 689229.

A Decentralised Management Scheme for Innovative Valorisation of Urban Biowaste

D4.2 – Report on laboratory prototype and biogas valorization performances and constraints

Grant Agreement N°	689229		
Acronym	DECISIVE		
Full Title	A Decentralised Management Scheme for Innovative Valorisation of Urban Biowaste		
Work Package (WP)	WP6		
Authors	Axelle Degueurce, Raquel Montes		
Document Type	Deliverable		
Document Title	Report on demonstration sites installation and performances		
Dissemination Level (mark with an «X» in the column to the far right)	**CO**	Confidential, only for partners of the Consortium (including the Commission's Services)	
	PU	Public	**X**
	PP	Restricted to other programme participants (including the Commission Services)	
	RE	Restricted to a group specified by the Consortium (including the Commission Services)	

ABSTRACT

The current report constitutes the deliverable D6.7 of the work package WP6.2 in the DECISIVE project. It aims to present and assess the performances of the demonstrations site forecasted in the project. For each demonstration site of Dolina, Lyon and Rennes, a presentation of the site, the technology and the biowaste providers is given. In addition, issues, successes and several performances indicators are assessed.

DOCUMENT HISTORY

version	date	editor	modification
Draft 01	01/09/2021	INRAE	First draft
Draft 02	21/10/2021	INRAE	Addition of reviewer 1’s comments
Draft 03	26/10/2021	INRAE	Addition of reviewer 2’s comments

CONTRIBUTORS

name	company	contributions include
DEGUEURCE AXELLE	**INRAE**	**AUTHOR**
MONTES RAQUEL	**AERIS**	**AUTHOR**
FONTANA CLAUDIO	**ITS ENERGY**	**AUTHOR**
BERTOLUTTI FREDERICA	**A&T 2000**	**AUTHOR**

REVIEWERS

name	company	contributions include
PRADO OSCAR	**AERIS**	**REVIEW**
KROFF PABLO	**SE**	**REVIEW**

Table of content

Glossary

AD	Anaerobic Digestion
BMP	Bio-Methane Potential
DRI	Dynamic Respirometric Index
FOS/TAC	Free Organic Solid to Total Alkalinity Capacity ratio
FW	Food Waste
HRT	Hydraulic Retention Time
m-AD	Micro-anaerobic digestion
MPR	Methane production rate
SSAD	Solid state anaerobic digestion
SSF	Solid State Fermentation
SRT	Solid Retention Time
TKN	Total Kjeldahl Nitrogen
TS	Total Solid
VFA	Volatile Fatty Acids
VS	Volatile Solid
WW	Wet Weight

Executive Summary

The current report aims to present and assess the performances of the demonstrations site forecasted in the project. For each demonstration site of Dolina, Lyon and Rennes, a presentation of the site, the technology and the biowaste providers is given. In addition, issues, successes and several performances indicators are assessed.

First, an overview of the demonstration site of Dolina in Italy is given. On this site, about 100 to 200t of households biowaste should be valorised each year with a SEaB technology. Several issues related to permitting delayed the start-up of this demonstration site. Thus, this document presents the on-going status of the demonstration site.

In a second part, the report proposes the history of the demonstration site of Lyon from the arrival of the technology on site on October 2019 to the last feeding on July 2021. That year and half was cut in three separated periods. During the first one, the digester was installed, started and several settings were changed to fix the first technical issues encountered. The second period is a more challenging period as the COVID-19 pandemic occurred and biowaste went missing. However, in a discontinuous mode, this period allowed to learn more about the operation of the digester. Finally, during the last period, a more stable feeding of the process was done, which allowed a fine characterization of the inputs and outputs. But, several issues disturbed the proper and accurate monitoring of biogas production and only few weeks of reliable results are presented and discussed.

Finally, the last part focuses on the performances of the new technology developed at INRAE. During three months, three feeding and operational strategies were tested to optimize the operation of the digester. In addition, solid digestate samples were sent to Barcelona to perform SSF experiment and try to grow Bt.

1. Introduction

One objective of the DECISIVE project was to develop and demonstrate a decentralized management scheme for innovative valorization of urban biowaste through anaerobic digestion (AD) and solid state fermentation (SSF) within the urban and peri-urban areas.

Two different models of decentralized systems were implemented during the project. The first one in Dolina (Italy), aimed at valorizing between 100 to 200t/y of biowaste mainly from household stakeholders. For the size of this demonstration site, anaerobic digestion technologies already existed and one of them was purchased to valorize biowaste. The second demonstration site developed in Lyon (France), was especially designed to handle about 50t/y of catering biowaste from nearby restaurants.

In addition, one micro-AD and one SSF pilots were developed to meet the challenges of a decentralized scheme. The micro-AD technology is the up-scaled version of the first solid-state anaerobic digestion prototype developed at INRAE (Rennes, France) and assessed in deliverable D4.2. That up-scaled version of the SSAD prototype is able to treat about 0.8t/y of biowaste. The SSF technology is also an up-scaled version of laboratory experiments developed by AERIS in association with the UAB (Barcelona, Spain) and assessed in deliverable D4.7. The SSF pilot performances were tested on the digestate obtained from the micro-AD technology of Rennes.

This deliverable synthetizes the performances, issues and successes of the two demonstrations sites of Dolina and Lyon, plus the performances and outlooks of the two prototype technologies (micro-AD and SSF) developed within the DECISIVE project.

2. Demonstration site of Dolina, Italy: 100 to 200t/y

2.1. SITE DESCRIPTION

2.1.1. Location

The last associate of A&T 2000 SpA is the municipality of San Dorligo della Valle – Dolina, located at the border between Italy and Slovenia, which is the only municipality of Trieste province served by the company.

Dolina has a heterogeneous territory (Figure 1), hosting a protected transboundary natural area as well as facilities of the free port, the most important ship engine factory in the north-east of Italy and a number of olive oil and wine producers.

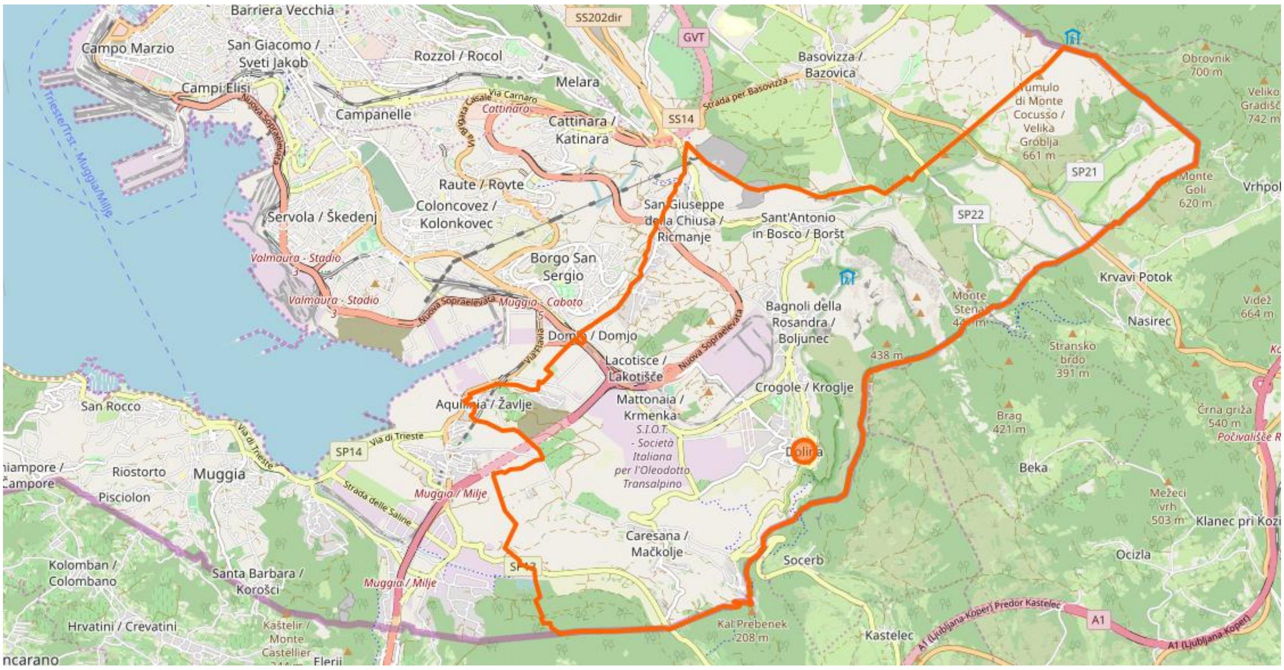

Figure 1 : Dolina location, showing the surrounding facilities as highways and ports

The demo will be installed in Località Mattonaia, San Dorligo della Valle - Dolina (TS, Italy) (Figure 2 - coordinates from OpenStreetMap: 45.60901, 13.84232). It is a part of a terrain rented by A&T 2000 which is very close to the highways, to the Slovenian Border, to the largest naval engine factory in Italy and to the fruit and vegetable market (under construction). The naval engine factory employs about 1300 workers and A&T 2000 is negotiating a deal to manage waste in the factory canteen, applying the separated and controlled collecting system performed in its basin.

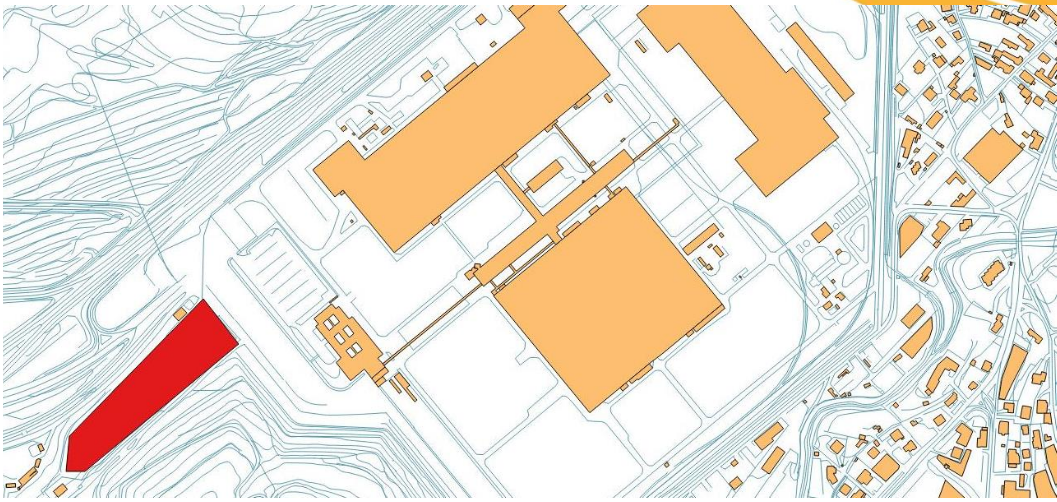

Figure 2: "Comunela" property (red area): the ship engine factory is located on the right in the figure, surrounded by high-speed roads

2.1.2. Design of the anaerobic digestion unit

The AD unit of Dolina is composed by four different containers and engineered by the company SEaB Energy LTD and one additional container useful to set the Stirling Engine module of ITS Company (see Figure 3).

Figure 3: Dolina's mAD layout

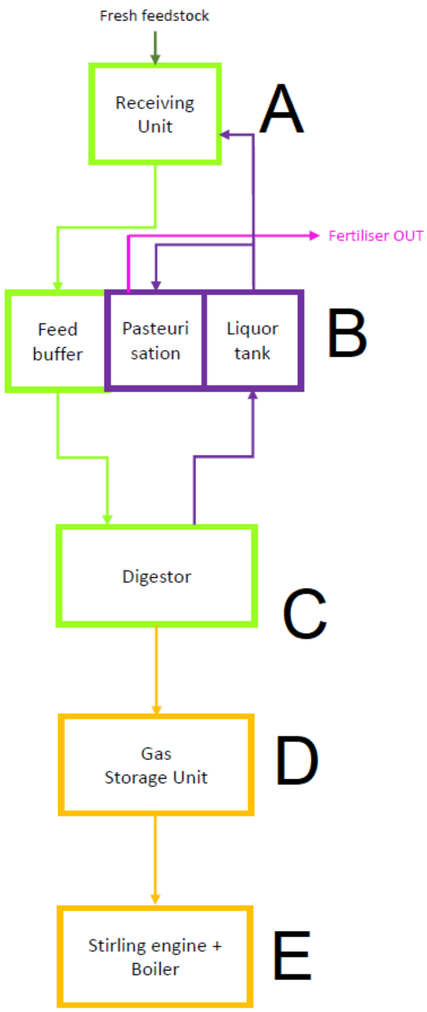

Figure 4: Dolina's demo site scheme

A) Receiving Unit: fresh material entered in the receiving unit it is shredded and diluted before going in the command unit;

B) Command Unit: material entered in the feed buffer is thermically treated before going in the digester;

C) Digester: the anaerobic conditions there allow the degradation of the material;

D) Gas storage: the biogas produced in the digestor, is stock in a bag in the gas storage before going on the next step;

E) Stirling engine and boiler: the biogas is used in the Stirling engine in order to produce energy and heat useful for the system;

B) Command unit: one treated in the digester, the material in transferred in a liquor tank where it is sorted: part of the material go to the receiving unit to dampen the fresh feedstock and part is pasteurized in order to produce the final digestate.

2.1.3. Food waste providers

The Dolina demonstration will valorize about 200 t/y of biowaste. Main sources of biowaste are households and commercial activities (i.e. restaurants, bars) collected through a door-to-door separated and controlled collection of organic waste.

Since the Municipality of Dolina joined the company (2017), its performance indicators improved in about six months reaching 73% in recycling rate last year (57% in 2016). In 2018, Dolina produced about 40 kg/inh./year of organic waste only from households and restaurants (in 2017 it produced 14,6 kg/year per inhabitant). The collection system performed reduces at minimum the presence of other materials in the separated waste (for organic waste it's less than 1%): in particular, organic waste is nearly absent in residual waste (which reduced from about 136 kg/inh./year in 2016 to about 76 kg/inh./year in 2018).

2.2. ON-GOING STATUS

A small closed-loop system is introduced in Dolina's demonstration site with the aim to recycle the organic waste collecting though a door-to-door system and able to create biogas and elements useful in agriculture.

The technology chosen is engineered by the English company SEaB Energy LTD. The plant was delivered in October 2020 and it composed by four different naval containers: the organic waste receiving unit, the command unit, the digester unit and gas storage unit.

In order to give the right space to all elements of the system, in February 2021 was set another container useful to set up the Stirling engine. This technology (built by ITS Energy) is the CHP of the system and is capable of producing energy and heat resulting from biogas combustion.

Nowadays the plant installation is going on while waiting for all the regional permissions in order to start up the system. The authorization is time consuming and A&T2000 expected to start up the system at the end of 2021.

3. Demonstration site of Lyon, France: 50t/y

3.1. OBJECTIVES

On the demonstration site of Lyon, the objective is to evaluate the DECISIVE concept with a AD technology especially designed for the project. This AD technology should be able to valorize about 50t of nearby restaurants' biowaste per year and produce about 1m^3/h of biogas so the Stirling engine can work steadily.

3.2. SITE DESCRIPTION

3.2.1. Location

The demonstration site of Lyon is located in the municipality of Ecully, one of the 59 municipalities of the local authority of the Lyon Metropole, Grand Lyon (

Figure 5). The municipality of Ecully covers 8.45 km² and in 2018 its population was 18 587 inhabitants. It also includes several educational institutions, one of which is the horticultural training school (CFPH-Centre de Formation et de Promotion Horticole).

The CFPH owns about 10 ha of agricultural lands shared between the school and several hosted companies and associations that develop different models of urban-farming, including DECISIVE partner Re-Farmers. This site offers many advantages as the biowaste of the farms could be valorized by the AD unit while the digestate and the energy produced could be directly reused on-site.

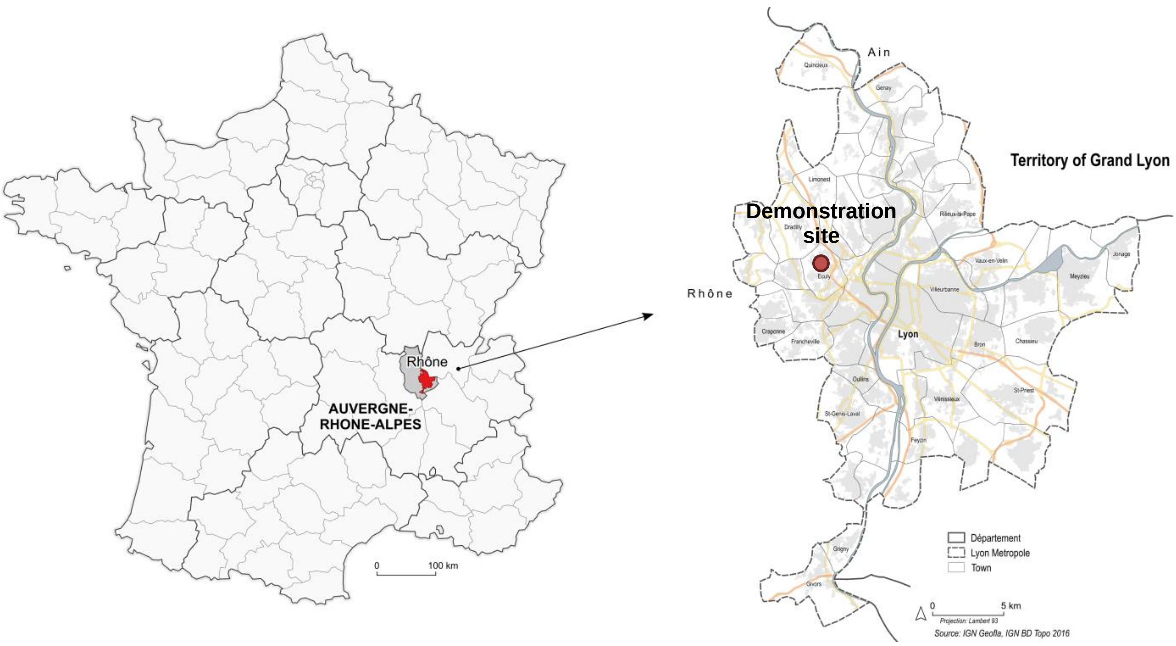

Figure 5: Location of the demonstration site in France

3.2.2. Design of the anaerobic digestion unit

The AD unit of Lyon is a 40 feet containerized solution developed by Enwise Company in association with Suez Group. It is composed of eight functional modules described below to which was added the Stirling Engine module of ITS Company (see

Figure 6 and Figure 7).

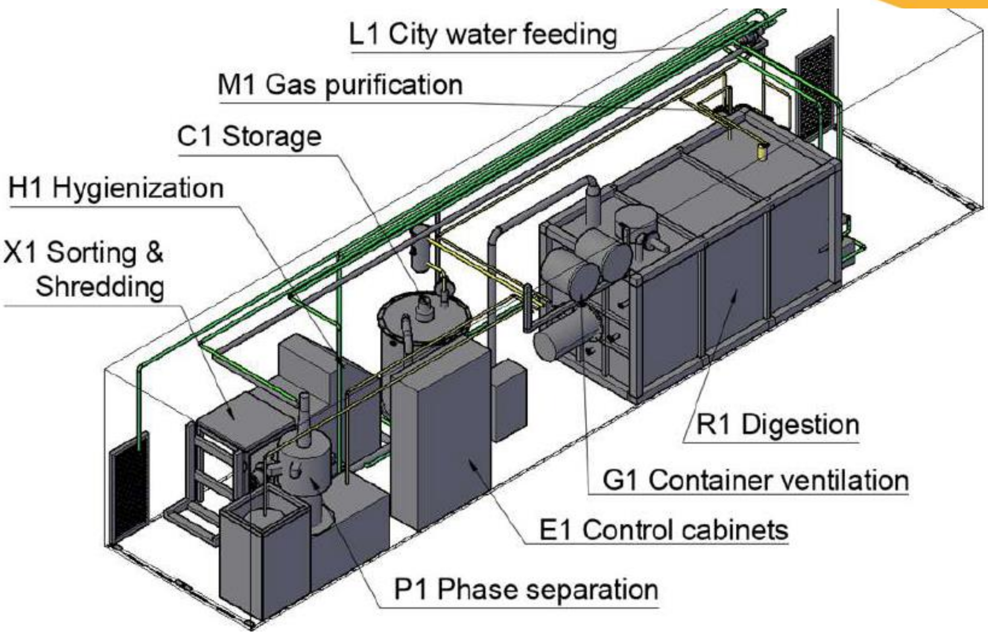

Figure 6: 3D scheme of the container shaped AD unit

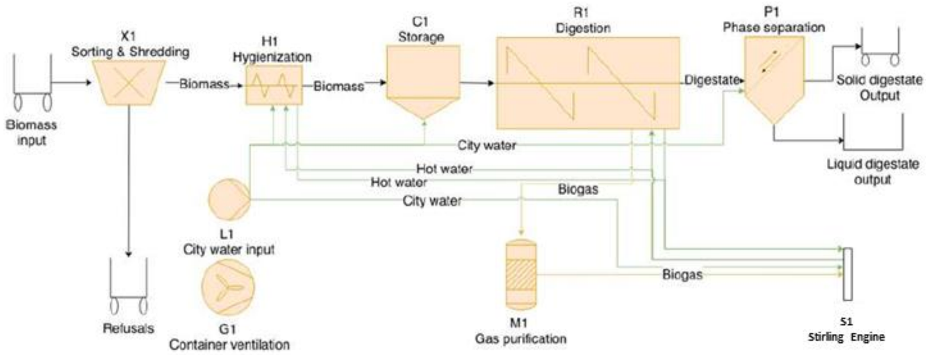

Figure 7: Overview flowchart

3.2.2.1. X1, Sorting and Shredding

Module X1 allows the sorting and shredding of the biomass. It is composed of a bin lifter, a sorting table and a shredder. The bin lifter eases the transfer of bins content to the sorting table where the operator can remove large and visible impurities from the biowaste before being shred. The sorting table is equipped with a weight cell to measure the amount of biowaste inputted in the system.

Figure 8: Manual sorting of biowaste

3.2.2.2. H1, Hygienization

Module H1 performs a pasteurization process of the biowaste stream. After shredding, biowaste fall by gravity in the hygienization vessel. The operator starts the hygienization cycle that consists in the circulation of hot water in the jacket of the hygienization vessel to heat the biowaste to 70°C for one hour.

3.2.2.3. C1, Storage

Module C1 stores the biowaste after shredding and hygienization, and controls the feeding of the digester. The storage tank is equipped with an agitator to maintain an homogeneous biomass stream.

3.2.2.4. R1, Digestion

Module R1 performs the digestion of the biomass in mesophilic conditions. The digester consists in a 5 m^3 horizontal plug flow technology equipped with a horizontal agitator that allows the biowaste to go from one end of the digester to the other. During the digestion, the biogas produced goes directly to the module M1 while the digestate goes to the module P1. A hot water circulation in the digester's jacket regulates the temperature of the biomass.

3.2.2.5. P1, Phase separation

Module P1 is a vibrating screen that separates the raw digestate in two streams, a solid digestate and a liquid digestate. The liquid digestate then goes to a flexible water tank before use (Figure 9 and Figure 10). The solid digestate can be either composted on-site or sent to SSF after separation.

3.2.2.6. M1, Gas purification

Module M1 removes water and hydrogen sulfide from the biogas. Biogas is first cooled to ambient temperature so water condensate. Then biogas passes through a desulfuration reactor before going to the module S1.

3.2.2.7. S1, Stirling Engine

Module S1 transforms biogas into energy. It is composed of the stirling engine itself, solar panels and a hot water storage tank. The Stirling Engine burns the biogas to generate hot water used for the hygienization step and to heat the digester. The hot water is stored in the water storage tank before use. Solar panels ensure hot water production in case of Stirling Engine failure.

Figure 9: Photo of the AD container with the solar panel and the flexible water tank for digestate storage

3.2.2.8. G1, Ventilation

G1 module monitors the air in the container and ensure a proper ventilation in the container to comply with the ATEX norm.

3.2.2.9. L1, City water input

L1 city water input provides city water to the different equipment and especially to the Stirling engine that ensure water heating for the digester operation.

Figure 10: Photo of the AD container's inside

3.2.3. Food waste providers

The demonstration site of Lyon aimed at valorizing biowaste from nearby commercial restaurants and catering. However, because of several lock downs in France due to the COVID-19 pandemic, many nearby restaurants initially involved in biowaste supply could not provide their biowaste. Thus, biowaste providers evolved during the experimental period to include nearby groceries stores or vegetable farm, and further jail canteens, which are more stable sources of biowaste.

Table 1: List of biowaste producers for Lyon demonstration site

Code	Name of Business	Type of business	Type of Waste	Distance from demonstration (km)
1	Ferme Abbé Rozier	Organic Farm	Only Vegetal	0
2	Cour des Loges	Gastronomic restaurant	Mixed biowaste	7.7
3	Biocoop Croix Rousse	Oragnic grocery	Only Vegetal	6.4
4	Octopus	Restaurant	Mixed biowaste	8.1
5	Le Ballon	Restaurant	Mixed biowaste	7.2
6	Beer Fabrique	Micro-Brewery	Spend grains only (vegetal)	6.7

7	Lycée Horticole	High School Canteen	Mixed Wastes with a lot of impurities	5.1
8	Chez Jules	Backery	Mostly Bread (99%)	5.5
9	Maison d'arrêt de Corbas	Jail canteen	Mixed biowaste	24.2
10	Restaurant Inter Administratif	Administrative Canteen	Mixed biowaste	7.6
11	Naturalia	Organic Grocery	Only Vegetal	7.8
12	Maison d'arrêt de Bourg en Bresse	Jail canteen	Mixed biowaste	71.2

The final list of the twelve biowaste producers is given in Table 1. It involves three commercial restaurants, one vegetable farm, four groceries stores and four canteens. All biowaste providers are located below 9 km from the demonstration site except for jail canteens that are located at 24.2 and 71.2km away. Moreover, 8 over 12 providers are located in the city of Lyon in a close area from one another, 1 is located directly on the demonstration site and the last three are located in a peripheral location which partly comply with the objective of locally valorizing biowaste (Figure 11).

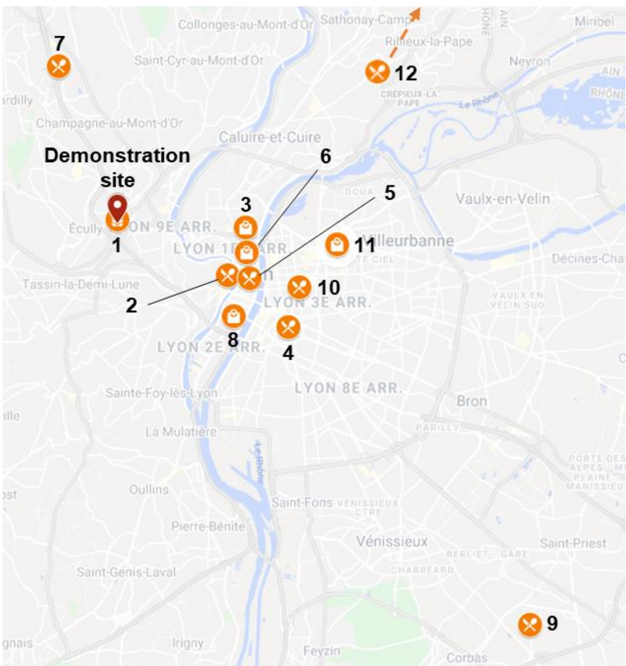

Figure 11: Location of biowaste producers of Lyon demonstration site (see Table 1 for number references)

3.3. OPERATION OF THE ANAEROBIC DIGESTION UNIT

3.3.1. Targeted settings

The AD unit was design to uncouple the biowaste collection to the digester feeding. In this way, during a week, sorting, shredding and hygienization steps can be done whenever biowaste and operator are ready. The hygienized biowaste is then stored in the dedicated tank and about 145kg is automatically fed in the digester every day. Considering the 4 m^3 working volume of the digester, the hydraulic retention time (HRT) should be around 24 days. In order to save energy from heating up the digester, the process was run in mesophilic conditions, between 35 to 37°C.

3.3.2. Period 1: Starting phase

The first period lasted 5 months between October 8th, 2019 and March 17th, 2020 and was dedicated to starting up the AD unit (see Table 2). The first month consisted in assembling, connecting and setting-up all modules of the AD unit. Then, the digester received about 4m^3 of inoculum that was composed of a mix of nearby farm manures and biowaste before starting the ramp-up. After 3 weeks of operation, feeding of the digester stopped so the operators on site could fix the issues encountered and manage to optimize the settings of the different modules to reach a steady feeding of the AD unit. On February 14th, 2020, the feeding operations started up again until the first lock-down in France. During the first period, biogas production and methane contents were not monitored.

3.3.3. Period 2: Learning about the AD unit during the pandemic

The second experimental period lasted 14 months between March 17th, 2020 and May 5th, 2021 which coincided with the COVID-19 pandemic. Thus, the operation of the AD demonstration was greatly disturbed by the lack of biowaste (commercial restaurant closed up to one year and half), but also by the lack of spare-parts and working forces to fix devices' failures. Table 2 summarizes the main periods during which the AD unit actually received biowaste and the events linked to the feeding difficulties. However, during the low feeding rate periods, optimization of the hygienization module, the storage module, and digester and Stirling engine managements continued.

Biogas production monitoring started on August 27th, 2020 (week 35) through the action of the burner of the Stirling engine. Methane content monitoring started on November 27th, 2020 (week48) after having fixed the dedicated device. When feeding phases occurred, the strategy consisted in feeding the digester in two steps of 70kg of hygienized biowaste within two hours.

3.3.4. Period 3: Stabilized process with regular physical-chemical analysis

The third experimental period lasted 3 months between May 5th, 2021 and July 30th, 2021 and corresponded to a more stabilized feeding of the AD unit. Indeed, biowaste providers changed to include producers that are more reliable. Thus, the steady feeding conditions of this period allowed the optimization of the feeding frequency from the storage tank to the digester. However, even if many technical issues have already been experienced and could be rapidly handled, more problems appeared with the Stirling engine and the feeding module which impacted the reliability of biogas production measurements.

Biogas production and methane content monitoring continued as it was during the second period. In addition, every week, biowaste from the storage tank and raw digestate were sampled and sent to INRAE laboratory to measure pH, total solid (TS), volatile solid (VS), Total Kjeldahl Nitrogen (TKN) and ammonia content. Total volatile fatty acid content (VFA) and FOS/TAC ratio were also measured on the digestate samples to assess possible failures of the digester. Moreover, every two weeks, bio-methane potential (BMP) and trace elements content (Zn, Cd, Cu, Ni, Pb and Cr) were performed on the biowaste and the digestate.

Table 2: Synthesis of events that occurred on the AD unit of Lyon during the experimental time

Year	Weeks	Period	Event	Feeding ?
2019	41	Starting phase	Pilot on site	No feeding
	42- 44		Pilot set-up and connections	
	45		Addition of inoculum	
	46-48		Ramp-up	Feeding OK
	49-52		Stirling and hygienization set-ups	No feeding
2020	1-7			
	8-11		Restart of the AD unit with new ramp-up period	Feeding OK
	12-19	COVID-19 Pandemic	First lock-down in France	No feeding
	20-27		Commercial restaurant closed	Low rate feeding
	27-35		Commercial restaurant and schools closed – No biowaste available *Week 35: First biogas production monitoring*	No feeding
	36-44		Commercial restaurant closed	Low rate feeding
	43		Digester Spillage: $3m^3$ of digestate lost	No feeding
	44-50		Second lock-down in France New ramp-up to refill the digester *Week 48: First methane content monitoring*	Low rate feeding
	51-53		Commercial restaurant closed	
2021	1-3			
	3-17		Fixing several modules of the AD unit and preparing the final trial	No feeding
	18-30	Stabilization	Stabilized period with reliable AD unit monitoring and samples analysis *Week 28: First electrical production with Stirling engine*	Feeding OK

3.4. PROCESS PERFORMANCES

3.4.1. Period 1: starting step

The start-up phase of the AD unit highlighted several module failures or wrong settings that were handled in the meantime. Main issues involved the Stirling engine and the hygienization settings that had consequences on the overall process.

The first objective was to set the temperature in the digester to 35°C with hot water heated by the Stirling engine. However, the temperature was very unstable for few months despite several settings modifications. Finally at the end of February 2020 (week 8), a last modification allowed to reach a stable temperature in the digester.

Once this issue solved, the first hygienization trials were performed but were not successful. Indeed, the biowaste did not reach 70°C even after several hours of heating. Moreover, the temperature in the digester also dropped during the hygienization step. To solve that issue two parallel actions were taken. First, the electrical heating was activated in addition to a protocol upgrading that consisted in stopping the digester heating a few hours before starting the hygienization cycle.

Finally, several pumps settings had to be modified so every module was efficiently fed and/or emptied during the process.

At the beginning of March 2020, the feeding ramp-up of the digester started but was rapidly stopped by the first lock-down in France, which started on March 17th, 2020.

3.4.2. Period 2 : Learning about the AD unit during the pandemic

With the COVID-19 pandemic and the first lock-down in France, the main issue encountered during this second period was the lack of available biowaste as all schools, restaurants and administrative canteens were closed. Even after the end of the lock-down, commercial restaurants (targeted sources of biowaste) remained closed until the summer 2021. Thus, then digester feeding was possible again, the objective of processing about 145kg/d of biowaste could never be reached.

However, the low feeding rate periods allowed the identification of several issues with the Stirling engine, which made possible advances and optimizations of the device. Two main defaults occurred frequently. The first one was due to the quality of biogas that blocked the start-up of the burner. This default was identified and understood very lately, at the end of year 2020, when the device measuring the methane content was fixed. From then, it appeared that with a methane content lower than 35-40%, the burner could not ignite. The second default is a consequence of a design weakness that did not allow a proper cooling of the engine that stopped immediately after starting-up. These issues were easily resolved by a manual restart of the burner. However, this could not be done during nights and weekends. Consequently, biogas production was not monitored reliably, and water heating was not always possible which regularly affected the hygienization cycles. More importantly, a part of the Stirling engine strongly melted which restrained the production of power. The spare part was changed only during the third period because of moving difficulties from one country to the other.

Apart from Stirling engine issues, other mechanical feeding problems occurred such as the collection of digestate that blocked several times. Therefore, in order to avoid an over filling of the digester, feeding from the biowaste storage tank stopped which also automatically stopped hygienization cycles. This issue was solved by increasing the digestate pumping time to ensure a good priming of the pump.

Another major event occurred during week 43 with a massive spillage of the digester during which, 3m^3 of digestate were lost, i.e. three quarter of the working volume of the digester. Most probable root cause of this issue was the accumulation of small straws that have progressively clogged the piping from the digester to the hydraulic guard. It caused a sudden pressure increase in digester and the leakage of digestate through the vibrating screen. After this event, a new procedure of periodical checking and cleaning of the biogas piping was initiated. Shortly after that event, the second lock-down started in France that allowed a restart of the digestion process with a low organic load, without any digestate collection, to recover the nominal level in the digester.

All these events and issues led to stop the digester several times with a willing or unwilling decrease of digester's temperature. However, it enables to demonstrate that the digester can be restart after several weeks at low temperature and without feeding, by reheating it and progressively refeeding it. Thus, the technology is robust enough to face several minor or major troubles.

3.4.3. Period 3: Stabilized

3.4.3.1. Biowaste Processed

During the 3rd period, about 10 tons of biowaste were processed within three months, which corresponds to an average feeding rate of 114 kg/d (Table 3). At this loading rate, about 40 tons of biowaste could have been valorized in one complete year. This rate is lower than the objective of processing 50 tons of biowaste per year or 145 kg per day. However, Figure 12 shows that the digester is able to process such quantities during several days when biowaste is available and no technical issues occurred.

Table 3: Biowaste quantity fed in the digester during the 3rd period

	May 2021	June 2021	July 2021	TOTAL
Total processed biowaste (tons)	3.08	3.53	3.40	10.01
Average feeding rate (kg/d)	114	118	110	114

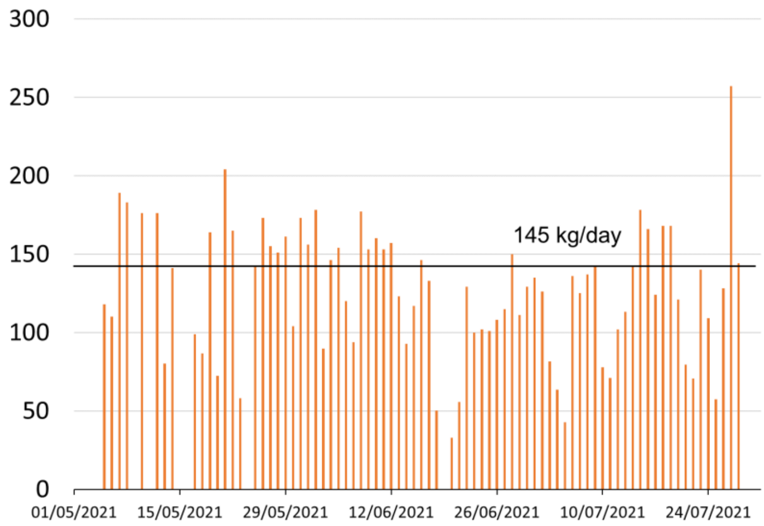

Figure 12: Daily rate feeding during the 3rd period

In terms of location, most of the biowaste processed came from the supplier 12 ("Maison d'arrêt de Bourg-en-Bresse" – Jail canteen) with 44% of waste fed during the period (Figure 13). Then comes the organic grocery store (supplier 3) with 15% and the brewery (supplier 6) with 12%. Other suppliers provided less than 10% of the total processed biowaste. When combining all the restaurants and canteens suppliers, the amount of biowaste processed rises to 63%. This type of biowaste comes mainly from food preparing and leftovers, which are similar to the initial target of commercial restaurant's biowaste. Thus, the following results and conclusions could be transposed to biowaste from commercial restaurant.

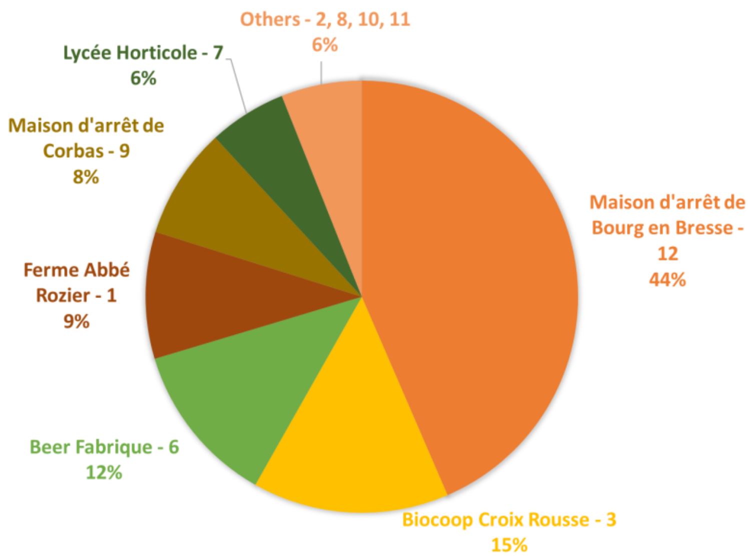

Figure 13: Proportion of biowaste fed in the digester depending on the supplier

3.4.3.2. Biogas production

Several issues implying the Stirling engine and the feeding module led to unstable monitoring of biogas production during the third period. Thus, to discuss the performances of the AD unit, two short time periods without failure in June and July were selected and presented in Figure 14. During the selected periods, the average values for biogas production rate were 0.6 ± 0.2 and 0.5 ± 0.1 m^3/h in June and July respectively. This represents half of the target value of 1 m^3/h that would allow a continuous operation of the Stirling engine. Considering that the average feeding rate was close to the target with 132 kg/d and 154 kg/d in June and July respectively, this shows that about half of the processed biowaste was not properly degraded. One solution to increase the performances of biogas production could be to increase the working temperature of the digester from 35 to 40°C. Another solution would be to double the working volume of the digester in order to double the production of biogas. However, both solutions imply an increase of energy demand to heat the digester. In addition, higher loading rates could be experimented with biowaste from additional surrounding sources.

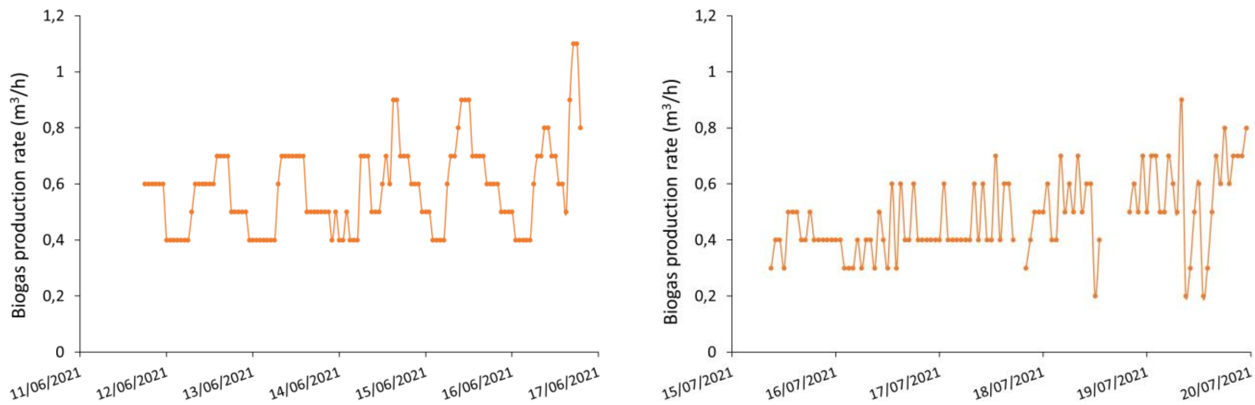

Figure 14: Focus on biogas production rate of two periods with a normal operating mode

3.4.3.3. Methane content and feeding rate frequency

The second experimental period highlighted the importance of reaching a steady methane content higher than 35-40% to avoid failures of the Stirling engine's burner, which was not optimal for this size of engine. Indeed, the smallest burner available on the market was too big for the 50 t/y digester. Thus, a special attention was paid to its correct functioning and different feeding strategies were experimented during the last period to complete this objective.

At the beginning of the 3rd period, feeding strategy consisted in 2 feedings of 75kg per day spaced from 2 hours. As a result, methane content was very unstable with an average of 44 ± 8 % leading to several drops below the limit of burner operation (see Figure 15). The second strategy of six feeding per day with 25kg per hour was still too though for the AD process and methane content was still unstable. Thus, the following strategy consisted in feeding 25kg every two hours instead of every hour. This time, methane content stabilized with an average of 46 ± 3 % but the lower values were still too close from the burner's limit. In order to improve that point, feeding strategy was set 10 events of 15kg every two and a half hour, which resulted in higher stability, lower drops in minimal values and higher average methane content with a value of 47 ± 2 %. The last strategy was done to possibly increase the global loading rate to 165kg/d by adding one feeding event each day. The average methane content remained very stable and comparable to the previous strategy with an average methane yield of 47 ± 2 %.

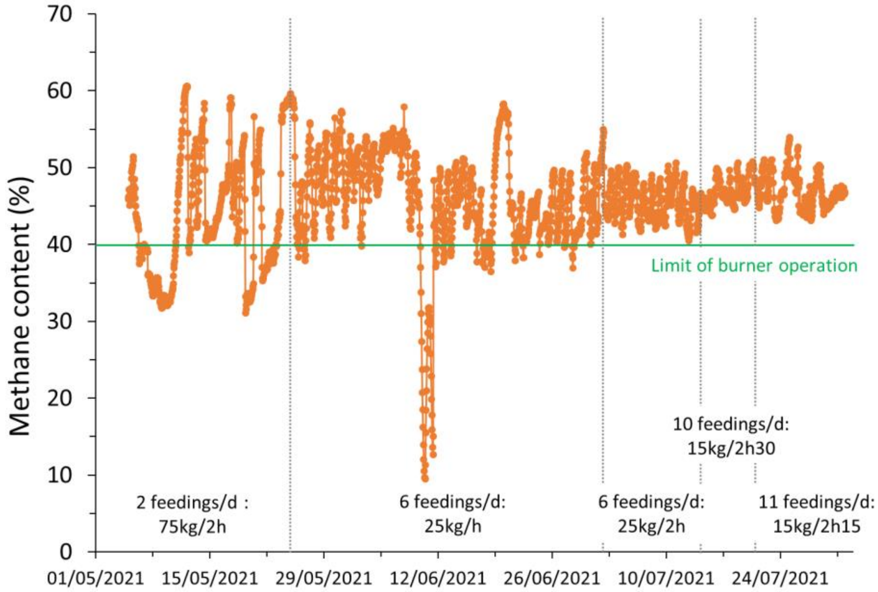

Figure 15: Evolution of methane content during the 3rd period with different feeding strategies

The assessment of methane content showed that the feeding strategy was of importance to drive a steady operation of the AD process and should be extended over time with stable loading rates to remain optimal.

3.4.3.4. Biogas valorization and Stirling engine performances

On June 9th, 2021, ITS replaced totally the previous version of the Stirling and the combustion chamber, including electronic control system with one more reliable. During the replacement, it appeared that the hot pipes completely melted due to high temperature in the burning chamber. After this upgrade, burner and the system worked well but the burner started and stopped frequently without waiting the increase of pressure in the digester. For this reason, the Stirling could not reach the starting temperature.

On July 14th, 2021, with the last changes and fixing, the best setting possible was reached. Stirling started when gas pressure reached the maximum possible in digester (7 mPa) and burnt until the minimum working pressure was measured in the burner. During that visit, the starting temperature of the stirling was set to 200°C instead 280°C to prevent possible failures (previous versions was 400°C). With this setup, the maximum temperature in the combustion chamber varied between 250 to 300°C and was lower than 100 °C in the fumes. With these temperatures, the Stirling could reach between 50 to100 W maximum of electrical power and all the energy was transformed in thermal energy to heat the air inside the container. On the other hand, the average thermal power produced was 4kW.

With the last setups, burner never stopped and both burner and Stirling seemed very stable and reliable.

3.4.3.5. Digestate characteristics

During the third period, thirteen regular sampling of FW and raw digestate were performed and analyzed (Table 4). Solid and liquid phases of the digestate were not available for sampling, as the vibrating screen used for phase separation was not efficient.

In terms of process performances, the raw digestate was liquid with a total solid content of 43 ± 2 g/kg$_{WW}$. Its pH of 7.9 ± 0.2 shows that the digestion process was stable without any acidification due to high loadings that could have inhibit the microorganisms. The assessment of BMP values, on the other hand, shows that only 40% of the methane potential was actually produced, which is in accordance with the biogas production rates monitored and discussed in paragraph 3.4.3.2.

Table 4: Physical-chemical characteristics of FW and Digestate on the demonstration site of Lyon

	pH	BMP ($_N$L/kg$_{VS}$)	TS (g/kg$_{WW}$)	VS (g/kg$_{WW}$)	COD (g/kg$_{WW}$)	NTK (g/kg$_{WW}$)	NH_4^+ (g/kg$_{WW}$)
FW (n=13)	3.6 ± 0.2	498 ± 43	143 ± 24	131 ± 25	194 ± 38	5.3 ± 1.0	0.5 ± 0.1
Digestate (n=13)	7.9 ± 0.2	274 ± 33	43 ± 2	29 ± 3	47 ± 5	5.7 ± 0.3	3.4 ± 0.2

In terms of French regulation, the digestate can be considered as a fertilizer as it contains about 5.7% of nitrogen (at least 3% needed according to the regulation NFU 42-001). In addition, the metallic trace-elements content in the digestate are below the limits of the French regulation NFU 44-051 for the elements tested, i.e. zinc, cadmium, copper, nickel, lead and chromium (see Table 5). Thus, in respect of French regulation, the digestate from the demonstration site of Lyon could be used in nearby farm fields for spreading.

Table 5: Synthesis of metallic trace elements contents in the digestate of Lyon

	Zn (mg/kgTS)	Cd (mg/kgTS)	Cu (mg/kgTS)	Ni (mg/kgTS)	Pb (mg/kgTS)	Cr (mg/kgTS)
Digestate	68 ± 6	1.2 ± 0.1	21 ± 3	18 ± 2	11 ± 4	32 ± 7
Regulation's limit	600	3	300	60	180	120

3.4.3.6. Global energy performance of the demonstration

With the last upgrades of the Stirling engine, thermal and electrical energy production could be monitored during the last two weeks of July 2021. In parallel, the electrical energy used to heat the digester and to operate all the electrical devices (hygienisation, stirring, shredding, pumping, etc.) was also recorded. All results are presented in Table 6. During this period, the average energy demand to heat and maintain the digester at 35°C was 59 kWh/d. The other modules of the demonstration site needed about 6 kWh/d of electrical energy to work properly. Overall, the raw energy demand was 65 kWh/d. On the other hand, the Stirling engine produced an average of 98 kWh/d of raw energy, which was divided into 96 kWh/d of thermal energy and 2 kWh/d of electrical energy. Thus, considering that the thermal energy could be used to heat the digester, the Stirling engine is able to cover that energy demand and produce even more heat. Nevertheless, the electrical demand of the demonstration site of Lyon is higher than the electrical production of the Stirling engine.

However, as discussed in paragraph 3.4.3.2., biogas production could be doubled with an optimization of the digester operation to increase the electrical production. This would imply a raise in temperature and thus, a higher thermal energy demand which is already available with the current operating setups.

In spite of the positive results concerning the energy demand, additional tests should be done during wintertime to assess the performances during less favorable periods in terms of temperature (in 2021, the average temperature in Ecully was 3.2 °C in January and 21.4°C in July).

Table 6: Energy demand and production during July 2021

	Thermal energy (kWh/d)	Electrical energy (kWh/d)
Production with Stirling	96	2
Consumption for heating the digester	0	59
Consumption for other devices (hygienization, stirring, shredding)	0	6

3.5. CONCLUSION

The operation of the demonstration site of Lyon was considerably disturbed by the COVID-19 pandemic. Thus, feedings were not performed in a stable way, and the objective of valorizing 145kg/d of FW was not reached. Therefore, biogas production reached only 60% of the final target set at 1 m^3/h. However, the unsteady operation showed that the process was robust enough to be stopped and started up again several times without any failure. In addition, the digestate, showed satisfying physical-chemical characteristics and complied with the French regulations in terms of ammonia content and metallic trace elements.

Biogas valorization with the Stirling engine also faced several issues mainly due to its initial design, which evolved several times during the experiment to overcome the initial limitations. The final version of the Stirling allowed the production of enough thermal energy to cover the demand of the digester's heating and even more, but the electrical production was below the need of electricity to operate all devices. However, the issues encountered will benefit to the Dolina demonstration site with a new design of the Stirling engine. Hot water production will be separated into two different tanks at two different temperature. The first one will store the hot water around 90°C to be used during the hygienization step. The second one will maintain water around 50°C to ensure a reliable heating of the digester and a reliable cooling of the Stirling engine.

Finally, additional experiments along a complete year with increasing the temperature and the working volume of the digester would be needed to increase biogas production and energy production to be able to face the external temperature variations along the year.

4. Demonstration site of Rennes, France: 0.8t/y

4.1. SITE DESCRIPTION

4.1.1. Objectives and location

The demonstration site of Rennes is located in the laboratory buildings of INRAE. This prototype is the up-scaled version of the micro AD prototype described in deliverable D4.2. The objective was to assess the technical and operational modifications of the first prototype, with the idea to develop a technology with the ability of digesting FW without neither sorting nor shredding steps, that integers phase separation of the digestate and that is as compact as possible.

4.1.2. Design of the anaerobic digestion unit

Figure 16 presents the micro-scale AD technology which consists in a semi-continuous solid state anaerobic digester divided into two parts. The first part is a tubular reactor of 100 holding the food waste to be degraded. The second part consists of a continuously stirred tank reactor of 250 L that contains the liquid inoculum called leachate. The two parts are linked to each other with an airtight flexible pipe that is equipped with a 3 mm sieve filter (Figure 16C). In that way, the leachate tank, the tubular reactor, the flexible pipe and the peristaltic pump form a leachate immersion circuit.

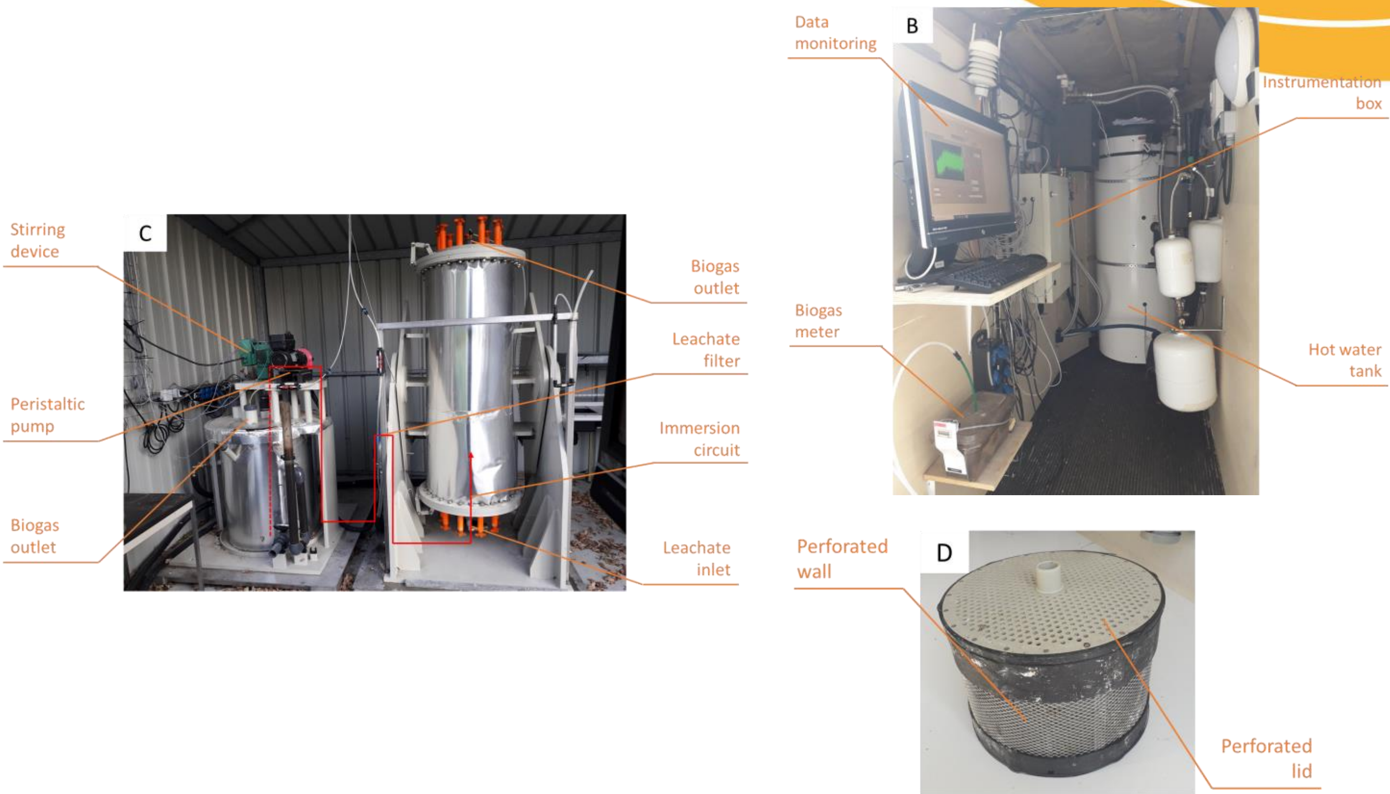

Figure 16: Pictures of the mAD prototype of Rennes (A: Global view of the installation, B: inside of the technical room, C: m-AD prototype, D: Perforated capsule)

Both tubular and leachate tanks are double-walled reactors that allow the circulation of hot water to heat the system. A solar panel allows the water heating of the system (Figure 16A). When the energy of solar panels is unavailable, an electric resistance takes over to ensure an efficient temperature regulation. Both the leachate tank and the tubular reactor are equipped with a probe that continuously measures the temperature of the tanks. Biogas outlets are located at the top of the tubular reactor and at the top of the leachate tank.

4.2. OPERATION OF THE ANAEROBIC DIGESTION PROTOTYPE

4.2.1. Routine operation

During the feeding phase, the tubular reactor is tilted into a complete horizontal position at human height. Then, FW is loaded into cylindrical perforated capsules (length: 12 cm; diameter: 30 cm) that are themselves loaded into the tubular filter. The capsules were designed so that heigh of them fit simultaneously inside the tubular reactor, which as the advantage of setting precisely the solid retention time (SRT). At each feeding event, the two capsules that are loaded at the top of the tubular reactor push out the two capsules located at the bottom side of the tubular reactor. Once loaded and during anaerobic digestion process, the reactor is straightened to a complete vertical position.

Periodically, FW is immerged with leachate. The perforations of capsules allow the transfer of small solubilized organic particles from the solid that is partly degraded, to the leachate during the immersion event. Finally, the organic matter flushed out the tubular reactor and filtered before going back to the leachate tank where the degradation continues. A valve at the bottom of the leachate tank allows the removal of extra-leachate produced during the AD process.

4.2.2. Experimental plan

A start-up phase and three immerging strategies were experimented overtime. The start-up phase consisted in feeding the prototype with a digestate from an industrial plant treating mainly biowaste from supermarkets (about 23 000 t/y). The leachate tank was filled with about 200 L of the liquid digestate from that plant and about 15.5 kg of the solid fraction of the same digestate was fed in the tubular reactor. In addition, 13.5 kg of fresh FW from a nearby collective restaurant was loaded at the top of the tubular reactor. Each week after the first loading, FW was loaded in the tubular reactor until it was completely filled with FW, without any remaining digestate from the industrial plant. Then, the feeding phase started with the different immerging strategies.

The targeted solid retention time was 4 weeks. Thus, once a week, the reactor was fed with about 15 kg of fresh FW from the same nearby collective restaurant than the FW used for the start-up phase. During immersion events, 40 L of leachate were sent to the tubular reactor. It remained inside the tubular reactor during one hour before going back to the leachate tank. The three feeding and immerging strategies defined three experimental periods described below:

- **Period 1: from week 4 to 7**. FW was shredded into pieces lower than 1 cm with an industrial cooking shredder (Robot Coupe® R15 V.V.) prior to its loading and immersion was performed once a day.
- **Period 2: from week 8 to 11**. As during the first period, FW was shredded before its loading but immersion was performed twice a day.
- **Period 3: from week 12 to 15**. FW was not shredded before its loading and immersion was performed twice a day. To do so, at the beginning of this period, the tubular reactor was completely emptied and reloaded with fresh and not shredded material. A special attention was paid to reload the equivalent quantity of VS in each capsule than the quantity present before the emptying step in order to avoid process failure due to possible overloading.

Along the experiment temperature was set to 40°C both in the leachate tank and in the tubular reactor. Biogas production rate was monitored continuously at standard temperature and pressure conditions with a volumic gas meter. Biogas composition and content were analysed by gas chromatography every 2 days. After weekly sampling, fresh FW and solid digestate were ground to pieces lower than 0.5 cm with a cooking shredder to analyze TS, VS, TKN and ammonia contents. pH of the leachate was continuously monitored in the leachate tank while the FOS/TAC ratio was measured every two days. pH of solid samples was also measured on their aqueous extracts.

4.3. SOLID STATE FERMENTATION EXPERIMENTS

With all the information compiled in the activities carried out in WP4, a complete design of SSF pilot plant was performed, including a 290-L reactor vessel (where the biological reactions take place) and an electrical panel with a programmable controller and a touch screen.

The process and instrumentation diagram (PID) are shown in Figure 17:

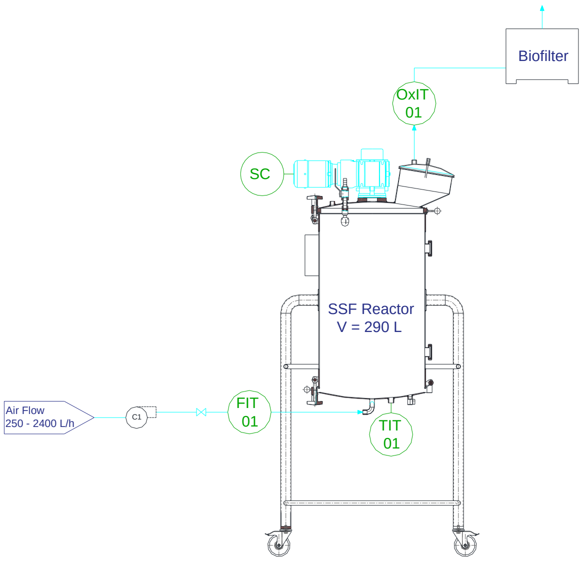

Figure 17: PID of the SSF pilot plant. FIT: Air flow rate sensor; TIT: Temperature sensor; SC: Frequency inverter/Speed controller; OxIT: Oxygen concentration sensor.

Some other annex devices are needed for the SSF process:

- Stirrer: there is an helicoidal stirrer inside the vessel, to ensure a good homogenization as well as to improve heat and mass transfer when needed.
- Feed/discharge: the reactor presents a manhole on its top side to allow the manual feeding. There is a tramex support grid which avoids solid material entering and eventually blocking the air inlet located in the lower part. A trolley must be located at the bottom of the plant to easily discharge the material when the lid of the reactor bottom is opened. A 1 m ladder it is necessary to be placed close to the pilot plant to facilitate the loading and the maintenance operations.
- Air supply: in case compressed air is not available, an air compressor must be located to supply the necessary flow rate compressed air for the process. An air flowmeter must be installed and present an analog output to connect it to the PLC to register the measured values.
- Gas outlets: it also incorporates two identical ½" air outlets, one used for the gas outlet towards the subsequent gas treatment and the other one for punctual oxygen measurements. A 25 L conventional biofilter will be installed downstream of the SSF plant and fed with the exhaust air from the reactor. This biofilter, which will be packed with wood bark, must be regularly soaked.
- Solid sampling: Three solid sample extraction ports are present along the axial axis of the vessel.
- Pressure safety: A safety valve for gas release in case of reactor overpressure has been incorporated as a protection measure.
- Monitoring devices: a temperature probe is inserted in the bottom of the reactor. Additionally, an oxygen sensor is placed inside the electrical panel, which monitors the oxygen content of the outlet gas coming from the upper part of the reactor. Temperature and oxygen data are stored in the data base of the program.

Figure 18: SSF pilot plant

The SSF process has been successfully validated using digestate from Granollers to grow Bt microorganisms. In order to validate the process, it has been tested using digestate from the second period of the pilot plant of Rennes.

4.4. AD PERFORMANCES

4.4.1. Period 1: Immersion once a day with FW shredding

After 3 weeks of starting phase, the first period started. During that period, FW was shred prior to its loading into capsules and immerging occurred once a day. With this strategy, the average methane production rate was 186 ± 78 L/kg_{VS}, which represents about 40% of the maximum theoretical methane production of FW[1] (Figure 19). The methane content during this period was very instable and varied between 24 to 71% with an average of 42 ± 17% (Table 7). The variations scheme are linked to the feeding events: after one feeding, the methane content dropped and increased again until the end of each week. These drops showed that the immerging event was able to catch rapidly a large part of the easily degradable organic matter from the FW.

[1] According to Fisgativa in “*Characterizing the variability of food waste quality: A need for efficient valorization through anaerobic digestion*” (2016), the average BMP of FW is 460 L/kgVS.

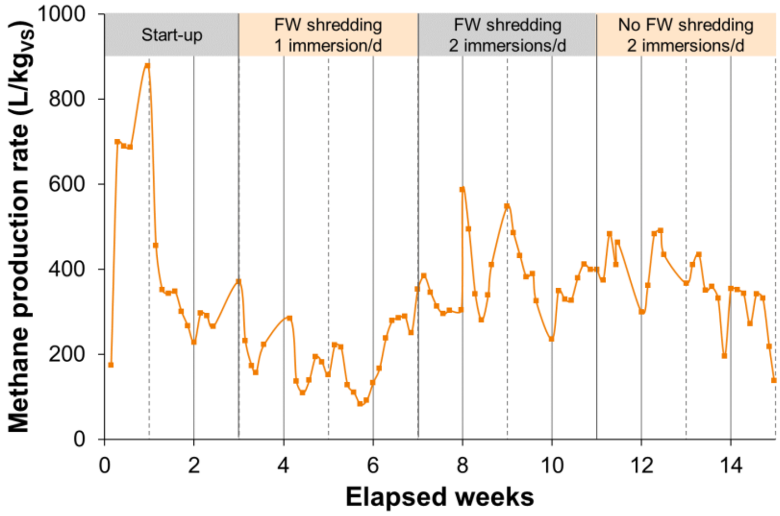

Figure 19: Methane production rate of the prototype in Rennes

4.4.2. Period 2: Immersion twice a day with FW shredding

The second period consisted in increasing the immerging frequency from once a day to twice a day. Compared to the first period, this change in strategy was very benefic for the AD performances. Indeed, the methane production rate doubled with an average value of 370 ± 83 L/kg$_{VS}$, which represents 80% of the maximum theoretical production of methane. In addition, the quality of methane content increased with an average of 54 ± 13 % but was still quite unstable with values between 38 to 70% due to the drop observed after each feeding phase.

Table 7: Synthesis of methane production and methane contents depending on the operating strategy

	Average CH_4 production (L/kg$_{VS}$)	Methane content (%)
Period 1	186 ± 78	42 ± 17
Period 2	370 ± 83	54 ± 13
Period 3	373 ± 106	54 ± 9
All periods	320 ± 121	50 ± 14

4.4.3. Period 3: Immersion twice a day without FW shredding

Finally, during the last period, immerging strategy remained unchanged while FW was no longer shred prior to its loading into capsules. As a results, AD performances were similar to the second period with an average methane production of 373 ± 106 L/kg$_{VS}$. Moreover, the methane content stabilized compared to the two previous periods (average of 54 ± 9% with values between 37 to 66%), which was probably due to a lower content of easily biodegradable organic matter as the FW was not shred.

The absence of shredding with high AD performances is of interest as it allows energy savings and avoid manual handling work, which comply with the preliminary objectives target of this prototype.

4.4.4. Assessment of digestate

In the leachate tank, pH was very high and stable along the experiment with an average of 8.0 ± 0.1 showing that the process did not suffered from inhibition and could easily handle higher organic loading rates. In the tubular reactor, a gradient of pH was observed with values going from 5.2 ± 0.3 when entering in the tubular reactor and 7.6 ± 1.4 when getting out, which shows that hydrolysis and acidogenesis steps were complete in the tubular reactor.

The digestate also showed a total solid content of 156 ± 67 g/kg_{ww} showing that the use of capsule partly separated the solid to the liquid digestate. Compared to industrial plants (about 400 g/kg_{ww} for the digestate used in the start-up phase) the separation efficiency is lower. However, this total solid content is enough to be used in SSF process.

Table 8: FW, leachate and digestate characteristics

Substrate	pH	TS g/kg_{ww}	VS g/kg_{TS}	NH_4 gN/kg_{ww}	TKN gN/kg_{ww}
Leachate	8.0 ± 0.1	31 ± 2	562 ± 41	4.8 ± 0.5	6.2 ± 0.2
Digestate	7.6 ± 1.4	156 ± 67	798 ± 52	4.8 ± 1.7	7.9 ± 1.4
FW	5.2 ± 0.3	236 ± 44	891 ± 33	0.1 ± 0.1	7.2 ± 2.5

4.5. SOLID STATE FERMENTATION PERFORMANCES

The material received was firstly classified by the visual aspect. It was observed that half of the material present a green color and the other half presented a dark color (mostly black) as can be observed in Figure 20.

Figure 20: Visual aspect of the digestate from Rennes (black and green)

A complete characterization of the digestate was performed in order to evaluate the differences with the one used in the previous stages of the project. Table 9 summarizes the parameters in terms of pH, dry matter, and organic material for the digestate as received and before the stabilization process.

Table 9: Characterization of the digestate from Rennes

	Black	Green	Mix
pH	7.01	7.38	7.17
Dry matter (%)	14.15 ± 0.14	13.86 ± 0.12	14.97 ± 0.07
Organic content (%)	80.99 ± 0.80	84.12 ± 0.80	83.57 ± 1.40

It was observed that the digestate contains high quantities of organic material and a low percentage of dry matter. No significant differences were observed between the black and green digestate in terms of pH, dry matter and organic content. So, it was decided to mix all the samples received and the characterization was done. The mix sample will be used for running the tests in order to obtain a homogenous sample.

On the other hand, a biodegradability test from the digestate was done through the dynamic respirometric index (DRI). The results are showed in Figure 21.

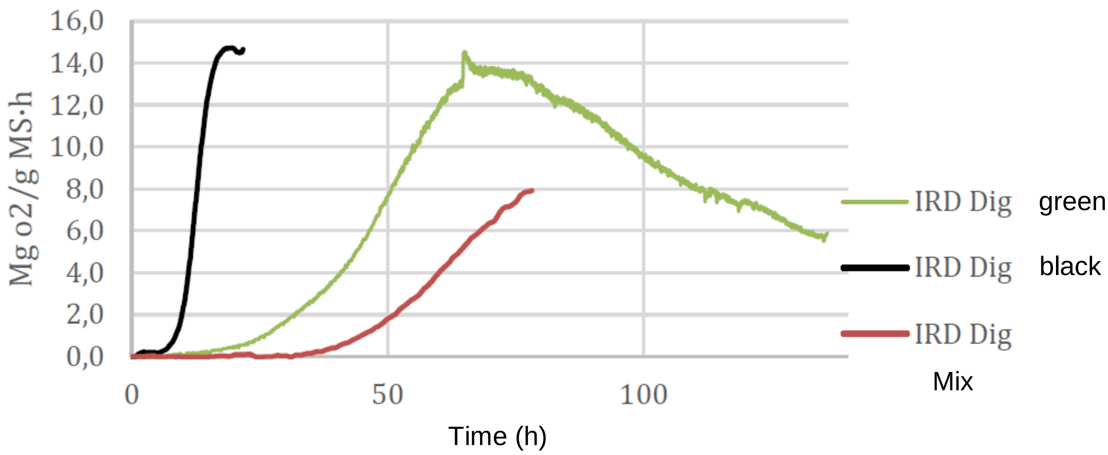

Figure 21: Dynamic respirometric index (DRI) of the digestate from Rennes

High values of DRI were obtained which confirms that the digestate needs high demands of oxygen, so this material is less mature and present less stability. Moreover, as can see in Table 9 the organic content is higher compared to the one from Granollers used in the SSF validation.

A first assay was performed using a 100 L reactor. The results obtained in the first assay showed that there was not Bt growing and oxygen consumption. This fact was mainly attributed to the characteristics of the digestate: high biodegradability (as can be observed in the DRI values) and low pH. Moreover, as can be observed in the DRI test, there is something that limits Bt growing in the green digestate due to the long latency phase. In order to solve this problem, more tests should be done in order to optimize the conditions for the Bt growing. These experiments highlight the differences between the Granollers digestate and the Rennes digestate. After that, it was decided to evaluate the performance inside the reactor.

It was evaluated the performance of the reactor evaluating the gradients in terms of dry matter and pH trying to obtain the most detailed process information that could lead to the problem of no Bt growing. Both parameters were evaluated during the SSF assay inside the reactor. The pH was vertical measured at different levels of the reactor. The results are showed in Table 10.

Table 10: Evolution of pH and dry matter during the test

	Dry matter (%)	pH
Beginning	34.11 ± 0.35	6.23
End bottom	39.22 ± 0.40	6.27
End middle	39.17 ± 0.41	6.28
End top	40.53 ± 4.15	6.28
End mix	42.95 ± 5.06	6.30

As can be observed no significant differences are observed in the different points of the reactor, demonstrating that the SSF is a homogeneous technology. However, the pH inside the reactor is not the optimal for the Bt growing.

In order to be able to evaluate de SSF process in more detail with the material received, it was decided to reduce the scale at which we were working and return to the lab scale. Two different experiments were done: the first one using 1.6 L of digestate and the vegetable organic fraction from Granollers as co-substrate and a second one using only 1.6 L of digestate from Rennes. During these tests no Bt growing were observed.

In the following tables are showed the results of the evolution of the dry matter and pH during the tests.

Table 11: Evolution of the dry matter content during the test

<table>
<tr><th>Dry matter (%)</th><th>SSF 1.6 L digestate</th><th>SSF 1.6 L digestate + co-substrate</th></tr>
<tr><td>Beginning</td><td>38.44 ± 3.1</td><td>34.84 ± 1.3</td></tr>
<tr><td>End bottom</td><td rowspan="4">35.58 ± 3.0</td><td rowspan="4">31.6 ± 9.2</td></tr>
<tr><td>End middle</td></tr>
<tr><td>End top</td></tr>
<tr><td>End mix</td></tr>
</table>

Table 12: Evolution of the pH during the test

pH	SSF 1.6 L digestate	SSF 1.6 L digestate + co-substrate
Beginning	7.38	7.31
End bottom	6.67	6.64
End middle		
End top		
End mix		

More experiments should be carried out in order to validate the digestate and optimize the Bt growing but taking into the amount the material received it was not possible.

4.6. CONCLUSION

The m-AD and SSF prototypes were successfully implemented during the project. However, firsts results showed a need for more investigations and data to optimize their operation.

In the case of m-AD, many initial objectives were completed as the low water addition requirement (no water used during the experiments) or the limiting use of pre- and post- treatments (no need of shredding and integrated phase separation for the digestate) with very good AD performances. To improve further the performances, additional experiments could be carried out to optimize the immerging step. For example, increasing the immerging frequency and optimizing the pausing time could help stabilizing methane content and increase the organic matter degradation rate. In that way, the SRT could be lowered and the organic loading rate increased to produce more energy. In addition, digestate would be of better quality for SSF valorization. Moreover, the energy demand needs to be assessed to prove that durability of this technology and discuss the sizing criteria, but this should be performed on a more finalized version to go further on the TRL scale.

5. Conclusion

In order to assess the concept of decentralizaed biowaste management in urban areas, DECISIVE project had the objective of building two demonstration sites: one in Dolina (Italy) and the other in Lyon (France). In addition, a micro-AD technology especially designed to valorize urban biowaste was developed in Rennes, on which digestate was used to perform SSF tests.

The Dolina demonstration site aimed at valorizing about 100-200t/y of households biowaste with an existing AD technology commercialized by SEaB. In spite of the advantages of already having a biowaste collection and having purchased an existing technology that eased the technical implementation of the demonstration site, permitting steps and timeline associated delayed the demonstration start-up. Therefore, this demonstration site will be operated after the end of the project, which won't allow the opportunity to assess the performances.

On the other hand, the demonstration site of Lyon gave interesting results during the small period of operation that was shortened because of the pandemic situation. Among other issues, the collection step was disturbed by the restaurants closure and lower feeding rates were achieved. As a results, the final biogas production reached about 60% of the initial target but with a lower feeding rate than the initial ambition (feeding rate of 80% i.e. 40 t/y instead of 50t/y). This allowed an energy production that covered the thermal demand to heat the digester and even more. However, the electrical production covered only 30% of the total power demand. To cover the electrical demand of the process, several changes could be done such as increasing the feeding rate to reach the initial objective, optimizing the AD process to increase biogas production, using solar panels to produce more power and using the thermal energy surplus to hygienize the biowaste instead of using power.

In Rennes, the two-stage solid-state technology developed by INRAE could valorize about 0.8 t/y of biowaste of a nearby administrative restaurant with a methane yield of 80% compared to the maximum theoretical potential. These performances were achieved with the objective to use the lowest amount of energy that is to say, without initial shredding nor final phase separation. In addition, SSF experiments were performed on its digestate without showing satisfying results. To go further in the assessment of such technology and increase the TRL, additional energy balance should be done on a more finalized version.

To conclude, the model of micro-AD unit was successfully implemented and showed satisfying performances in terms of energy production versus energy consumption during the small operating time scale. However, additional experiments would be needed to strengthen the first encouraging results of the demonstration site of Lyon and to go further in the technology developed in Rennes.

Contact

Anne Trémier
anne.tremier@inrae.fr
INRAE
17 avenue de Cucillé
CS 64427
35044 Rennes Cedex

DISCLAIMER
The content of this report does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the report lies entirely with the authors.