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# D4.4. BECoop small-scale demonstration activities

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| Dissemination Level | |
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| X | PU - Public |
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# Document history

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# Legal Notice

# About

Over the last years, the EU has witnessed some remarkable steps in Renewable Energy (RE) deployment. However, at the same time, we see an increasingly uneven penetration of RE across the different energy sectors, with the heating and cooling sector lagging behind. Community bioenergy schemes can play a catalytic role in the market uptake of bioenergy heating technologies and can strongly support the increase of renewables penetration in the heating and cooling sector, contributing to the EU target for increasing renewable heat within this next decade. However, compared to other RES, bioenergy has a remarkably slower development pace in the decentralised energy production which is a model that is set to play a crucial role in the future of the energy transition in the EU.

The ambition of the EU-funded BECoop project is **to provide the necessary conditions and technical as well as business support tools for unlocking the underlying market potential of community bioenergy.** The project's goal is to make community bioenergy projects more appealing to potential interested actors and to foster new links and partnerships among the international bioenergy community.

**The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952930.**

# Project partners

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# Abbreviations

| | |
|---|---|
| **a.r.** | As received |
| **CHP** | Combined Heat and Power |
| **d.b.** | Dry basis |
| **DH** | District Heating |
| **DHW** | Domestic Hot Water |
| **DT** | Deformation Temperature |
| **FT** | Flow Temperature |
| **HT** | Hemisphere Temperature |
| **t** | Metric tons |
| **ORC** | Organic Ranking Cycle |
| **PV** | Photovoltaic |
| **RES** | Renewable Energy Source |
| **RESCoop** | Renewable Energy Source Co Operative |
| **SCR** | Selective Catalytic Reduction |
| **SST** | Shrinkage Starting Temperature |

# Executive Summary

The BECoop project seeks to tap into the potential of bioenergy communities. In order to achieve this goal, different actions are being developed along the project. Task 4.4 aims to provide small-scale demonstrational activities in order to illustrate the technical feasibility of the solutions proposed by the BECoop project. This means that the project partners help BECoop RESCoops in developing a demonstration action plan in order to showcase the implementation of their bioenergy heating visions. The task leader CERTH, together with the project's developed bioenergy RESCoops and technical partners (CERTH, CIRCE, WUELS), identified the key activities that are crucial in each BECoop RESCoop's bioenergy vision, based on the outcomes of T4.1 (Co-definition of community bioenergy heating roadmaps), T4.2 (Deployment of the BECoop technical support services), T4.3 (Deployment of the BECoop business and financial support services) and the analysis of their needs/ challenges, and were demonstrated. In brief, Task 4.4 tries to elaborate in a more concrete form on the proposed activities, in order for the project's RESCoops to better understand in practice the transition from planning to implementation stages.

Every BECoop RESCoop performed several small-scale demo activities, tailored on their current needs and state, as a steppingstone prior to their transition to a RESCoop that exploits biomass for the production of community bioenergy. In this task, for each BECoop RESCoop and their corresponding value chain, demonstrations took place regarding different stages and parts of the value chains that are considered critical. Thus, different critical steps in each case were demonstrated such as demonstration of harvesting/collection of biomass type that is of interest for the BECoop RESCoop, solid biofuels analysis, boiler testing with new biofuels produced, etc.).

Task 4.4 has well achieved and exceeded its intended goal of demonstrating parts of community bioenergy concepts and disseminating the bioenergy message to the local people and securing their approval. Based on the DoA, a KPI of one demonstration per pilot area was set. Nonetheless, in total **13 small-scale demonstrations were performed** in all four BECoop RESCoops.

Apart from the demonstrations, a core aim of this task was also to **inform local communities** and **secure their approval** and **support** to the suggested BECoop activities, in order to empower such community bioenergy projects and initiatives. Across all pilot cases and their demonstrations performed, around **540 stakeholders** were involved.

Throughout the following sections, each of the demonstrations will be closely examined along with their results and what lessons were drawn from them. Concluding, the task leader has integrated the outcomes from the activities mentioned in the present deliverable, that will be further used as input for drafting the evaluation report of the activities performed by the BECoop RESCoops in Task 4.5.

# 1 Introduction

Task 4.4 was a crucial phase of the project that aimed to build on the outcomes of T4.1 (cases roadmaps), T4.2 (technical support services) and T4.3 (business and financial support services) and carry out the implementation of the proposed activities for the pilot cases. The subject of this task of the BECoop project was to provide a variety of small-scale demonstrations of parts of the proposed activities of BECoop RESCoops. The BECoop RESCoops, up until now, have benefited from the technical, financial, and business support services provided to expand/ develop their activities in the heating market or to establish biomass-based value chains from scratch. The project has already handed them the foundations required to develop/build their own individual cases, expand them, and strengthen their relationships with local institutions. Now, what was left for the four BECoop RESCoops was to highlight how these potential bioenergy activities and concepts look like in "action".

Each pilot team was responsible for its demonstration activities. In brief, the Spanish pilot team consisted of GOI and CIRCE, the Polish team consisted of OBS and WUELS, the Italian pilot team consisted of FIPER and supported by PolMil[1], and the Greek pilot team consisted of ESEK and CERTH. Each of the pilot cases had its own set of characteristics, with a complex mix of innovative ideas and practices, all aimed at the goal of a more sustainable and less energy-poor future for rural communities:

- In the Spanish initiative, there are two distinct support measures being implemented. Firstly, in Aberasturi, the objective is to utilize local forest biomass, to provide thermal energy via a district heating network that serves most of the buildings in the municipality. The demonstration here was focused on the harvesting of local forest biomass. The other initiative was implemented in Murgia, where certain public buildings already use biomass-fuelled boilers, although the biomass is not locally sourced. The purpose of this initiative was to assess whether the locally produced biomass meets the required standards for the biomass boilers in Murgia.
- The Polish BECoop RESCoop aims to establish a biomass-based logistical chain in which local farmers and forest management stakeholders provide biomass to a local pellet plant. The produced biomass pellets would then be used into the local market towards community heating purposes. The demonstrations here focused on the harvesting of local forest biomass, the production of pellets and their distribution to local citizens and evaluation of their feedback.
- The Italian BECoop RESCoop focuses on the concept of biomass CHP district heating. The technologies targeted in the Italian BECoop RESCoop are already well-established and matured – the Italian pilot region is known for its successful forest biomass district heating systems, already widespread in the area. The aim was to showcase forest biomass harvesting methods and conduct on-site visits to operational biomass CHP district heating plants.
- Finally, the Greek BECoop RESCoop's main activity is the management of a biomass plant for the production of solid biofuels to generate energy for heating purposes and operate as a bioenergy ESCO, installing biomass boilers and selling heat to the end-users. During the demonstrations, the collection of alternative (non-exploited) biomass feedstock was performed (e.g. coffee residues, urban prunings) along with the production of mixed pellets with such raw materials. Finally, such produced pellets were used to fuel a boiler installed at a local municipal building.

The four pilots are different in terms of maturity level as some had already been created before the start of BECoop project while others started "from scratch" during the project, thus the extend of the demonstrations or type of demonstrations was on a case-by-case basis. For instance, the Greek BECoop RESCoop is based on an already-existing energy community that already owns a solid biofuels plant, whereas the Polish BECoop RESCoop is based on the willingness of the OBS commune and local authorities/ people to build from scratch a bioenergy community with nothing at place yet.

[1] PolMil, as FIPER's subcontractor

Notwithstanding, deployment of demonstrations was crucial in the development of the BECoop RESCoops regardless of their level of maturity.

The aim of the current deliverable is to summarize the results of the small-scale demonstration activities that took place in each BECoop RESCoop and for different critical parts of their value chains. This was achieved by providing support to the four pilots of BECoop project in order for them to demonstrate crucial parts of their activities in accordance with the roadmaps created in D4.1 and the technical activities described in D4.2. This task and deliverable also provides input to T4.5 ("Monitoring and evaluation of BECoop market uptake support impact") that shall further include all the lessons learned during the support services of WP4.

In terms of D4.4 structure, posterior to the description of methodology (Chapter 2), the deployment of technical support services is provided for each pilot.

Therefore, **sections 3, 4, 5 and 6 are dedicated to Spanish, Polish, Italian, and Greek pilots** respectively. The same structure is followed in each section with the following subsections:

- The first subsection provides a brief **overview of the pilot BECoop RESCoop** and its bioenergy vision.
- Then, the second subsection provides an **overview of the demonstrations performed** by each BECoop RESCoop.
- Third subsection elaborates on each demonstration performed providing details concerning: i) a **brief description** of the demonstration; ii) the **results** of the demonstration; iii) the **participants** and **type of stakeholders** engaged through the demonstrations and their potential role in the BECoop RESCoop; iv) the **lessons learned** through the demonstrations
- Moreover, additional subsections are added in each country section regarding **additional "lighter" activities** performed that informed and engaged local citizens over the potential bioenergy concepts of the BECoop RESCoop.

Finally, in the Annexes, there is additional information on several demonstration activities performed in each BECoop RESCoop that were not included in the main part of the current deliverable.

# 2 Methodology

The methodology followed in Task 4.4 consisted of several steps. The first step was to carefully review the roadmaps developed in Task 4.1 and use them as a foundation to build upon. In parallel, a lot of focus was put in the activities on-going in Tasks 4.2 and 4.3, where more detailed activities and concepts of the developing BECoop RESCoops were being investigated. CERTH, as leader of this task, built upon the outcomes of T4.1, T4.2, and T4.3 and attempted to elaborate in more concrete terms on the lessons from the previous phases of the project, in order to better understand in practice the transition from planning to implementation. After this, bilateral calls were conducted with each pilot team. During the bilateral calls, CERTH worked closely with each pilot team to develop a demonstration plan for each pilot case. The demonstration plan identified the activities required for each pilot case based on the outcomes of D4.1 and the needs of each pilot. The demonstrations were tailored on the current needs and state of each, as a preliminary step towards transitioning into a RESCoop that extensively utilizes biomass for community bioenergy production. Further to the support activities provided until now, through T4.4, small-scale demonstrations illustrated the economic and technical feasibility of the proposed solutions. The focus was on demonstrating crucial parts of the value chains involved in the exploitation of biomass for each RESCoop. These demonstrations aimed to cover the entire process, starting from the local biomass supply to its end-use. The specific biomass availability, selected technologies, and heating applications relevant to each RESCoop have been taken into account.

In brief, the Spanish pilot team consisted of GOI and CIRCE, the Polish team consisted of OBS and WUELS, the Italian pilot team consisted of FIPER and supported by PolMil[2], and the Greek pilot team consisted of ESEK and CERTH.

For each RESCoop, the demonstrations conducted showcase different critical stages and components of the value chains. These demonstrations addressed specific needs and the level of development of each case in implementing community bioenergy concepts. Examples of these demonstrations included biomass harvesting solutions, testing boilers with newly produced biofuels, fuel analysis of produced biofuels etc.

CERTH conducted several bilateral calls with the pilot teams during the course of the implementation of the demonstrations in the pilot cases. These calls helped to keep the project team and the pilot teams aligned on the objectives of the pilot cases and ensured that the tasks of the pilots were appropriately oriented.

It is worth emphasizing that every BECoop RESCoop is unique in its own way. Each pilot case differs based on their bioenergy vision, capacities, chosen technologies, and level of maturity.

In this light, **the report tries to give a homogeneous presentation of the demonstrations performed in each case**, however it should be noted that in each case, different demonstrations were performed and to a different extent, based on criticalities of each BECoop RESCoop and the local conditions.

[2] PolMil, as FIPER's subcontractor

# 3 Small-scale demonstration activities- Spanish BECoop RESCoop

## 3.1 Overview of the Spanish BECoop RESCoop

In the Spanish initiative, two different accompaniments are being supported. Firstly, in Aberasturi, the goal is to utilize local biomass, including straw and wood chips, to fuel a district heating network that will supply thermal energy to all housed and buildings in the municipality. The process of harvesting herbaceous biomass is well-known, but when it comes to forestry, the primary objective is to maintain the local forests, which are currently neglected. Therefore, biomass extraction operations should prioritize this objective, and it's crucial to assess the associated costs and the quality of the fuel to determine feasibility.

On the other hand, in Murgia, some public buildings are equipped with boilers that are currently fuelled with biomass, although not sourced locally. Additionally, the local high school is training students in forest biomass harvesting methods. The aim of this accompaniment is to verify whether the quality of this local biomass produced by the high school is suitable and appropriate for the biomass boilers used in Murgia and the surrounding area.

## 3.2 Overview of the small-scale demonstrations performed

***Small- Scale Demonstration: Mechanized harvesting demonstration of forest residues and fuel analysis***

| | |
|---|---|
| **Brief Description:** | Demonstration of local forest biomass harvesting. |
| **When:** | From 13/10/2022 to 11/11/2022 |
| **Where:** | Aberasturi, Spain |
| **Why:** | A demonstration was conducted to identify the most effective and sustainable method for obtaining biomass in the region, while also assessing the associated costs and the quality of the fuel. |
| **No of participants:** | 13 |
| **Type of stakeholder:** | Biomass Owners, Authorities, Municipalities, BECoop partners (GOI and CIRCE), Biomass management companies. |

***Small- Scale Demonstration: Combustion test with local biomass and fuel analysis***

| | |
|---|---|
| **Brief Description:** | A combustion test in the biomass boiler of the municipality of Murgia with local forest biomass (woodchips) produced from the local high school was carried out. |

| | |
|---|---|
| **When:** | From 15/02/2023 to 17/02/2023 |
| **Where:** | Murgia, Spain |
| **Why:** | Murgia would like to use local biomass for their facilities (currently they buy non-local biomass) and therefore they want to know if the initiative of the high school to produce local biomass is suitable for their facilities. |
| **No of participants:** | 23 |
| **Type of stakeholders:** | High school of Murgia (students), council of Zuia, technical advisor of Murgia, BECoop partners (GOI and CIRCE), Manufacturer of biomass boiler (Hargassner) |

## 3.3 Mechanized harvesting demonstration of forest residues and fuel analysis

### 3.3.1 Description of the small-scale demonstration

In Aberasturi, the utilization of local biomass serves not only as means of securing a local energy source but also addresses significant challenges that arise from its absence. One crucial aspect for them is finding solutions to the problems arising from the non-utilization of biomass, such as effectively managing straw remnants after grain harvesting and ensuring the proper maintenance of their neglected forests. The current inadequate growth of these forests causes maintenance problems and poses a heightened risk of major consequences in the event of a fire outbreak.

For this reason, Aberasturi, with the support of the BECoop project and the Vitoria City Council, has drawn up a forest management plan to determine the amount of biomass that can be obtained from Aberasturi's woodland, with the aim of improving its sustainability. Table 1 shows the amount of biomass that can be harvested annually from the public forest (493 t/year). This amount would be sufficient to cover the energy demand of the district heating network annually just with local forest biomass.

*Table 1. Amount of biomass that can be collected each year from Aberasturi according to the forestry management plan carried out.*

| Annual volume increase with bark | $m^3$/year | t/year (d.b) |
|---|---|---|
| Queijo (type of oak) | 577.62 | 404.34 |
| Oak | 24.88 | 20.87 |
| Beech | 88.36 | 68.22 |
| **Total** | 690.86 | 493.42 |

However, in addition to knowing that this quantity can be extracted annually, it is necessary to know the operations to be carried out, their cost and the quality of the fuel obtained, for this reason it was decided to carry out a demonstration for harvesting forest biomass.

Given the dense population and challenging accessibility of the Aberasturi Forest, the proposed operations for enhancing forest sustainability will focus on thinning various tree species (normally felling one tree out of every three/four). Considering the circumstances, utilizing heavy machinery for this purpose becomes problematic. Consequently, the most suitable approach to obtain biomass from this area has been determined with manual chainsaw for cutting the trees and a skidder for the extraction of the tree out of the forest to a storage area.

The process begins with the assessment and selection of trees that require thinning for improved forest sustainability. Skilled workers equipped with chainsaws meticulously cut down the identified trees using precise cutting techniques. Each tree is carefully evaluated to ensure safe and controlled felling.

Once a tree is felled, two options were raised in the demonstration. The first method is to leave the tree as it is without doing anything else, and remove it with the skidder, and the second method is for the workers to firstly remove the branches and cut the trunk into manageable sections for being later removed with the skidder.

After these operations, a skidder, which is a specialized vehicle designed for hauling heavy loads, comes into play. The skidder is brought to the felled tree's location, and the workers attach the whole logs (option 1, Figure 1) or cut sections (option 2, Figure 2) to the skidder using chains or other appropriate fastening methods.

The skidder, operated by trained personnel, then pulls or drags the felled trees out of the forest. It navigates through the forest terrain, carefully maneuvering around obstacles and avoiding damage to the remaining trees and vegetation. The skidder transports the extracted trees to a designated storage area, which could be a centralized collection point or a temporary storage site.

Once the felled trees reach the storage area, they can be further processed (in the option 1 the whole tree needs to remove the branches and cut the trunk into manageable sections before being transported) or transported to the desired destination.


*Figure 1. Diagram of value chain operations followed in option 1.*

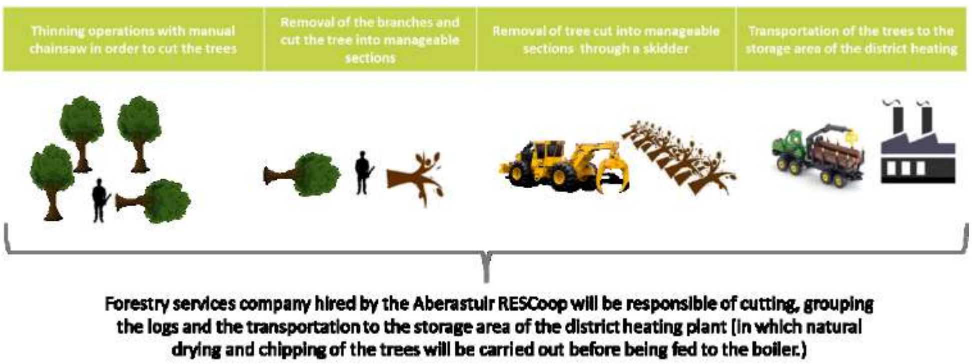


*Figure 2. Diagram of value chain operations followed in option 2.*

Throughout the operation, strict adherence to safety protocols is maintained to ensure the well-being of the workers and the preservation of the forest ecosystem. Proper waste management practices are also followed, promoting sustainability by minimizing environmental impact and maximizing the utilization of harvested biomass, as, in addition to using some of the material for biomass, the remaining forestry waste was shredded to serve as natural fertilizer for the soil.

By combining manual chainsaw tree cutting with the use of a skidder for extraction, the operation enables efficient and controlled thinning of the Aberasturi Forest while overcoming the challenges posed by its dense population and difficult accessibility.

## 3.3.2 Results of the small-scale demonstration

The demonstration was carried out on 4.3 ha of public forest belonging to Aberasturi. As indicated, the operation was carried out in two different ways.

Option 1 was carried out in 2.1 ha and consisted of 2 operators with chainsaws felling and limbing, 2 operators stacking whole trunks and hooking them to the skidder and 1 operator in the storage area unhooking and cutting at 2.5 m. The skidder is managed by 1 operator and pulls whole trees (3-5 m) to the storage area. Finally, the transportation was carried out with a forestry truck managed by one operator. The tariff costs associated with each of these operations are as follows:

- Chainsaw operator: 22 €/day
- Skidder+operator: 65 €/h
- Forestry truck+operator: 84 €/h

This operation was carried in several days, for which the following results regarding the associated cost per operation are presented in Table 2.

*Table 2. Cost associated to each operation in Option 1.*

| Parameters | Chainsaw operations | Skidder operations | Forestry truck operations | Total |
|---|---|---|---|---|
| Total Cost (€) | 6,336 | 5,070 | 1,092 | 12,498 |
| % of cost that imply each operation | 50.7% | 40.6% | 8.7% | 100.0 % |

The biomass obtained in this demonstration was 73.22 metric tons (at 37 % of moisture), so the ratio of productivity and cost per operation of these wet biomass are indicated in Table 3, whose final result indicates that the associated cost of these operations is of 170.7 €/t (at 37 % of moisture).

*Table 3. Ratios of productivity and cost per operation in Option 1.*

| Parameters | Chainsaw operations | Skidder operations | Forestry truck operations | Total |
|---|---|---|---|---|
| Productivity (t/h) | 0.254* | 0.939 | 5.632 | - |
| Cost (€/t) | 86.5 | 69.2 | 14.9 | 170.7 |

*it was considered 8 hours per day for the chainsaw operators.

Option 2 took place in 2.3 ha, in which there was one operator with chainsaws felling trees, two operators removing the branches and cutting into manageable sections (2.1 m), and two operators stacking these trunks and hooking them to the skidder. The skidder is managed by 1 operator and pulls these pieces of trees (2.1 m) to the storage area. Finally, the transportation was carried out with a forestry truck managed by one operator.

The tariff costs are the same that have been indicated above, and the associated costs are reflected in Table 4.

*Table 4. Cost associated to each operation in Option 2.*

| Parameters | Chainsaw operations | Skidder operations | Forestry truck operations | Total |
|---|---|---|---|---|
| Total Cost (€) | 6,160 | 1,305 | 1,092 | 8,557 |
| % of cost that imply each operation | 72.0% | 15.3% | 12.8% | 100% |

If these costs are compared with the previous ones (option 1), they are similar for two of the operations (chainsaw and forestry truck) but much lower cost in option 2 for the skidder operation. This is due to the fact that cutting the trees prior to removing them from the forest improves the yield of this operation.

In the second option, the amount of biomass obtained was 122.98 t (at 37% moisture), which is also considerably higher than that obtained in option 1, which together with the lower cost of skidder operation results in more favorable efficiency and economic ratios. Table 5 presents the productivity indicators along the costs of the operations with a total cost of these operations at 69.6 €/t (at 37% moisture), which is considerably lower than in option 1 (170.7 €/t).

*Table 5. Ratios of productivity and cost per operation in Option 2.*

| Parameters | Chainsaw operations | Skidder operations | Forestry truck operations | Total |
|---|---|---|---|---|
| Productivity (t/h) | 0.439 | 7.686 | 9.460 | - |
| Cost (€/t) | 50.1 | 10.6 | 8.9 | 69.6 |

*it was considered 8 hours per day for the chainsaw operators.

For this reason, option 2 has been selected as the most appropriate harvesting operation for the Aberasturi forest, and therefore the one that will be implemented in the coming years to obtain the forest biomass to feed the municipality's district heating.

Also, the economic results obtained from this option 2 are the ones that have been considered to carry out the feasibility model that has been reflected in the deliverables 4.2 and 4.3 of the BECoop project.

In addition, by carrying out the demonstration, it was possible to obtain the biomass that would be used in the future district heating, and therefore a sample of it was taken to analyse its physical and chemical properties. Thus the fuel characteristics were evaluated, which will be taken into account for the sizing of the heat network and for the selection of the type of boiler to be installed.

Table 6 shows the results of the characterization, and the following conclusions can be drawn from it:

- The moisture content is high if the material is to be used for energy valorization at that moisture content, although this is not the case, since that moisture content is the one contained in the material after extraction from the forest, which will undergo a process of chipping and subsequent natural drying to achieve a boiler input moisture content of between 20-30%.

- The volatile matter content of 74.8% on a dry basis (d.b.) suggests that the fuel has a high combustible component. This indicates that the fuel can readily release energy during combustion.
- The ash content of 2.5% on a dry basis represents the inorganic residue left behind after combustion. This value is suitable for a forest biomass containing bark such as that intended for energy use.
- The fixed carbon content of 22.8% on a dry basis indicates the non-volatile solid residue remaining after volatile matter is driven off. It contributes to the energy output during combustion.
- The ultimate analysis (content of C, H, N, S, Cl and O) provides information about the elemental composition of the fuel. These elements are important because they determine the fuel's calorific value (C and H) and emissions potential (N, S and Cl). The values obtained are adequate for this type of biomass, and its energy valorization, perhaps simply to highlight that the N content is somewhat higher than that of a forest chip, and therefore in the design of the installation it would be necessary to see if a system to minimize NOx emissions is necessary.
- The energy that the fuel contains is indicated through the low heating value, being the value obtained in dry basis suitable for energy valorization, even though on a wet basis the value is lower and for this reason is recommended a natural dry to reduce the content of moisture and therefore increase the low heating value in wet basis.
- Finally, ash melting temperatures provide information about the fuel's behavior during combustion and its potential to form clinker or slag deposits. The SST value is a little bit low, even though the rest of the temperatures are adequate, so sintering phenomena are not expected to occur during the combustion of this material.

*Table 6. Characterization of forest biomass from Aberasturi.*

| Parameter | Unit | Value |
|---|---|---|
| ***Proximate analysis*** | | |
| Moisture | % a.r. | 37.1 |
| Volatile | % d.b. | 74.8 |
| Ash | % d.b. | 2.5 |
| Fixed carbon | % d.b. | 22.8 |
| ***Ultimate analysis*** | | |
| C | % d.b. | 48.10 |
| H | % d.b. | 5.80 |
| N | % d.b. | 0.42 |
| S | % d.b. | 0.02 |
| Cl | % d.b. | 0.01 |
| O | % d.b. | 43.20 |
| ***Heating value*** | | |
| High heating value (HHV) | MJ/kg d.b | 18.6 |
| Low heating value (LHV) | MJ/kg d.b | 17.4 |
| Low heating value (LHV) | MJ/kg a.r. | 10.0 |
| ***Ash melting temperatures*** | | |
| Shrinkage starting (SST) | ºC | 900 |
| Deformation (DT) | ºC | 1,330 |
| Hemispherical temperature (HT) | ºC | 1,430 |
| Fluid temperature (FT) | ºC | 1,450 |

It can therefore be concluded that the demonstration has made it possible to identify which method is most suitable for the harvesting of the biomass (option 2), to confirm very competitive biomass harvesting costs (70 €/t at 37% of moisture), and to verify that the biomass obtained has suitable quality for energy valorization.

## 3.3.3 Participants and type of stakeholders attended

The aim of the demonstration was to assess the economic viability of acquiring biomass from public forests through thinning operations, always considering sustainability criteria. To achieve this objective, all relevant stakeholders were actively involved in the demonstration.

On one hand, the forest owners, represented by the Aberasturi Council, played a crucial role. Not only they are responsible for the forests, but they also will be consumers of the district heating. This dual role allows them to contribute insights on both forest management and the potential benefits of biomass utilization for heating purposes.

On the other hand, the Vitoria City Council was also actively engaged in the demonstration. Two members from the environmental department, who oversaw the forest management plan for these specific forests, participated. Their responsibility was to guide the forest management company, comprised of six people in charge of the thinning operations, by identifying the trees to be removed.

Additionally, the Spanish BECoop pilot partners, CIRCE and GOIENER, were part of the demonstration as coordinators. They played a vital role in gathering the necessary technical and economic data required to assess the feasibility of implementing this initiative successfully.

By involving all these stakeholders, the demonstration aimed to comprehensively evaluate the costs associated with obtaining biomass from public forests through thinning operations, while taking into account sustainability considerations.

*Table 7. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Biomass Owners | 2 | Aberasturi council, since it is a public forest that belong to the inhabitants of the municipality. Also, the inhabitants of Aberasturi will be the consumers of the district heating |
| Authorities/Municipalities | 2 | Vitoria council, they will support the creation of the community |
| BECoop partners | 3 | Provide technical and business support to facilitate the decision-making |
| Biomass management companies | 6 | They will be subcontracted by the RESCoop of Aberasturi to carry out the harvesting of forest biomass in a sustainable way |

## 3.3.4 Lessons learned

The following conclusions can be drawn from the demonstration carried out:

- The specific characteristics of the orography of the Aberasturi forest make the use of heavy machinery in the forest very complex, so very few forest service companies were interested in carrying out the service, as the operation would have to be carried out mostly by human resources.
- The demonstration carried out, with two different harvesting options, has shown that one of them is more feasible than the other, and has therefore established the harvesting model to be followed, since this price can be competitive (around 70 €/t at 37% moisture, cutting, extraction and transportation of the trees).
- The involvement of local authorities is crucial, particularly for public forests, as they are responsible for authorizing the harvesting process. In this case, the authorization aligns with the forest management plan, ensuring a sustainable biomass extraction rate throughout the heat network's useful lifespan. Also, their involvement could help finding public funding for forest management actions that could lower down the considered price of the forestry biomass.
- The quality of the biomass fuel obtained, is appropriated for energy valorization, as it has a suitable energy and composition, although a natural drying process is recommended to lower its moisture and thus make better use of the fuel's energy during the combustion process.
- Some concerns arose during the harvesting among some citizens when they saw that trees were being cut and the procedure for a sustainable forest management was explained during the following meeting.
- For shredding operations, to rent the machinery was considered as the best option, since the amount needed for the district heating is not big enough to make a return on investment. In fact, the operation would be to collect all the material in the storage area and to subcontract the chipping service to do it jointly and thus optimizing the costs of this operation.

## 3.4 Combustion test with the local biomass and fuel analysis

### 3.4.1 Description of the small-scale demonstration

In Murgia, there is a situation where certain public buildings rely on biomass-fueled boilers (Table 8), but the biomass used is not sourced locally. However, there has been an interesting development in the local high school, where students are being trained in forest biomass harvesting methods.

*Table 8. Public buildings that consume biomass in the surrounding area of Murgia.*

| Building | Type of Biomass | Amount consumed (t/year) |
|---|---|---|
| CITY COUNCIL MURGIA | Woodchip | 17 |
| BEA MURGIA + OREGI | Pellet | 18 |
| SPORT CENTER ZUIA* | Woodchip | 150 |

*Currently under construction but planned to have biomass boiler fed with woodchips.

This initiative aims to explore the potential of utilizing locally sourced biomass as a renewable energy source for heating purposes. By training students in biomass harvesting methods through the high school, the project seeks to evaluate the quality of biomass produced by them and determine if it meets the necessary standards for efficient and sustainable operation in the current biomass boilers of Murgia.

If the locally produced biomass proves to be of sufficient quality, it would have several benefits for the community and the environment. Firstly, it would reduce reliance on external biomass sources, thereby promoting local economic and employment development and self-sufficiency. Additionally, using locally sourced biomass can minimize transportation costs and carbon emissions associated with long-distance biomass transportation.

Furthermore, by involving the high school in this process, the initiative provides valuable educational and practical opportunities for students. They gain firsthand experience in sustainable forest management and biomass production, preparing them for potential future careers in the renewable energy sector.

As a result, this project in Murgia highlights the potential for utilizing local biomass resources to meet energy needs sustainably. It not only aims to ensure the compatibility of locally produced biomass with existing biomass boilers but also promotes community engagement, economic development, and environmental sustainability.

For this reason, the demonstration in Murgia was focused on:

- The assessment of the quality of the biomass obtained which was carried out by CIRCE.
- A combustion test in a biomass installation, specifically in the boiler located at the city council. This was supported by some of the students of the institute as well as the staff of the municipality, the boiler manufacturer, and the project partners.

The test was planned for February at a period of high thermal energy demand, to see how the installation responded to this new fuel. First, with the silo empty (left image of Figure 3), it was filled with the new material manually (center and right images of Figure 3), in order to involve the students of the institute who had collected the biomass.

*Figure 3. Images of the silo loading with the new fuel. Silo empty (left), people from the institute helping by weighing and helping to put the material into the silo (centre), staircase where the material was fed through (right).*

At the same time as the material was being loaded into the silo, the boiler (which had been shut down a few hours earlier) was cleaned by the technician of the boiler so that it would be clean. Therefore the ashes generated and the deposits that could accumulate with the new fuel at the end of the test could be observed.

After these two actions, the test started, and the results obtained are detailed in the following section.

## 3.4.2 Results of the small-scale demonstration

One of the first doubts that arose was whether the quality of the woodchip produced by the high school would be suitable for the biomass boiler located in the city council of Murgia, as the city council had problems on certain occasions with the woodchip used.

For this reason, the biomass produced by the institute was analysed and the results can be seen in Table 9 and Figure 4.

*Table 9. Characterization of forest biomass from the high school of Murgia.*

| Parameter | Unit | Value |
|---|---|---|
| ***Proximate analysis*** | | |
| Moisture | % a.r. | 18.3 |
| Volatile | % d.b. | 77.0 |
| Ash | % d.b. | 2.3 |
| Fixed carbon | % d.b. | 20.7 |
| ***Ultimate analysis*** | | |
| C | % d.b. | 51.30 |
| H | % d.b. | 5.60 |
| N | % d.b. | 0.47 |
| S | % d.b. | 0.01 |
| Cl | % d.b. | 0.01 |
| O | % d.b. | 40.40 |
| ***Heating value*** | | |
| High heating value (HHV) | MJ/kg d.b | 19.5 |
| Low heating value (LHV) | MJ/kg d.b | 18.2 |
| Low heating value (LHV) | MJ/kg a.r. | 14.4 |
| ***Ash melting temperatures*** | | |
| Shrinkage starting (SST) | ºC | <950 |
| Deformation (DT) | ºC | 1230 |
| Hemispherical temperature (HT) | ºC | >1500 |
| Fluid temperature (FT) | ºC | >1500 |
| ***Physical analysis*** | | |
| Bulk density | $kg/m^3$ d.b. | 220.4 |
| Bulk density | $kg/m^3$ a.r. | 269.8 |
| Accumulated size distribution | < 315 mm | 1.29 |
| | < 8 mm | 31.11 |
| | < 16 mm | 97.52 |
| | < 315 mm | 99.96 |
| | < 45 mm | 99.98 |
| | < 63 mm | 100.00 |
| | < 100 mm | 100.00 |

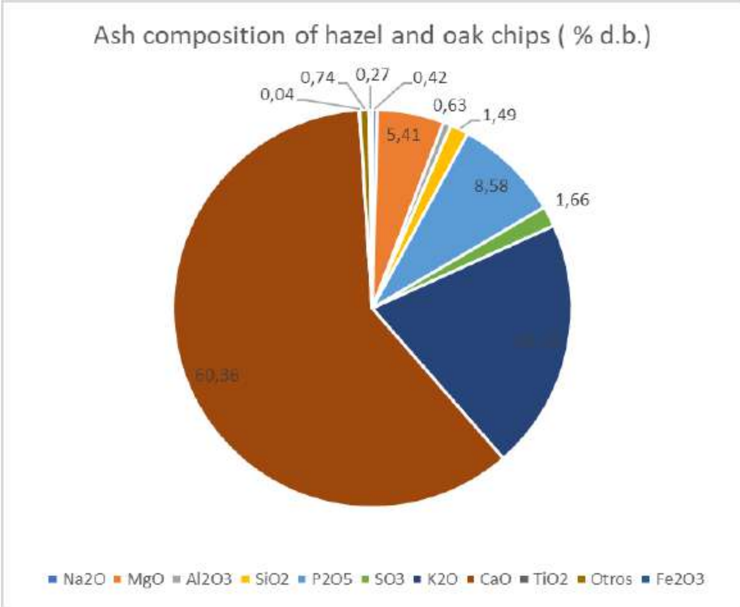


*Figure 4. Ash composition of forest biomass from the high school of Murgia.*

From this analysis, the following conclusions can be drawn:

- The moisture content is quite good, and even lower than the expected moisture content of a forest chip, which is usually in the range of 25-35%.
- The bulk density value obtained is quite adequate to ensure good handling of the material, which is also linked to the homogeneity of the sample and the small particle size (being the majority between 3.15 and 16 mm).
- The amount of fines (< 3.15 mm) is minimal (1.29%) as well as the amount of large particle size material, which is good in order to optimize the combustion process and to avoid problems with the feeding systems.
- The analyzed biomass has a low ash content and is suitable for good combustion, although the value obtained is slightly higher than a quality forest wood chip, which usually has a content of around 1% d.b.. Therefore, according to the ISO-17225-4 standard and the BIOMASUD certification, this wood chip would fulfill a B1 quality standard.
- The C and H content of the analysed biomass is good and very similar to that of a reference forest woodchip, which explains why the calorific value of the biomass under study is also very adequate.
- The N, Cl and S content is very low, in fact it fulfills the maximum quality of the BIOMASUD standard for woodchips (A1).
- The low energy value is very good both on a dry basis and at the moisture at which it is found.
- It possesses a slightly lower melting temperature compared to a good quality forest woodchip, which typically have temperatures exceeding 1500 ºC. However, its melting point remains within a range that is considered suitable for preventing or minimizing sintering in the boiler.
- Finally, regarding the ash composition, the major component is CaO, followed by $K_2O$, $P_2O_5$ and MgO. As for the rest of the components, they appear as a minority. This composition, in which CaO is the major component followed by $K_2O$ and $P_2O_5$ compounds, is the usual one in forest wood chip biomasses and it is expected that its behavior in a combustion system, if it is worked properly, should not present any problems.

As a result of this analysis, the behaviour in conventional combustion systems can be expected to be adequate and similar to that of any other good quality forest woodchips, even though to validate this, a real test has been carried out in the biomass boiler located in the city council of Murgia.

The methodology followed to carried out the test, was indicated in the previous section but as a summary: the silo was empty, filled with the new biomass (502 kg), and the biomass boiler was cleaned to observe the deposits of ash. Once all these operations were carried out, the boiler was switched on and the test started, and at the same time the technical manufacturer of the biomass boiler gives a brief explanation of the operation of the boiler to the attendees.

During the whole time, the current boiler temperature, the target temperature, the temperature of the buffer tank, the output gas temperature and the actual power output of the boiler were monitored.

The 500 kg fed served to feed the boiler for about 3 days, consuming about 165 kg per day, similar to that consumed by the other woodchip usually used. Also during all these test days:

- The boiler reached its temperatures without difficulty, and modulated its power output without any problem.
- The inertia temperatures are maintained and the equipment reacts quickly to sudden consumption.
- The flue gases maintain temperatures within logical operating values.

After checking the correct operation of the equipment, it was proceeded to assess the dirt accumulated in the boiler during this test.

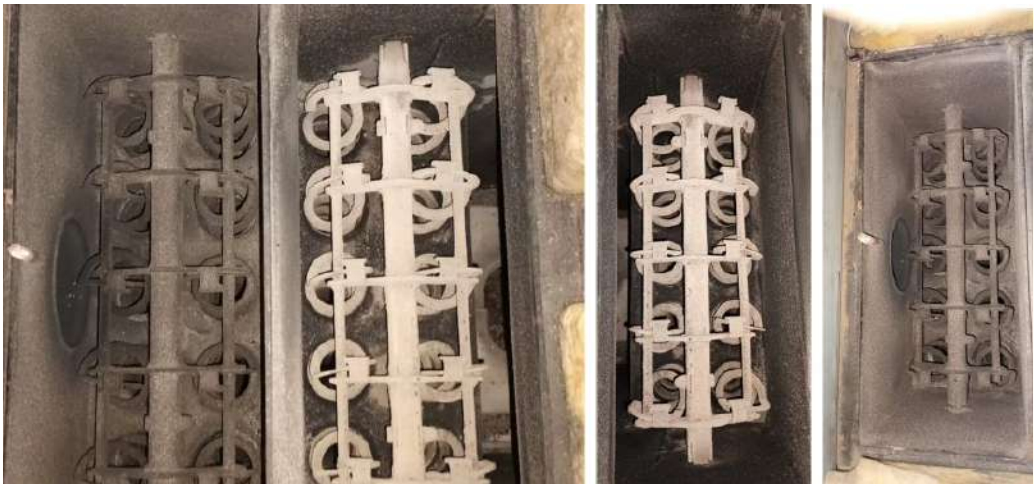

*Figure 5. Images of the heat exchanger of the biomass boiler after the test.*

The Figure 5 shows the accumulated dirt in the first and second flue gas passages of the heat exchanger, the images are quite normal, so there is no noticeable wear and tear, nor any soot accumulation.

*Figure 6. Images of combustion chamber walls (left) and the lower part of the combustion chamber where the burner is located (right).*

The walls of the combustion chamber seem to have quite a lot of ash, but it is not encrusted, it is not pitch but soot (left image of Figure 6), as far as the lower part of the combustion chamber is concerned (right image of Figure 6), there is quite a lot of soot accumulated for the short period of time of the test, it is nothing dramatic and it is not an impediment to the combustion of the engine, it simply requires a periodic preventive cleaning of the equipment.

These accumulated fines in the combustion chamber are probably derived from the use of branches in the fuel processing, which causes them to burn very quickly and come out in the form of volatiles.

As a conclusion, the test was very good and confirms that this fuel can be used in these installations; it is true that it would be interesting to carry out tests of longer duration to check the accumulation of soot, but the operation of the equipment is correct, and no problems of any kind can be detected.

## 3.4.3 Participants and type of stakeholders attended

The process involved the active participation of an institute responsible for the collection and production of the biomass, as well as the city council for the valorisation.

In this context, the institute responsible for the biomass collection and processing played a crucial role. They could work closely with the local council, represented by Murgia/Zuia. This dual role allowed the Institute to provide valuable insights into biomass management training and for the potential benefits of local biomass utilization for heating purposes.

*Figure 7. The students during an educational activity, being explained the BECoop opportunities*

Participation of students in the demo was especially significant because it gave a very practical opportunity for explaining the possibilities that an energy cooperative could have for supplying local biomass to public buildings. Different aspects of the BECoop project were explained and students welcomed them with high interest as it could promote local development and jobs for the region, related with their studies.

The demonstration also included the participation of the institute's coordinating partners, such as the Spanish BECoop pilot partners. These partners, represented by organizations like CIRCE and GOIENER, played a crucial role in facilitating the technical and economic aspects of the demonstration. They gathered necessary data related to the feasibility of implementing this biomass collection and valorisation initiative successfully. Also, a technician of the manufacturer biomass boiler provided the go-ahead to use this type of material in its boilers.

*Table 10. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| High school of Murgia (students) | 18 | Supply of the biomass |
| Council of Zuia | 1 | Consumer of the local biomass |
| BECoop partners (GOI and CIRCE) | 3 | Provide technical and business support to facilitate the decision-making |
| Manufacturer of biomass boiler (Hargassner) | 1 | Validate the new biomass fuel to be used in the installation |

## 3.4.4 Lessons learned

The following conclusions can be drawn from the demonstration carried out:

- The installation has been found to be highly compatible with the fuel derived from the biomass collected and processed by the institute. Through rigorous testing and evaluation, no significant problems or issues have been detected that could hinder the effective utilization of the biomass fuel in this specific installation. The fuel quality meets the necessary standards and requirements, ensuring optimal performance and efficiency.
- Some adjustments might be required in the feeding system of the silo, as the actual system requires a truck with a pneumatic system for unloading.
- The local authorities have shown great interest in promoting and utilizing local biomass resources. Recognizing the environmental and economic benefits of biomass utilization, they have actively supported and encouraged the use of locally sourced biomass as a renewable energy source. This interest reflects the council's commitment to sustainability and their desire to reduce carbon emissions by shifting towards cleaner and greener energy alternatives.
- While the institute may not have the capacity to supply biomass to all the boilers in the area, they play a vital role in promoting knowledge and expertise in biomass operations. Recognizing the importance of proper handling and utilization of biomass fuel, the institute offers training programs to students in biomass operations.

# 4 Small-scale demonstration activities- Polish BECoop RESCoop

## 4.1 Overview of the Polish BECoop RESCoop

In practice, the Polish BECoop RESCoop bioenergy vision is to set up a biomass-based logistic chain where local farmers and institutions dealing with forest management could sell biomass to a local pellet production plant, from which, in turn, the residents of the commune (or other companies and institutions) would buy the produced fuel (biomass pellets) for heating their households, businesses or other facilities public utility. Within this case, the following critical elements have been defined: biomass harvesting, biomass transportation to the processing plant, biomass delivery to the final users, biomass storage issues (fuel properties, storage conditions etc.), selection of the biomass boilers for heat production.

Although the main considered form of biomass fuel in OBS Pilot Area is pellet, it should be underlined, that other forms of fuel (briquettes and/or wood logs) are also possible. This is related to the fact that in the OBS area there are the two kinds of domestic boilers popular: fully automated biomass/coal boilers (designed for pellets or pea coal) and biomass/coal batch boilers (designed for briquettes, wood logs or nut coal). Moreover, the effort is focused to convince local residents to use biomass instead of any kind of coal for energy purposes that is currently the most dominant source of heat in OBS commune leading to the significant environmental pollution in the region.

Taking into account those facts within the OBS region, numerous demonstrations have been organized to pass the knowledge to the local stakeholders and to indicate the crucial issues influencing the selected parts of the logistics chain. Finally, the different demonstrations are aimed to prove the reliability of the concept (the wider usage of biomass for heating).

## 4.2 Overview of the small-scale demonstrations performed

***Small-Scale Demonstration: Mechanized forest biomass harvesting***


| | |
|---|---|
| **Brief Description:** | The complete mechanized forest biomass harvesting in the OBS Commune has been organized. The whole logistic chain including the tree cutting, branch removing, cutting to the required length, wood forwarding, cleaning the field using chainsaw have been demonstrated. Finally, further activities related to the sustainable forest management that will be applied in the coming 2-3 years have been described. |
| **When:** | 30 May 2023 |
| **Where:** | Bagno, Cieplice Forestry, Oborniki Śląskie Commune, Poland |
| **Why:** | Local biomass harvesting is important in terms of its utilisation for energy purposes. However, it is crucial to indicate and show the local stakeholders that sustainable wood acquisition from forests is required and it does not lead to the deforestation of the region. |
| **No of participants:** | 20 |
| **Type of stakeholders:** | Biomass processing company, farmers, energy advisers, agricultural cooperatives, mayor of OBS commune, end-users, municipal authorities, mayor of Piekary cottage, woodsmen |

***Small-Scale Demonstration: Sustainable forest management***



| | |
|---|---|
| **Brief Description:** | During the demonstration the procedures related to the sustainable forest management have been shown and discussed. |
| **When:** | 30 May 2023 |
| **Where:** | Jary, Oborniki Śląskie Commune, Poland |
| **Why:** | The knowledge about sustainable forest management is important for local society to indicate that the forest biomass utilisation for heating purposes does not cause deforestation process in the commune. The demonstration and workshop performed by the forest expert aimed to explain the necessity of biomass harvesting to maintain the proper structure and trees density in the forest. Users of forest biomass should be convinced and confident that the use of local biomass for energy purposes does not have a negative impact on the local environment, especially when it is to a large extent to replace fossil fuel (coal). |
| **No of participants:** | 18 |
| **Type of stakeholders :** | Biomass processing company, farmers, energy advisers, agricultural cooperatives, mayor of OBS commune, end-users, municipal authorities, mayor of Piekary cottage, woodsmen. |

***Small-Scale Demonstration: Biomass pellets production***

| | |
|---|---|
| **Brief Description:** | The demonstrations of the pellets production from biomass have been organized for different stakeholders as this form of compacted biofuel is dedicated to replace coal in the heating systems of the OBS commune. |
| **When:** | May-June 2023 (some activities will also be done in July-August 2023) |
| **Where:** | Strzeszów, Wroclaw, Paniowice, Uraz, Pęgów - Poland |
| **Why:** | Biomass processing into pellets is very important as the proposed short logistic chain in OBS Commune relies mainly on the pellets production and its utilisation for heating in the domestic boilers by final users. It is important to demonstrate that pellets can be produced in the large scale as well as in the small scale. Furthermore, during the demonstrations and tests the issues of materials preparation (particle size, moisture content), pellets properties (bulk density, size, lower heating value), safety issues (ignition), and local biomass potential (from forest and agriculture) were discussed. Finally, the demonstration was important in order to convince local society (final users) to use biomass for heating purposes instead of coal. |
| **No of participants:** | In total: 52 |
| **Type of stakeholders :** | Biomass processing company, farmers, students, end-users, municipal authorities. |

***Small-Scale Demonstration: Biomass pellets distribution to households***


| | |
|---|---|
| **Brief Description:** | Biomass pellets were distributed among local end-users (inhabitants of the Oborniki Śląskie commune), who until now used automatic boilers to heat their households, and hard coal was the input fuel. After the tests a satisfaction survey have been fulfilled by those users. |
| **When:** | 25 October 2022 – 25 November 2022 |
| **Where:** | Oborniki Śląskie Commune, Poland |
| **Why:** | In the Oborniki Śląskie Commune (as well as in whole Poland) more than 50% of households are heated directly by coal. To encourage those coal users for a change to more environmental-friendly fuel (biomass) the distribution of pellets have been organized. As a result, the opportunity to test the pellets in the usually coal fired boiler has been created. The aim was to convince the users that this change is feasible without any sophisticated changes. The added value is the much lower pollution of the environment and the possibility to use ash from biomass as fertilizer in their own garden. |
| **No of participants:** | 49 |
| **Type of stakeholders:** | End-users, farmers. |

# 4.3 Mechanized forest biomass harvesting

## 4.3.1 Description of the small-scale demonstration

In the forest close to the Bagno cottage (Oborniki Śląskie commune) the mechanized biomass harvesting has been organized (30 May 2023). During the demonstration the required machineries (biomass harvester and biomass forwarder) have been used. The aim was to present the stakeholders the operation steps of the biomass harvesting process together with the safety rules.

*Figure 8. Forestry activities*

As a result, the stakeholders were more familiar with this activity and the capacity and efficiency of this process. During the demonstration, the woodsman described also further steps related to the forest management (preparation of the field for new trees planting).

## 4.3.2 Results of the small-scale demonstration

The stakeholder could get new knowledge, how the biomass is harvested in the forest. They have been informed that there are three basic sources of forest woody biomass: logging residues from final fellings, small-sized wood (from early thinnings) and stump wood. Actually, in terms of pellets production, the most popular are logging residues from final fellings in pine stands. The biomass harvesting expert informed that there are following main technologies used for energy wood harvesting: wood logs (with the length 2.4 m), wood chip production (on the forest site or at roadside), and the bundling of tree branches and tops. The applied technology decides about the form in which the energy wood is delivered to the biomass processing company or to the final user. It was underlined that the most commonly used technology for energy plants is wood chips production that is performed with a large capacity chipper. The feeding of the material to the chipper is done with a crane with a grapple. The transport of chips is independent of the chipping operation and the container system is applied. Mechanized technologies of wood chip production are characterized by high productivity (50-400 $m^3$ per hour). However, large wood concentrations on the chipping site is required to maintain the efficiency of the operation. Taking into account the pellets production, the energy wood transported to the processing company is very often in the form of logs to insure clean material and its high quality.

### 4.3.3 Participants and type of stakeholders attended

In the demonstration of the mechanized biomass harvesting in the forest located in the Oborniki Śląskie commune there were 20 participants. Their role in the BECoop RESCoop is presented in Table 11.

*Table 11. Stakeholders that attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| SME | 3 | Biomass processing |
| Waste Management Company | 1 | Biomass collection and processing |
| Woodsman | 1 | Supply of biomass |
| Scientist | 2 | Technical support |
| Mayor of OBS commune | 1 | Initiator |
| Mayor of the cottage | 2 | Final user / Supporter |
| Farmer | 5 | Final user/ Supply of biomass |
| Citizens | 5 | Final user |

### 4.3.4 Lessons learned

The practical demonstration of the mechanized biomass harvesting seems to be very valuable as it enabled better understanding of this process that in fact influences the whole logistic chain for biomass dedicated for energy purposes. The presence of the forest expert during the demonstration was crucial to get adequate knowledge and the certainty that forest biomass can be successfully used for energy production without causing deforestation and loss of biodiversity.

## 4.4 Sustainable forest management

### 4.4.1 Description of the small-scale demonstration

During the last years, there was a very intensive discussion about the utilization of biomass for energy purposes. There are many opinions about a negative impact of biomass harvesting for energy, including the deforestation process/risk. Even more, in this regard, discussions are also conducted at the European level on the introduction of restrictions or bans on the use of biomass for energy purposes. The resulting discrepancies and controversies make it necessary to increase awareness among the local community and reliable knowledge (provided by the experts) about the reasons or the need to conduct proper forest management, including tree cutting and biomass harvesting to cover some energy demands.

Taking this into account, the knowledge about sustainable forest management is important for local society to indicate that the forest biomass utilization for heating purposes does not cause deforestation process in the commune. The demonstration and workshop was performed (30 May 2023) by the forest experts aimed to explain the necessity of biomass harvesting to maintain the proper structure, type and trees density in the forest. Users of forest biomass should be convinced and confident that the use of local biomass for energy purposes does not have a negative impact on the local environment, especially when it is to replace fossil fuel (coal).

*Figure 9. Forest management activities, aimed towards sustainability*

## 4.4.2 Results of the small-scale demonstration

The performed demonstration allowed to understand the basics of forest management procedures causing biomass harvesting from forests. The most important facts are, as follow:

- selected trees must be cut down to provide others with more space and further development,
- some areas are completely cut down due to the need to change the species of trees growing in a given region,
- trees cut down due to diseases, felled as a result of strong winds or snow storms are used for energy purposes as they very often do not meet requirements for other applications,
- wood raw material is used for energy purposes, which, due to its qualitative, dimensional and physical-chemical characteristics, has a reduced technical and utility value that prevents its industrial use,
- sustainable forest management does not lead to deforestation of the region, moreover, short logistic chain related to local biomass harvesting increases significantly the energy effectiveness of the system and improves the energy balance of this process.

## 4.4.3 Participants and type of stakeholders attended

In this demonstration 18 participants were engaged. The stakeholders were from different parts of the logistic chain proposed by Oborniki Śląskie commune (Table 12).

*Table 12. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| SME | 2 | Biomass processing |
| Waste Management Company | 1 | Biomass collection and processing |
| Woodsman | 1 | Supply of biomass |
| Scientist | 2 | Technical support |
| Mayor of OBS commune | 1 | Initiator |
| Mayor of the cottage | 2 | Final user / Supporter |
| Farmer | 4 | Final user/ supply of biomass |
| Resident | 5 | Final user |

## 4.4.4 Lessons learned

It was very important to convey information (pass the message) that the use of local forest biomass does not lead to deforestation of the area in any way, and it is even recommended to ensure proper development and growth of the forest in the commune. Of course, provided that it is an action consistent with sustainable forest management aimed at maintaining appropriate welfare. The involvement of experts (in this case, foresters) in the field of forest management and forest care is a good idea to maintain credibility and provide reliable information on obtaining biomass from local resources. Especially when opinions in the mass media are often inconsistent with reality and rules of conduct. Support from specialists is very helpful in the implementation of the BECoop project assumptions and it is also important in the context of creating energy cooperatives based on natural resources.

## 4.5 Biomass pellets production

### 4.5.1 Description of the small-scale demonstration

Within the BECoop project and Polish Pilot case in Oborniki Śląskie the most promising and feasible logistic chain is based on biomass utilization in the compacted form of pellet. This is due to the frequent replacement of old manually fed coal-fired boilers with automatic pellet-fired boilers and the possibility of a simple replacement of coal fuel (eco-pea coal) with biomass pellets in automatic coal-fired boilers. Considering that local biomass of forest and/or agricultural origin should be used for the production of pellets, it is reasonable not only to disseminate knowledge about pellets and their properties, but also to show the production process and equipment included in it, including pellet machines. The more familiar the local community or users are with these issues, the more they will get used with such an energy source and increase their willingness to use it, especially instead of coal. An important advantage in the case of pellets, which coal does not have, is the fact that biomass pellets can be produced both on an industrial scale and on a local scale. Therefore, practical demonstrations were organized to present the production of pellets, as well as the device itself. In addition, it was also possible to independently test the pellet machine, or to test the production of pellets from selected types of biomass. Demonstration activities were carried out in various locations (Strzeszów, Paniowice, Pęgów) to reach a wide group of stakeholders.


Drive type: Electric
Capacity: up to 100 kg/h
Motor power: 4 kW
Voltage: 400 V (3-phase power supply)
Engine speed: 1500 rpm
Die rotation speed: 250 rpm
The diameter of the holes in the die: 6 mm
Die thickness: 32 mm
Die diameter: 150 mm
Number of rollers: 2 pcs.
Number of knives: 1 pc.
Length: 900 mm
Width: 500 mm
Height: 1100 mm
Weight: 180 kg

*Figure 10. Technical data of the pelletizing machine*

### 4.5.2 Results of the small-scale demonstration

The small-scale demonstrations of the pelletizing machine and pellets production that have been performed in different places contributed to following results:

- the stakeholders could observe the operation of the pelletizing machine,

- the stakeholders got more familiar with the issues related to the pellets production procedures,
- selected stakeholders could test the production of pellets in the small scale,
- during the demonstrations and tests the issues of materials preparation (particle size, moisture content) have been discussed,
- the pellets properties (bulk density, size, lower heating value) have been described,
- the stakeholders have been informed about some safety issues (ignition, injury),
- the potential of pellets to replace coal in the heat generation has been described.

## 4.5.3 Participants and type of stakeholders attended

This demonstration was engaged by 48 local residents (end-users, farmers). The number and type of stakeholders attended the demonstration and their potential role in the BECoop RESCoop is presented in Table 14

*Table 13. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| SMEs | 8 | Biomass processing |
| Residents | 18 | Final user |
| Students/activists | 10 | Community actors |
| Farmers | 7 | Biomass supply/biomass processing/final user |
| Local government | 5 | Initiator |
| Technical expert | 4 | Energy Advisor |

## 4.5.4 Lessons learned

From the demonstrations related to pellets production and pelletizing machine presentation, the following lessons learned can be listed:

- stakeholders prefer a direct contact with technical specialist combined with the possibility to see solutions or machineries in reality,
- the stakeholders were very pleased with the opportunity to test the operation of the pellet press themselves,
- the willingness to use a new solution (e.g. using pellets instead of coal for heating purposes) is the greater the more often basic information related to this is provided to the stakeholder in an accessible way,
- stakeholders, especially from rural areas, need time to get used to solutions that are new to them,
- knowledge and "live" presentations have a much better and faster impact on the stakeholder, including the understanding of the issue and the involvement of the listener.

# 4.6 Biomass pellets distribution to households

## 4.6.1 Description of the small-scale demonstration

In the Oborniki Śląskie Commune (as well as in whole Poland) more than 50% of households are heated directly by coal. The aim was to convince the users that this change is feasible without any sophisticated changes in their boiler as well as in the heating system. To encourage those coal users for a change to more environmental-friendly fuel (biomass), the distribution of pellets was organized. In the period of 25 October 2022 – 25 November 2022, the biomass pellets were distributed among local end-users (residents of the Oborniki Śląskie commune). The action was dedicated to the residents who use the automatic boilers fired by coal (peat coal) for household heating. Each resident was provided with four bags (free of charge) of high quality pellets (ca. 60 kg). As a result, the opportunity to test the pellets in the usual coal fired boiler has been created. The final users could observe the operation of the boiler with a new fuel (biomass pellets). Moreover, there was a possibility to observe if any additional activity was required, caused by the fuel change. This demonstration was very important for the Polish BECoop as the final users could test the pellets by them-selves, in their own boiler.

So, their experience can influence directly on their potential decision related to the resignation from coal in favour of pellets. Moreover, it can be a major reason to join the bioenergy cooperative focused on the use of biomass for heating purposes. The final users have been informed also about other added values, such as the much lower pollution of the environment and the possibility to use ash from biomass as fertilizer in their own gardens. To obtain some valuable feedback after the tests, the residents have been asked to fulfil the elaborated satisfaction survey.

## 4.6.2 Results of the small-scale demonstration

The users were very satisfied with the tests carried out. In fact, there were no negative opinions from the tests carried out. No one observed the influence of changing the fuel (from coal to pellets) on the temperatures necessary to heat their households (the test was carried out in the autumn and winter heating period). No operational problems of the boilers were found/ stated.

Some users (during additional conversations after the tests) pointed out several issues, the most important of which are:

- The boiler tank should be refilled a little more often
- Significantly less ash remains after burning pellets
- The smell of pellets is not bothersome and even more pleasant than coal
- Works related to filling the tank are less dirty
- Unlike coal, pellets certainly require absolute storage in a dry room to retain their properties
- No clear black smoke from the chimney
- It is necessary to provide a technical room and its appropriate size for storing pellets during the heating period
- Despite good experience with pellets, the relatively higher price may be a barrier
- Some users were not aware of the possibility of replacing coal with another alternative fuel (e.g. biomass pellets) that can be burned in their boiler

The citizens/ end-users emphasized that these are not critical remarks, but issues that need to be taken into account in such a fuel change.

The final users pointed out that in the case of a favourable price of pellets and its good quality, they would be able to change coal to pellets from biomass, and implementing it through an energy cooperative seems to be a good and attractive solution.

### 4.6.3 Participants and type of stakeholders attended

This demonstration was engaged by 49 local residents (end-users, farmers). The number and type of stakeholders attended the demonstration and their potential role in the BECoop RESCoop is presented in Table 14.

*Table 14. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Citizens | 40 | Final user |
| Farmer | 9 | Final user/biomass provider |

### 4.6.4 Lessons learned

The demonstration carried out should be considered very successful and necessary, as it allowed for independent testing of pellets as an alternative fuel for coal, and for collecting personal experience with the use of one's own heating boiler. This seems crucial in the context of attracting potential supporters of the strategy implemented by the commune of Oborniki Śląskie as part of the BECoop project. Such activities should be repeated and promoted among the local community, especially in rural areas. In order to achieve success, it is necessary to ensure an attractive price of pellets/fuel (or other form of biomass) in relation to coal, because economic aspects play the most important role in the current situation in Poland. Other positive features of biomass pellets (less ash, local energy source, renewable fuel, less pollution, local development, etc.) should also be emphasized in order to increase the likelihood of convincing the end user to make a fuel change.

## 4.7 Additional activities performed

Further to the abovementioned demonstrations, more “light” activities were performed under T4.4 aiming to inform/ engage local citizens about the bioenergy community activities of the Polish BECoop RESCoop. Such activities re described in the corresponding Annex.

# 5 Small-scale demonstration activities- Italian BECoop RESCoop

## 5.1 Overview of the Italian BECoop RESCoop

The pilot case in the three municipalities of Mortirolo takes place in the Valtellina region of northern Italy, specifically in the Province of Sondrio. This area is known for its successful forest biomass district heating systems, such as the TCVVV system in Tirano. Additionally, the use of wood biomass in domestic boilers and stoves is already prevalent in the region. The three municipalities have expressed their intention to develop a biomass CHP district heating system, driven by their awareness of sustainability issues at the community level. During the BECoop project, various scenarios were evaluated and determined to identify the most suitable conditions for the adoption of the bioenergy community concept of building a biomass CHP district heating system.

In collaboration with FIPER and local stakeholders, the three municipalities have made the decision to establish a benefit company, known as a "Società Benefit," as the preferred governance model for the development of the bioenergy community. This choice reflects the optimal approach for achieving the project's goals and ensuring the effective management and operation of the bioenergy initiatives.

Within this case, the most critical elements have been defined such as the forest biomass harvesting and biomass CHP operation. As the technologies aimed at in the Italian BECoop are well in place and well-matured, the idea was to showcase the forest biomass harvesting demonstration and to perform on-site visits on operational biomass CHP district heating plants.

## 5.2 Overview of the small-scale demonstrations performed

***Small-Scale Demonstration: Visit woody biomass CHP district heating of Tirano***

| | |
|---|---|
| **Brief Description:** | The Tirano's district heating is the first CHP biomass plant installed in Italy. It was a pilot for the sector. Case of high temperature biomass DH located in a mountain area in northern Italy.<br>The system is managed by TCVVV[3] and provided heat and DHW to the municipality (total 20 MW for thermal energy and 1.1 MW for electricity production). A PV plant is also included in the site with 392 panels for peak power of 68.1 kW. |
| **When:** | 8th November 2022 |
| **Where:** | Tirano (SO) Italy |
| **Why:** | The Tirano plant represents a best practice in Valtellina for the diversification of the use of woody biomass and the testing of new abatement systems for atmospheric emissions. |
| **No of participants:** | 24 people |
| **Type of stakeholders:** | Majors of Mortirolo, forest operators, pilot partner of BECoop project, environmental association |

***Small- Scale Demonstration: Three harvesting methods of forests residues by Ferrari company***

[3] TCVVV biomass CHP District Heating, www.tcvvv.it

| | |
|---|---|
| **Brief Description:** | The demonstration was organised in Val di Fiemme that was affected by storm Vaia in order to illustrate three different types of forest biomass harvesting and forestry sites.<br>The Ferrari company[4] is among the most innovative forestry companies in Italy. Among the few to also use helicopters for the most inaccessible mountain areas. The aim of the visit: to illustrate the opportunity cost of the various technologies available on the market, starting with an analysis of the different forest parcels to be managed. Demonstration video is also available online. |
| **When:** | 29th March 2023 |
| **Where:** | Val di Fiemme- Val di Fassa |
| **Why:** | The organisation of the upstream supply chain is crucial for the start-up of a biomass district heating plant. The demonstration aims to provide insights into: i) Forestry innovation in timber harvesting, ii) Logistics management to reduce costs, iii) Opportunity cost analysis of each forest site, iv) Safety plans for risky work. |
| **No of participants:** | 24 people |
| **Type of stakeholders:** | Majors of Mortirolo, forest operators, pilot partner of BECoop project, environmental associations |

***Small- Scale Demonstration: Visit Bioenergia Fiemme- Biomass district heating – pellet and essential oil production***

| | |
|---|---|
| **Brief Description:** | Bioenergia Fiemme[5] represents a best practice of effective circular economy and production process optimisation. A visit was performed at the local biomass district heating plant (two 4 MWth boilers) together with a cogeneration plant (4.5 MWth + 1 MWe) to cover the heating demands of 4,000 inhabitants. In fact, apart |

[4] Ferrari company, ***https://ferraribrusio.ch/***
[5] Bioenergia Fiemme, ***https://www.bioenergiafiemme.it/***

| | |
|---|---|
| | from the CHP district heating plant, the production of pellets was started from the recovery of DH process heat. 9,000 tonnes/year of fir pellets called 'Fiemme pellets' (Enplus A1 certified) are produced using sawdust from neighbouring sawmills and quality wood chips.<br>Further to the CHP plant and the pellet production, on the 20th July 2019 Bioenergia Fiemme together with three other partners decided to inaugurate the new 'Magnifica Essenza' project. This latest idea stems from the desire to recover the last waste part of the conifer (spruce needles). Thanks to the recovery of steam, through a distillation process, a quality essential oil is thus produced, collected, and processed in the area. 120 litres/year of oil produced are distributed in the area's network of hotels and tourist facilities in 10 ml containers. |
| **When:** | 29 March 2023 |
| **Where:** | Cavalese – TN – Italy |
| **Why:** | First example in Italy of a district heating service and pellet production. The aim of the demonstration is to illustrate: i) How to optimise the heat from the district heating process to produce pellets and essential oils, ii) Circular economy start-up; every part of the woody residue is used for productive purposes, iii) How to promote sustainable forest management through the production of pellets and essential oils, iv) Territorial marketing through the forest supply chain |
| **No of participants:** | 24 people |
| **Type of stakeholders:** | Mayor of Mortirolo, forest operators, pilot partner of BECoop project, environmental associations |

## 5.3 Visit woody biomass CHP district heating of Tirano

### 5.3.1 Description of the small-scale demonstration

TCVVV (Teleriscadamento Coogenerazione Valtellina Valchiavenna Valcamonica) represents one of the first experiences in Italy on the development of the biomass-energy chain from the start-up of a district heating plant. TCVVV is among the founding member companies of FIPER. The aim of the visit to the Tirano power plant was to demonstrate the feasibility of a bioenergy community that invests and operates a biomass CHP and district heating.

The existing DH system is based on 3 biomass boilers with a thermal power of 2x6 MW + 1x8 MW, for a total 20 MW; the system is equipped also with 2 storage tanks of 130 $m^3$ each. It is a CHP system with an electric power of 1.1 MW. The thermal network has a length of 32.3 km with 741 connected buildings, for a total thermal power, users' side, of 58.34 MW. Recently it has been integrated a small DC system with an absorption chiller of 70 kW in a mall while a different cooling system based on a HP of 35 kW is ready to be tested. This way of operation guaranties the exploitation of different available local RES.

### 5.3.2 Results of the small-scale demonstration

The aim of the visit to the Tirano power plant was to demonstrate the feasibility of a bioenergy community and to illustrate the salient aspects for assessing pre-feasibility, in particular:

## Evolution of the supply chain

Security of biomass supply is one of the most important aspects of logistics management. This is why the supply chain is diversified  and consists of the following channels:

- Sawmill residues
- Residues from sustainable management
- Agricultural prunings (apple orchards, vineyards)
- Urban prunings

In recent years, the supply from sustainable forest management and the increased use of by-products from land management (riverbed cleaning, public and private green management) has increased. It is also important to diversify in the type of residues: for the medium-term log stocks were recommended. Wood chips can be in the start-up phase of the DH purchased and then it should be planned to purchase a chipper to produce them in-house.

## Boiler operation, network, ORC module

During the visit, the operating system was illustrated from the production of wood chips to the production of heat and its distribution to the grid combined with the boiler connected to the cogenerator that produces electricity.

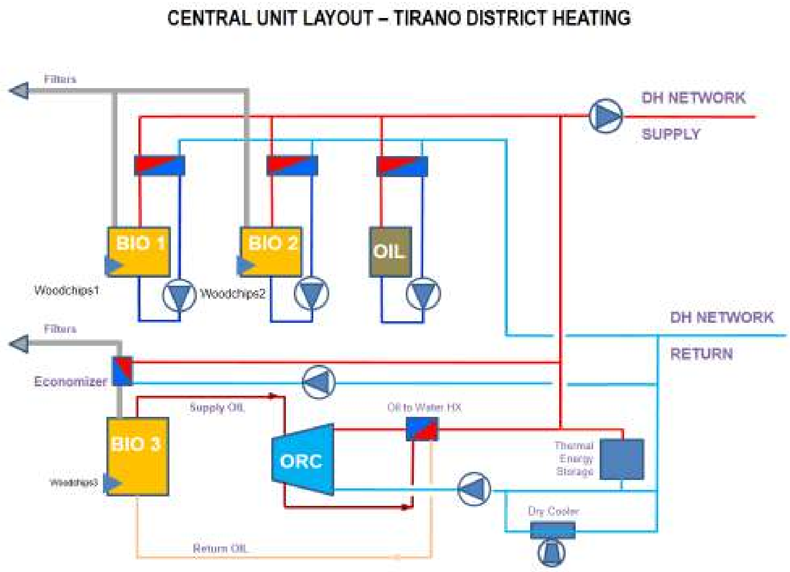


*Figure 11. Tirano district heating central unit layout*

The start-up of the plant was gradual and designed in modules. The analysis of the potential demand was essential to proceed step by step with the extension of the network and its connections. Another strategic aspect was to assess the cost-opportunity of combining cogeneration for electricity production. The evaluation for the pilot case will depend on the support system for electricity production and the possibility of using the same energy within the energy community. During the visit, the Organic Ranking Cycle (ORC) was explained. In Table 15 are presented the main indicators for the plant. In brief, per 2.5 kg of biomass, 4 kWh of thermal plus 1 kWh of electrical power were produced.

*Table 15. Main biomass plant operational indicators*

| Indicator | Quantity |
|---|---|
| Gross total electrical efficiency | 20% |
| Total energy efficiency | 98% |

## Emission abatement system

The main critical issue for the environmentally friendly operation of thermal power station fueled by woody biomass concerns the fine particulate and nitrogen oxides ($NO_X$) emissions. The plant that was visited had particularly devoted its efforts to optimize its emission abatement system.


*Figure 12. Emission abatement system*

As it is known, any plants of significant size (hundreds of thermal kW and above) that use wood biomass for district heating and cogeneration purposes are now normally equipped with baghouse filters with a particulate removal efficiency of 99%. These are structures in which the so-called "bags" are housed, consisting of a number of tubes made of fabric that is able to withstand high temperatures (up to 200 °C or more). Similarly, the $NO_X$ emission can be significantly reduced by the so-called "secondary denitrification interventions" such as the SCR (Selective Catalytic Reduction), already applied on a large scale, where ammonia is injected into the boiler flue gases. Thanks to the use of a highly active pelletized catalyst, able to operate even at temperatures as low as 140 °C, Ricerca Sistema Energetico S.p.A. (RSE) developed and demonstrated, in collaboration with Teleriscaldamento Cogenerazione Valtellina Valchiavenna Valcamonica S.p.A. (TCVVV), the feasibility to integrate both techniques inside the pre-existing baghouse filters, without the need for additional space, with cheap modification works and avoiding any additional heat losses to the stack. This solution offers several advantages such as:

- the already existing filter structure is used, without any additional space requirement, consequently, the cost and time required for the new installation are lower than in case of a completely new reactor.
- the catalyst employment on a flow of already dedusted flue gases avoids the well-known degradation phenomena of the catalysts due to a dusty environment.

In 20 years of operation, TCVV's plants have produced the following results, demonstrating that a biomass district heating represents positive investment with a low risk. The table below contains a list of economic and environmental figures associated with the adoption of this small scale demonstration.

*Table 16. Economic and environmental figures of the TCVVV*

| Parameter | Unit | Value |
|---|---|---|
| Total investments | M€ | 63 |
| Customers connected | People | 1,222 |
| Connected power | MWt | 96 |
| Built network | km | 56 |
| Heat sold | MWh | 830,000 |
| Diesel saved | M lt | 99 |
| $CO_2$ | Metric Tons | 287,000 |
| Wood chips | Metric Tons | 738,000 |
| Value of wood chips used | M€ | 36 |
| Turnover from heat sales | M€ | 82 |
| Savings to customers | M€ | 43 |
| Economic benefits for municipalities | M€ | 5.6 |
| Dividends to shareholders | M€ | 1.6 |

## 5.3.3 Participants and type of stakeholders attended

The following stakeholders participated in the abovementioned demonstration.

*Table 17. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Local institutions (majors) | 3 | Initiators |
| Facilitators (FIPER) | 3 | Promoters of the project |
| Forest operators and environment associations | 4 | Supply Chain |
| Other EU cases | 14 | Supply chain, research, and knowledge exchange |

## 5.3.4 Lessons learned

From this demonstration activity the lessons learned for the BECoop RESCoop were the following:

- Woody biomass supply chain analysis and its operation
- Logistics management of such a plant

- District heating service
- Electricity production in ORC cogeneration
- Emission abatement system and its results
- How does a heat storage system work
- How can mix of technologies and renewables sources be employed (photovoltaic plan, storage system, district cooling)

## 5.4 Three harvesting methods of forests residues by Ferrari company

### 5.4.1 Description of the small-scale demonstration

In recent years, Italy has witnessed several natural disasters, such as tornadoes, landslides, and fires, especially in mountainous areas. On the territory of the Mortirolo municipalities in 2022, a whirlwind knocked down several hectares of publicly owned forest. Starting from the need expressed by mayors to cope with forest management after calamitous events, FIPER organized the forestry demonstration in Val di Fiemme in the wake of storm Vaia. Another critical aspect affecting both territories is the advance of the bark beetle. The objective of the demonstration was to:

- Provide a range of possibilities for managing forestry sites, starting with an analysis of the specific features of the slope where forest management is to be carried out.
- Illustrate the opportunity cost of the various technologies available on the market, starting with an analysis of the different forest parcels to be managed.

*Figure 13. Forestry operations - harvest of forest biomass*

The Ferrari company is among the most innovative forestry companies in Italy. Among the few to also use helicopters for the most inaccessible mountain areas. For the harvesting demonstration three different harvesting methods were showcased:

- Mechanized harvesting with processor and cutting Model “John Deere 1470 D”.
- Forestry site with helicopter model Ecoreuil B3 Ecolight
- Forestry ropeway (with cable car) with New Holland 245 in valley not accessible by truck

Apart from the forest biomass harvesting, another key aspect concerns the logistical organization. For instance, Ferrari company has set up a network of companies that ensures that the different stages of the supply chain are carried out upstream to a single point of contact. From pick-up to delivery to the sawmill and/or district heating plant, there is only one interlocutor. The network of companies consists of 41 employees. The conveyor system becomes strategically important to deliver 18-metre-long logs to the sawmill, so that laminated timber can be produced without the use of glue. To this end, Ferrari prototyped a 23-metre-long trailer, which is already in operation in Val di Fiemme for the delivery of logs to the Magnifica Comunità di Fiemme sawmill.  Magnifica Comunità di Fiemme[6] boasts a thousand-year-old history. Its existence was first stated in the Gebardini Pacts, a document dated 1111 A.D. This organization safeguards the people of the Valley and makes the most of their environmental, historical and cultural heritage. As caretaker of ancient laws and traditions, it nowadays manages a significant forest and real estate heritage subject to civic uses, owned by the Community of Neighbors (residents in the area. The wood from the owned forests is processed in the local sawmill, owned by the community and it is transformed into timber, woodchips, and other semi-finished products. All forest enterprises of the area bring forest biomass, harvested from over 15,000 ha public forest and 50 km radius to this sawmill.

## 5.4.2 Results of the small-scale demonstration

Three harvesting methods were demonstrated. One using a processor with a harvesting arm, one with a helicopter and one with a ropeway (cable car). Via the demonstrations, a comparison of different forest harvesting methods was showcased focusing on the costs of each method and their performance. It emerged from the data provided that to mechanize and optimize the forest harvesting process, it is necessary to have significant investment in the purchase of machinery.

The first method was a processor with a harvesting arm. The whole equipment cost 800,000 €. With this method, 300 $m^3$ per day forest biomass is harvested. For the logistics, 12 $m^3$ - 15 $m^3$ trucks are used to transport the biomass from the forest site to the end-user. Furthermore, out of the 300 $m^3$ forest biomass harvested per day, 90% is used for furniture manufacturing, packaging, whereas the remaining 10% of the forest residues are  utilised for energy applications.

*Figure 14. Forest biomass harvesting demonstration with processor with harvesting arm*

The second harvesting method showcased was that of a helicopter bringing the cut logs to a open space where the rest cutting and chipping is performed. This method is performed in places that is difficult to reach by mechanized means. The cost of harvesting forest biomass with the helicopter is comparable with the cable harvesting method. Nonetheless, helicopter is faster in difficult areas to

[6] Magnifica Comunità di Fiemme , https://www.mcfiemme.eu/

reach. The helicopter can pick up to 150 kg maximum forest biomass. In this method, the helicopter is piloted for 9 hours in total every day, for 6 days a week, whereas in every 40 minutes there are stops made for refueling the helicopter. After the helicopter unloads a tree, an excavator new Hallandale 250 with harvesting arm is used to cut the tree (with the length/ size that you define). With this method 100 m3 of forest biomass per day is treated. For the branches that are left while cutting the tree, a woodchipper is used afterwards to produce chips. During this harvesting method, they harvest 2,000 m3 of forest residues (chips) a month. The cost of the harvesting machine is at 100,000 € for the harvester head, plus the cost of excavator.

*Figure 15. Forest biomass harvesting demonstration with helicopter*

The last method was with the use of a ropeway and a cable car. In this method, two people cut the tree and they transport it via a cable car down to an open space. The cost for such harvesting method is around 400,000 € for the cable line.

*Figure 16. Forest biomass harvesting demonstration with helicopter*

Based on the above harvesting methods some comparison results were retrieved while harvesting forest biomass. In brief, it was concluded that the first method with the harvester had less cost, whereas the most cost was for the second method with the helicopter. Furthermore, in terms of harvesting performance, the first method (harvester) harvest around 300 $m^3$/day, the second method (helicopter) 200 $m^3$/day, whereas the third method (cable car) harvest around 150 $m^3$/day. Finally, regarding, the people working in the different methods, it was seen that 1 people is needed to work the in first method (harvester), 5 people in the second method (helicopter), and 3 persons are needed in the third harvesting method (cable). A rough personal cost of 40 euro per $m^3$ can be assumed in general, whereas 20 €/$m^3$ is calculated only for the first method (harvester).

## 5.4.3 Participants and type of stakeholders attended.

The following stakeholders participated in the abovementioned demonstration (Table 18).

*Table 18. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Local institutions (majors) | 3 | Initiators |
| Facilitators (FIPER) | 3 | Promoters of the project |
| Forest operators and environment associations | 4 | Supply Chain |
| Other EU cases | 14 | Supply chain, research, and knowledge exchange |

## 5.4.4 Lessons learned

From this demonstration activity the lessons learned for the BECoop RESCoop were the following:

- Three different harvesting methods were demonstrated and compared
- Forestry innovation in timber harvesting
- Logistic management to reduce costs.
- Opportunity cost analysis of each forestry site
- Safety plans for jobs at risk
- Additionally, through this small-scale demonstration, the importance of planning the forest management was highlighted, as a mean to ensure greater resilience for the forest, in the face of calamitous events or pests

## 5.5 Visit Bioenergia Fiemme - Biomass district heating – pellet and essential oil

### 5.5.1 Description of the small-scale demonstration

Bioenergia Fiemme[7] was founded in 1999 with the ambitious aim of heating the town of Cavalese using waste from the wood supply chain. For 20 years now, the company has been producing alternative energy to fossil fuels using virgin wood chips deriving from the cultivation of the woods of the Magnificent Community of Fiemme. The company operates a biomass cogeneration district heating plant with a pellet production line. The plant uses the recovered heat to cover the thermal demands required for producing pellets. All this is made possible by exploiting processing waste and also through the production of pellets derived from sawdust. Over time, the company has developed other activities regarding the valorization and recovery of food waste by exploiting its intrinsic energy capacity by producing biogas and biomethane within a circular economy perspective.

The aim of the visit was to showcase how a biomass CHP plant with biomass district heating operates. Bioenergy Fiemme's claim is 'everything deserves a second chance'. In fact, Bioenergia Fiemme is one of the most significant examples in the Alpine area of the diversification of activities that can be achieved by having a woody biomass district heating plant. Such plant is within the bioenergy vision of the Italian BECoop RESCoop, thus it was considered significant demonstration activity that could be replicable in the Italian case.

### 5.5.2 Results of the small-scale demonstration

The visit to Bioenergia Fiemme highlighted how such plants operate and provided knowledge on:

#### *Company evolution in the diversification of production activity*

Bioenergia Fiemme, one of the founding members of FIPER, began the construction of the Cavalese district heating network in 1999, which up-to date covers a large part of the municipality's end-uses as a total of 663 users were connected between 1999 and 2021. The network is fed by 3 biomass boilers (two boilers with a capacity of 4 MW, and one of 4.5 MW). The main one is used for co-generation and it is associated with a 999 $kW_{el}$ Turboden ORC unit that continuously produces electricity that is fed into the local distribution network of the municipality of Cavalese (0.12 €/kWh selling price to the grid).

Since 2016, BioEnergia Fiemme has also been producing pellets that are marketed through its own brand FiemmePellet. This is an activity that recovers wood waste (sawdust), creating more value to the Fiemme Valley wood supply chain. The raw material, strictly locally sourced, is processed and dried using heat from the district heating network. The sawdust dried in this way is then transformed into FiemmePellet, a very high-quality product certified En Plus A1. Therefore, where there are no conditions to extend the district heating network, Bioenergia Fiemme offers the possibility of supplying zero-kilometer pellets. Yearly, 9,000 tons of pellets are produced and sold to over 700 local end-users. Pellets are either delivered to end users (minimum order of 2 metric tons) or end-users come and pick up pellets with big bags from the plant or via corporate distributors.

[7] Bioenergia Fiemme, https://www.bioenergiafiemme.it/index.html

*Figure 17. Pellet production line*

In 2019 born Magnifica Essenza Fiemme that produces essential oil is made by exploiting, on the one hand, the excess vapors produced by the Bioenergia Fiemme district heating plant and, on the other, by using the green part of the plant that would otherwise have to be discarded (e.g. needles, leaves etc.). At the Cavalese plant, a steam current distillation is carried out, which allows the oil contained in the plant to flow through the plant mass, breaking the bonds inside the plant and allowing the oil to escape. The steam then captures these oily particles and rises to the top of the basket. Then, by means of a condenser, the vapor is cooled back to a liquid state. It is at this stage that the oil becomes visible, settling on top of the process water. The latter is then separated from the essential oil and reused as hydrolate, suitable for uses other than essences, more related to aesthetics and body care.

*Figure 18. Essential oil production*

Finally, apart all this biomass-based activities, the plant has also 250 kW of PVs for covering part of its own consumptions.

## Awareness-raising activities and multi-sensory routes related to the wood industry

Awareness- raising activities are essential for the successful implementation of bio-based value chains, and the experience from the demonstrated case can offer important feedback on the replication of its activities by the Italian BECoop RESCoop. Bioenergia Fiemme has created a sensory path for children inside the district heating plant. The course, which start in the multimedia room and then move outdoors, all five senses will be involved, and, thanks to their perception, they will immerse themselves in the world of the circular economy starting with the activities carried out by Bioenergy in the wood chain and the recovery of organic waste. The visit will be introduced by some films and animations, it will then continue with sounds, tactile games, olfactory paths at the essential oil distillation plant and a visit to Bioenergia's production activities. An idea that aims to create a strong link between environment and nature, community and visitors, tradition, and innovation.

### *Territorial marketing*

The choice of distribution network of essential oil and pellet, which favors territorial marketing, should be emphasized. In fact, the essential oil is distributed in the tourist circuit (hotels, typical product stores, pharmacies, natural product stores) in 10-ml packs. The marketing of pellets is also done in the local distribution network (consumer cooperatives) under the name Fiemme Pellet, just to show the local origin. Smart marketing that through olfaction promotes the Val di Fiemme territory and indirectly also the wood industry in its various facets. Through the marketing of essential oils, tourists get to know Val di Fiemme.

In brief, Bioenergia Fiemme's main performance indicators, as recorded for 2021, are that 663 users were connected to the heating network. The heating network was 27.7 km and the total thermal energy supplied was at 33,100 MWh for the year. In parallel, the total electricity produced was at 9,690 MWh. Woodchips consumption was around 100,00 $m^3$, with a price around 30-50 €/$m^3$. In the whole plant, 8 workers are employed for the correct operation of the unit. In total, 9,367 $tCO_2$ were avoided during the operation of the plant in 2021. Finally, 9,000 pellets and 120 liters of essential oil were produced from the additional activities of the plant.

## 5.5.3 Participants and type of stakeholders attended

The following stakeholders participated in the abovementioned demonstration (Table 19).

*Table 19. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Local institutions (majors) | 3 | Initiators |
| Facilitators (FIPER) | 3 | Promoters of the project |
| Forest operators and environment associations | 4 | Supply Chain |
| Other EU cases | 14 | Supply chain, research, and knowledge exchange |

## 5.5.4 Lessons learned

From this demonstration activity the lessons learned for the BECoop RESCoop were the following:

- Circular economy: every part of the woody residue is used for productive purposes
- How to promote sustainable forest management through pellet production and essential oils

- Territorial marketing through the forest supply chain
- How to operate a biomass CHP district unit and optimize the district heating process heat to produce pellets and essential oils

# 6 Small-scale demonstration activities- Greek BECoop RESCoop

## 6.1 Overview of the Greek BECoop RESCoop

The Energy Community of Karditsa (ESEK) is a citizen energy cooperative located in Thesaly, Central Greece. It was established in 2010. Nowadays it counts more than 400 members of the cooperative (an estimated 8% of which is comprised by municipalities, SMEs, associations etc.). The main activity of the energy community is the **management of a biomass plant for the production of solid biofuels to generate energy for heating (and cooling) purposes.** The raw material consists of industrial residuals (sawmills) such as sawdust woodchips, logging residues such as branches, tops and stumps, coming from Forest Cooperatives.

A main element of Greek BECoop RESCoop is the expansion of products and services of the already existing ESEK's pellet production facility. In particular, the main targets are the processing and production of new mixtures of alternative and cheaper biofuels focusing on the exploitation of spent coffee grounds from local coffee houses, along with urban and forest residues. Apart from the investigation of new feedstock, WP4 tasks targeted the expansion of activities of ESEK to operate as an ESCO by installing and operating biomass boilers in municipal buildings and selling heat to end-users. By this way, ESEK will provide the end-user with solid biofuels, operate the installed biomass boilers and get revenues by selling heat (per kWh or per tonne biofuel), whereas end-users will only have to pay for their heat consumptions and not bother with the maintenance of the boilers and their fuel supply.

Within this case, the most critical elements have been defined such as the coffee residues collection, the collection and chipping of urban prunings, as well as the production of new "alternative" solid biofuels from mixing of coffee residues with other biomass residues, along with their fuel analyses, and their combustion into biomass boilers.

## 6.2 Overview of the small-scale demonstrations performed

| *Small- Scale Demonstration: Collection and chipping of city prunings* |
|---|

| | |
|---|---|
| **Brief Description:** | City pruning collection was performed with the use of two trucks with a crane and crab. Urban prunings were collected by the local municipality. Afterwards, chipping of city prunings was also demonstrated in a biomass management company with the use of one truck with a crane and crab and a woodchipper. Urban prunings were chipped and transported to ESEK's plant for further processing and pellet production. The collection, transportation and chipping were monitored for recording operational data of such activities, required for the Greek BECoop RESCoop. |
| **When:** | May and October 2022 |
| **Where:** | Karditsa , Greece |
| **Why:** | To estimate the amount of city prunings that the community can exploit as well as monitor the time and cost of the collection and its treatment and to measure the required work-effort. |
| **No of participants:** | 5 |
| **Type of stakeholders :** | Municipal authorities, BECoop partners (CERTH, ESEK), biomass management company |

***Small- Scale Demonstration: Collection of coffee residues***

| | |
|---|---|
| **Brief Description:** | One of the new feedstock investigated through BECoop project is that of coffee residues. In this light, the collection of coffee residues from the local coffee houses was demonstrated. The coffee residues collected were used for the production of mixed pellets. |
| **When:** | September - May 2023 |
| **Where:** | Karditsa, Greece |
| **Why:** | The collection of coffee residues is part of the new activities of the BECoop RESCoop, thus its demonstration would highlight the barriers and lessons learned of the process |
| **No of participants:** | 275 |
| **Type of stakeholders:** | Citizens, coffee shop owners, BECoop partners (CERTH, ESEK), local authorities, NGOs |

***Small- Scale Demonstration: Mixed Coffee pellet production and fuel characterization***

| | |
|---|---|
| **Brief Description:** | Pilot pellet production of coffee residues mixed with several biomass residues e.g. residues from sawmills, urban prunings, agricultural residues and more. The production was performed at ESEK's pellet plant. After that, the produced mixed pellets were analysed at CERTH/CPERI's labs. |
| **When:** | December 2022 |
| **Where:** | Karditsa, Greece |
| **Why:** | One of the activities proposed for the BECoop RESCoop is the production of new "alternative" biofuels. In this light, new fuel mixtures were demonstrated in order to further examine their fuel properties. |
| **No of participants:** | 3 |
| **Type of stakeholders:** | BECoop partners (CERTH, ESEK) |

***Small- Scale Demonstration: Pellet boiler installation and emissions monitoring***

| | |
|---|---|
| **Brief Description:** | Installation of a 35 KW pellet boiler in a kindergarten and combustion tests with three different fuels. |
| **When:** | November 2022 - May 2023 |
| **Where:** | Karditsa , Greece |
| **Why:** | To demonstrate one of the basic activities proposed for the BECoop RESCoop, that of installing biomass boilers in public buildings and covering the thermal demands with the new produced biofuels. |
| **No of participants:** | 10 |
| **Type of stakeholders:** | Municipal authorities, energy community, boiler supplier, research organization, local citizens |

# 6.3 Collection and chipping of city prunings

## 6.3.1 Description of the small-scale demonstration

Annually, trees from city parks and roads are pruned for maintenance and plant health reasons. From such activity, an adequate amount of biomass is produced. This feedstock remains unexploited, as in most cases it is disposed of in illegal landfills or burned on-field, although it is a prohibited practice, producing emissions harmful to human health and environment. In the frameworks of BECoop, the exploitation of urban prunings was investigated in order to expand the biomass feedstocks that are processed from the BECoop RESCoop. In this light, in May of 2022, a demonstration of urban pruning collection was performed. During the collection of the city prunings that the municipality of Karditsa performed, the distance, the time of loading/unloading, the quantities of biomass and the moisture content of the prunings were measured.

For the collection of the prunings, one truck with a crane and crab was used. The municipal workers collected manually or with a front loader the urban prunings and loaded them to a truck.

The measurements started at the central station of the municipality of Karditsa (where the truck starts for the collection of prunings). The truck collects urban prunings from random areas where pruning of urban trees has been performed.  In total, the workers visited 5 collection points that the municipality indicated, through four different areas in the prefecture of Karditsa. After being fully loaded, the truck is weighed and is sent to ESEK's plant. There, the urban prunings were unloaded and stored in open space in order to be further processed by ESEK. Through the demonstrations performed the municipal staff have been trained for the collection of prunings as not to collect plastics and other residues, together with the urban prunings, but to sort only the woody biomass.

*Figure 19. Urban pruning collection.*

Further to the urban pruning collection, another demonstration was performed for treating the collected prunings. Due to the size of the prunings (long and thin), they could not be processed directly by ESEK. In this light, a demonstration of chipping the urban prunings was performed in an external biomass management company (trades firewood and woodchips) in order to monitor the pre-treatment process prior to the pelletization of the urban prunings.

*Figure 20. Top left; Chipping machine. Top right; city prunings chipping.*

*Bottom: Produced woodchips*

The stationary chipper used was a Pezzolato model PTH 700/660 drum chipper (Table 20.), suitable for all types of wood with the following characteristics:

*Table 20. Chipping machine characteristics*

| Specification | Data |
|---|---|
| Maximum diameter of material provided | 400 mm |
| Maximum length of material provided | 300 mm |
| Hourly production | 40-50 $m^3$ |
| Grinding drum width | 640 mm |
| Grinding drum diameter | 660 mm |
| Drum weight | 840 kg |
| Number of knives | 2 |

### 6.3.2 Results of the small-scale demonstration

The collection of urban prunings was performed by the municipal workers and monitored in order to record the data of the process. The distance that was covered from the truck (from starting point and back) was 56 km and the time on the road was 2 hours and 16 minutes. The loading and unloading time of prunings amounted to 1 hour and 8 minutes and the amount of urban prunings collected was 2.47 metric tons (wet basis), with a moisture content around 50%. The total collection performance was 0.73 t/hr (wet basis). The truck used for the collection of urban prunings had a platform of 6$m^3$. In total, in the span of one year, 30 loads of approximately 4 metric tons each were delivered, with an average water content of 45%. This resulted in a total urban prunings collected of 120 metric tons of wet prunings. Loads are still being delivered today, depending on the season.

*Figure 21. Truck used for urban prunings collection*

The monthly salary of each municipal worker of Karditsa responsible for transportation is around 1,000 €. Two persons are required for this work, thus, the total salary cost for transportation will be 2,000 €. Regarding the quantity of harvested residues, it is assumed that up to 5 metric tons for 1 shift. Considering that each month the days of operation are 22, the maximum quantity of residues transported to ESEK will be 110 metric tons. Regarding the cost of fuel for transportation of the total distance (truck depot - collection sites - ESEK- truck depot), it is considered 100 km/shift. Furthermore, an assumption for the fuel cost to be 1.70 €/lt was considered. Taking into account the category of vehicle having been used for the transportation, the fuel consumption of it is up to 32 €/100km. All of the above sums to a transportation cost of urban prunings to ESEK at around 29 €/t. However, the collection cost of urban prunings is not attributed to ESEK (BECoop RESCoop) but to the municipality, as the latter is responsible for the transportation of urban prunings to ESEK.

Further to the collection of urban prunings, a demonstration of chipping the urban prunings was performed at a biomass logistic center in the area that trades mostly firewood and woodchips. The process of chipping was also monitored in order to record various process data. A complete lap of the machines used for the chipping process lasted for 45 minutes. Out of this, the net chipping time was about 40.5 minutes, whereas around 2 minutes was idle time for maintenance such as taking out some prunings that were caught in the wires of the machines and around 2.3 minutes were spent to squeeze the chips and make them more compact in the bin. During this small-scale presentation 7.3 Metric tons of woodchips were produced. In brief, taking into consideration the gross chipping efficiency and this setup of 9.9 metric tons of woodchips can be produced per hour.

Based on the feedback retrieved during the demonstration, the operational costs of maintaining the blades of the chipping machine is 2 €/t, bringing the cost per ton of wood chips, including fuel cost, to 8 €/t (maintenance and fuel cost).

## 6.3.3 Participants and type of stakeholders attended

Table 21 lists the number and type of stakeholders involved with this small-scale demonstration. Their involvement in this project has multiple aspects. The energy community is the primary target of the demonstration, it’s development and integration in the municipality. Such a community would address the issue of energy poverty, that is the main goal of the BECoop project. The involvement of the local authorities of the municipality is also crucial, to provide proof of concept for the local consumers and also to facilitate in material terms with its own resources. Finally, SMEs are at the core of this venture, as they provide the raw material needed and the processes to convert it to biofuel, as well as a future prospect for the potential expansion of this RESCoop.

*Table 21. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Energy community | 1 | Biomass valorization |
| Municipality | 2 | Supply of biomass |
| SMEs | 1 | Supply of biomass |
| Research Organization (CERTH) | 1 | Technical support |

### 6.3.4 Lessons learned

This small-scale demonstration could be characterized as a success in general terms. It provided an alternative to fossil fuel, while utilizing resources that would have otherwise been wasted. The demonstration showcased how the municipality (member of the RESCoop) can collaborate with the RESCoop and transport a new feedstock, yet unexploited in the area, in order to produce new alternative pellets, as investigated during the BECoop project. Of course, this does not mean there is no room for further optimization and improvement in similar future endeavors:

- A greater optimization of the route system would lead to greater overall efficiency
- The operation would greatly benefit from a new fleet of transportation vehicles of the municipality. The vehicles currently used were of older technology and frequently needed repair, as well as they were prone to frequent breakdowns that disrupted the gathering and distribution of materials.
- An expansion of the fleet would also allow for a wider area of operations, covering potentially the whole municipality of Karditsa.

## 6.4 Collection of coffee residues

### 6.4.1 Description of the small-scale demonstration

One main demonstration in the frameworks of BECoop was the collection of coffee residues in the area of the Greek BECoop RESCoop. In this light, in becoming more innovative and in an attempt to involve more local actors, ESEK and CERTH, in collaboration with **InCommOn**[8] and their project: "**Kafsimo**[9]: participatory coffee waste recycling" (Figure 22), collected coffee residues from local coffee houses and citizens. The collection was performed mainly by having a bin for coffee residues in the

[8] https://incommon.gr/
[9] https://incommon.gr/kafsimo/

center of the city of Karditsa, where nearby local coffee houses could bring their coffee wastes. Then ESEK, would come and collect the bin once a week or every 15 days.


*Figure 22: Coffee residue collection receptacles*

Concerning the coffee waste chain, the project ensures its sustainability. It has an in-built multiplier mechanism in that it not only educates the public, coffee shop staff and energy producers, but it also empowers them to be multipliers of the idea among their peers - be that in school, at work or in their social circles. Involving the public to engage in the project as active participants, ensure the social and therefore, environmental sustainability of the project, while ensuring a reliable supply chain for the RESCoop.

## 6.4.2 Results of the small-scale demonstration

At first, a small-scale demonstration regarding the exploitation of local coffee residues in the city of Karditsa was performed with the BECoop partners and IncommOn, in order to see the productivity of such residue. In brief, ESEK communicated with several local coffee-houses that were willing to participate (10 local coffee houses) in the demonstration and collected their coffee-residues from two consecutive days. The collection was performed directly in the coffee houses. Around 100 kg of coffee residues were collected from this demonstration.

After this first demonstration, the collection of coffee residues was performed for a greater period and at a greater scale. Coffee residues from each coffee house were disposed in dedicated bins, located at central points. Based on extensive discussions with the managers of coffee houses to determine and point out the most effective way of residual coffee collection, as well as the timeline for the collection of residues in order to avoid problems with storage and biodegradation, it was decided that the most suitable collection frequency was once per 15 days. Thus, every 15 days, coffee residues were collected by ESEK and transported to ESEK's biomass plant for storage and treatment. Coffee residues were stored in the open and spread (not in high piles) in order to lower its moisture (> 60% initial moisture content). After two-three weeks, the coffee residues were treated for pellet production.

In brief, in the whole coffee residues collection campaign, 5 coffee businesses daily separated and correctly managed spent coffee grounds. In total, 20 coffee businesses participated in the separation of their coffee grounds by using the centrally located bin that has been placed for coffee waste collection. Further to the coffee businesses, 50 people correctly sorted organic waste at source and provided their coffee residues. In this light, over the long term local citizens acquire circular behavior with regard to the specific waste stream. Through the coffee collection activity, around 250 people were engaged and adapted an eco-friendly behavior. In total, more than 1,000 households have been informed about the possibility of recycling household coffee and organic waste in general.

Furthermore, at least 240 people have taken part in information-dissemination activities about utilizing home coffee for reuse. An estimated 30% in any group of people/citizens of Karditsa are aware about the project when questioned.
In total, around 7 metric tons of coffee waste diverted away from landfills due to the collection campaign (September-May 2023) that led to an estimated 31 tons of $CO_2$ equivalent saved. On the contrary, around 20 metric tons of pellets have been produced from mixing coffee residues with other biomass residual streams (e.g. pruning waste).

Regarding the costs for the collection of coffee residues by the BECoop RESCoop, these were calculated based on the results of the demonstration. The distance from ESEK's plant to the city of Karditsa is approximately 7 km thus, the total distance of transporting the residues to ESEK and going back to Karditsa is up to 14 km. Transportation to ESEK is realized by car with fuel cost set at 0.15 €/km, thus the total cost for transport of the feedstock to ESEK and going back to the town of Karditsa is 2.1 €. The employees of the coffee houses dispose of the coffee residues to the bins, which have been provided close to the shops for this reason. For transportation costs, we take into consideration only the fuel cost as a person from ESEK is responsible for this and no additional personnel cost would occur. The quantity of coffee residues collected twice per month was approximately 100 kg each time, thus 200 kg/month can be assumed. In this light, a collection cost of 21 €/t can be assumed.

## 6.4.3 Participants and type of stakeholders attended

The following stakeholders participated in the abovementioned demonstration (Table 22).

*Table 22. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Citizens | 250 | Coffee residues producers |
| NGOs (InCommOn) | 2 | Participation at the collection of coffee residues |
| Coffee houses | 20 | Coffee residues producers |
| Local authorities | 1 | Participation in the dissemination/ end user |
| Energy Community (ESEK) | 1 | Main initiator/ BECoop RESCoop |
| Research Organization (CERTH) | 1 | Technical support |

### 6.4.4 Lessons learned

The collection of coffee residues was a good opportunity for the BECoop RESCoop to identify the barriers and drivers in the collection of such a feedstock for its new activities as investigated in the project. Several diverge and important lessons could be summarized from this particular small-scale demonstration of the BECoop project, in order to optimize this, and future operations further:

- The implementation of an improved system for the sorting of coffee grounds
- Raising local business awareness of the project in order to provide a larger pool of coffee ground residues
- Raising citizen awareness around the message of circular economy and how it can be integrated in their daily life, through this or similar endeavors
- Municipalities can increase the network of coffee houses by giving them motivation (i.e., through the reduction of municipal taxes), benefiting both SMEs and the public.
- For the collection of coffee residues, electrical vehicles (e-bikes, e-cars etc.) can be used for further improving the sustainability and the environmental impact of the coffee residues exploitation value chain.

## 6.5 Mixed Coffee pellet production and fuel characterization

### 6.5.1 Description of the small-scale demonstration

Coffee residues were collected from local coffee houses in the city of Karditsa, Thessaly, Central Greece. The idea of the current demonstration was to test various fuel mixtures of coffee residues together with other residual biomasses. The various residual biomass feedstocks that were mixed with coffee residues were the following:

- Forest residues sourced from the nearby local forest
- Sawmill residues sourced from local sawmills
- Urban prunings sourced from maintaining the health of trees in urban parks and roads
- Maize residues (stalks, cobs, leaves) sourced from the local area
- Peach prunings sourced from nearby peach farms
- Miscanthus from a local farmer

ESEK produced new pellets by mixing wood and agricultural residuals with coffee in various percentages to investigate their properties. The mixed pellets that were produced and analyzed had the following mixtures:

- Coffee residues mixed with forest residues (from now own: CF) at 0/100 (CF0), 10/90 (CF10), 30/70 (CF30), 50/50 (CF50), 70/30 (CF70), 90/10 (CF90) wt% ratios
- Coffee residues mixed with sawmill residues (from now own: CS) at 0/100 (CS0), 10/90 (CS10), 30/70 (CS30), 50/50 (CS50), 70/30 (CS70), 90/10 (CS90) wt% ratios
- Coffee residues mixed with urban prunings (from now own: CU) at 0/100 (CU0), 10/90 (CU10), 30/70 (CU30), 50/50 (CU50) wt% ratios
- Coffee residues mixed with maize residues (from now own: CM) at 0/100 (CM0), 10/90 (CM10), 30/70 (CM30), 50/50 (CM50), 70/30 (CM70), 90/10 (CM90) wt% ratios
- Coffee residues mixed with peach prunings (from now own: CP) at 0/100 (CP0), 10/90 (CP10), 30/70 (CP30), 50/50 (CP50), 70/30 (CP70), 90/10 (CP90) wt% ratios
- Coffee residues mixed with miscanthus (from now own: CMI) at 0/100 (CMI0), 30/70 (CMI30), 50/50 (CMI50) wt% ratios

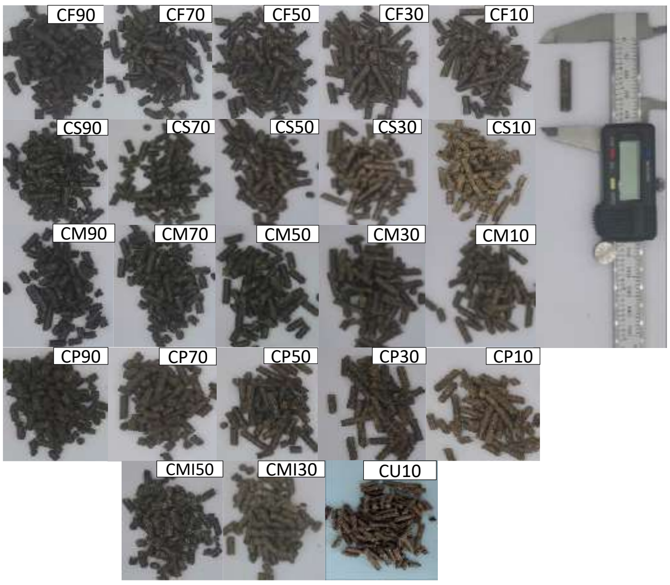


*Figure 23. Mixed coffee pellets produced at ESEK plant*

Further to the pellet production, samples of the produced pellets were analyzed. In total, 31 different pellet samples were analyzed. The fuel characterization of the produced pellets was performed in CERTH/CPERI's laboratories in Ptolemaida by applying established standards.

## 6.5.2 Results of the small-scale demonstration

In the following sections, results from the fuel analyses of pellets deriving from coffee residues mixed with sawmill residues at different ratios are presented indicatively. The rest fuel mixtures' results can be found in Annex IV.

### 6.5.2.1 Fuel Analyses of mixed biofuels: Spent coffee grounds with sawmill residues

Table 23., Figure 24 and Figure 25 present the fuel characterization and major and minor elements of the coffee pellets mixed with sawmill residues.

*Table 23. Main fuel characteristics of coffee pellets mixed with sawmill residues*

| Property | Units | CS0 | CS10 | CS30 | CS50 | CS70 | CS90 |
|---|---|---|---|---|---|---|---|
| Moisture | %, a.r.[10] | 6.69 | 9.2 | 7.4 | 8.1 | 8.4 | 9.3 |
| Ash | %, d.b. | 0.9 | 1.2 | 1.7 | 1.9 | 2.1 | 2.3 |
| Volatiles | %, d.b. | 78.9 | 78.8 | 77.5 | 77 | 76.4 | 75.6 |
| C | %, d.b. | 50.5 | 50.53 | 50.36 | 50.63 | 50.84 | 50.88 |

[10] *d.b.: dry basis; a.r.: as received

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| H | %, d.b. | 6.05 | 6.02 | 6.11 | 6.14 | 6.24 | 6.28 |
| N | %, d.b. | 0.19 | 0.43 | 1.14 | 1.88 | 2.51 | 3.24 |
| S | %, d.b. | 0.01 | 0.03 | 0.07 | 0.1 | 0.14 | 0.21 |
| Cl | %, d.b. | 0.01 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |
| HHV | MJ/kg, d.b. | 18.88 | 19.51 | 19.35 | 19.95 | 20.05 | 20.29 |
| LHV | MJ/kg, a.r. | 16.23 | 16.29 | 16.5 | 16.91 | 16.91 | 16.94 |
| Bulk density | kg/m3, a.r. | 698 | 712 | 715 | 720 | 724 | 735 |
| Mechanical Durability | %, a.r. | 95.7 | 94.2 | 92.3 | 93 | 93 | 94.1 |
| SST | °C | 1147 | 1089 | 948 | 951 | 876 | 1083 |
| DT | °C | 1255 | 1183 | 1212 | 1219 | 1276 | 1172 |
| HT | °C | 1384 | 1374 | 1279 | 1265 | 1371 | 1239 |
| FT | °C | >1550 | >1550 | 1292 | 1269 | 1402 | 1253 |

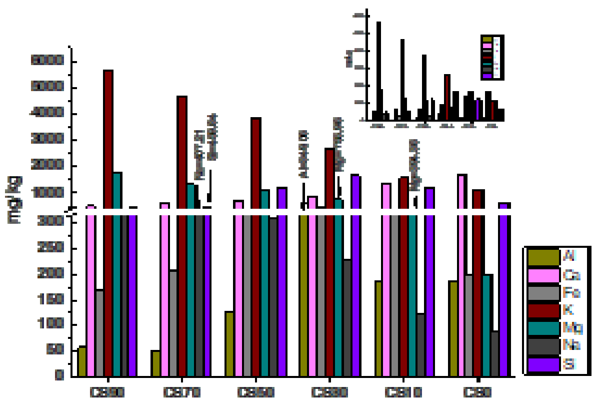


*Figure 24. Major elements (mg/kg d.b.) of coffee pellets mixed with sawmill residues*

The produced pellets have a range of LHV from 16.23- 16.94 MJ/kg (a.r.) and ash content from 0.9-2.3 % (d.b). From the results, almost the same trend with the previous mixtures is followed as well. As the content of coffee residues increases, the heating values, bulk density, carbon, and hydrogen content increases. However, the increased coffee residues also increase the ash content (from 0.9% to 2.3%), along with the nitrogen and Sulphur content and decreases the mechanical durability of the pellet. Finally, the properties of this mixture comply with the A2 limits set by ISO 17225-2 for wood pellets with up to 10% coffee residues (CS10), apart from LHV where the limit is at 16.5 MJ/kg and that of CS10 pellet at 16.23 MJ/kg, while the CS30 and CS50 comply with the class B limits.

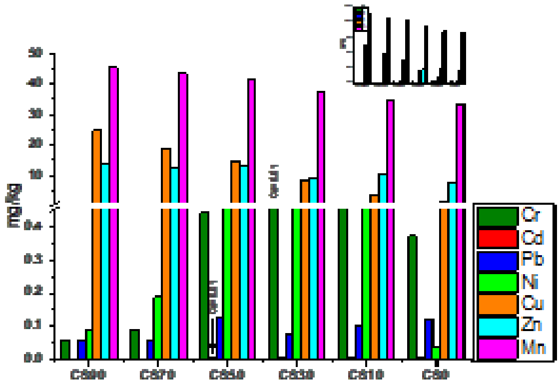


*Figure 25. Minor (down) elements (mg/kg d.b.) of coffee pellets mixed with sawmill residues*

Regarding the major elements, they follow the same trend as previously. By increasing the content of coffee residues in the mixture, the potassium (K) increases from 1,161 mg/kg (CS0) to 5,665 mg/kg (CS90), along with Magnesium (Mg). Nonetheless, increasing the content of coffee residues in the fuel mixtures, the content of calcium and silica decreases significantly. Other major elements such as Al also decreases, whereas Na increases. Regarding the minor elements, by increasing the coffee residues in the fuel mixtures, the Cu and Mn content increases. On the other hand, by increasing the spent coffee ground, the content of Cr and Pb decreases. All the rest minor elements are either reduced or they have negligible alterations. All pellet mixtures are in line with the limits of ISO 17225-2 for wood pellets (class A and B pellets) regarding minor elements, apart from Cu. The limit is surpassed for pellet mixtures with 50% coffee residues (Cu at 14.8 mg/kg) and above (CS50, CS70, CS90).

### 6.5.3 Participants and type of stakeholders attended

The stakeholders participating in the demonstration can be seen below. In practice, the stakeholders that participated were the workers of the pellet plant.

*Table 24. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Pellet plant | 2 | Production of pellets/ Main initiator/ BECoop RESCoop |
| Research Organization (CERTH) | 1 | Technical support |

### 6.5.4 Lessons learned

In general, the addition of spent coffee grounds in the fuel mixtures had some horizontal influence on the properties of the pellets. More specifically, by increasing the spent coffee ground, the bulk density, heating value, carbon and hydrogen content of the fuels increased. Furthermore, the increased coffee residue content decreased the ash content of the fuels (apart from CS mixtures) and in most cases decreased the chlorine content as well. On the other hand, the addition of coffee residues in the mixture increased the content of Nitrogen and Sulphur and decreased the mechanical durability of the produced pellets. The granular form of coffee residues and the smaller particles and less lignin content, compared to the other biomass feedstock, most probably caused the reduction in the mechanical durability. However, with better fine-tuning of the pelletizing process (e.g., compaction ratio), this could be addressed.

Regarding the major elements, the addition of spent coffee grounds resulted to some "patterns" as well. By increasing the coffee residues in the fuel mixture, the K (apart from CM and CP samples) and Mg content (apart from CM, CP and CMI samples) increased. Furthermore, in all samples, increasing the spent coffee grounds led to the reduction of Ca and Si content. Regarding the minor elements, by increasing the coffee residues ratio resulted to increased Cu content. Mn content as well increased but only for the CS and CP samples. The rest minor elements were reduced with the addition of spent coffee grounds.

The results of the analyses show that the mixing of biomass residues with coffee could result to competitive solid biofuels. More specifically, CS10 sample comply with the A2 limits set by ISO 17225-2 for wood pellets with up to 10% coffee residues, while the CS30 (up to 30% coffee residues) comply with the class B limits for wood pellets for commercial/residential applications. In the same light, urban prunings mixed with 10 wt% coffee residues are within the limits set for class B wood pellets. In general, based on the local biomass availability, the biomass type and percentage of mixing, the produced pellets could find application to either commercial/ residential applications or industrial applications provided suitable combustion systems and air pollution control measures and devices are implemented. Thus, mixed coffee pellets can be competitive solid biofuels contributing to a clean energy production, and significantly lowering GHG emissions compared to their landfill disposal, by using local unexploited biomass feedstock.

## 6.6 Pellet boiler installation and emissions monitoring

### 6.6.1 Description of small-scale demonstration

As a part of this small-scale demonstration, a biomass boiler was installed at a municipal building (kindergarten) in the area of the BECoop RESCoop. The biomass boiler was fed by the pellets produced by ESEK in order to cover its heating demands. The combustion tests was also a validation test for the new alternative pellets produced and as a replication of the new activities of ESEK as a BECoop RESCoop (bioenergy ESCOO that could sell heat to municipal buildings). The boiler is of simple technology with a three-pass design and a PellasX Hybrid 35kW burner with remote management system (Figure 26.). The feedstock was housed in a 300-litre galvanized heat resistant steel silo. Its main advantage is its robustness and efficiency, offset by it's difficult cleaning procedures due to the lack of automation.

*Figure 26. Biomass boiler installation*

In the span of three days the combustion of three different types of pellets was realized and monitored. The produced pellets that were used as feedstock are presented in Figure 27. The three pellets used were: i) A1 wood pellets produced by ESEK; ii) coffee pellets (10% coffee residues) mixed with urban prunings (CU10); iii) coffee pellets (10% coffee residues) mixed with sawmill residues (CS10).

*Figure 27. Top left; Wood pellets. Top right; urban waste wood with coffee grounds (CU10). Bottom; sawmill residues with coffee grounds (CS10).*

During the combustion tests, firstly, fuel samples before their use were retrieved for fuel analyses. Furthermore, flue gas emissions were monitored on site during the trial run of the boiler with the three different fuels. The equipment used in the measurement of flue gas emissions involved a Testo 330-LL handheld measuring device, suitable for flue gas emission measurements of small furnaces, low-temperature and condensing boilers and gas heaters. Furthermore, at the end of each testing day, ash samples were collected and analyzed in CERTH/CPERI's laboratory, following established standards.

## 6.6.2 Results of the small-scale demonstration

Table 25. contains the main fuel characteristics of the biofuels used in the small-scale demonstration. The feedstock consisted of wood pellets, as well as two types of pellets, each with 10% percentage of coffee residue and the rest with urban pruning and sawmill residues. Figure 28 describes their major and minor elements.

*Table 25. Main fuel characteristics*

| Property | Units | Wood pellets | CU10 | CS10 |
|---|---|---|---|---|
| Moisture | % a.r. | 8.7 | 12.7 | 11.9 |
| Ash | % d.b. | 1.4 | 1.9 | 2.5 |
| Volatiles | % d.b. | 78.7 | 78.2 | 77.4 |
| Carbon, C | % d.b. | 49.86 | 50.43 | 48.86 |
| Hydrogen, H | % d.b. | 6.03 | 6.03 | 6.02 |
| Nitrogen, N | % d.b. | 0.39 | 0.45 | 0.39 |
| Sulphur, S | % d.b. | 0.02 | 0.03 | 0.03 |
| Chlorine, Cl | % d.b. | 0.02 | 0.02 | 0.02 |
| Higher Heating Value (HHV) | MJ/kg, d.b. | 19.45 | 19.62 | 20.66 |
| Lower Heating Value (LHV) | MJ/kg, d.b. | 18.14 | 18.31 | 19.35 |
| Higher Heating Value (HHV) | MJ/kg, a.r. | 17.76 | 17.12 | 18.21 |
| Lower Heating Value (LHV) | MJ/kg, a.r. | 16.35 | 15.67 | 16.76 |
| Bulk density | $kg/m^3$ a.r. | 687 | 643 | 650 |
| Mechanical durability | % | 97.8 | 98.4 | 97.6 |
| Fines (<3.15 mm) | % | 0.4 | 0.2 | 0.2 |
| Length | mm | 23 | 20.8 | 21.4 |
| Diameter | mm | 5.2 | 5.9 | 6.1 |
| Oil content | % d.b. | 0.1 | 0.72 | 0.15 |
| Shrinkage starting temperature (SST) | °C | 1065 | 769 | 1060 |
| Deformation temperature (DT) | °C | 1297 | 1345 | 1340 |
| Hemisphere temperature (HT) | °C | 1418 | 1543 | 1520 |
| Flow temperature (FT) | °C | 1436 | 1548 | 1524 |

d.b.: dry basis, a.r.: as received

It can be seen from the comparison of the fuels, that the fuel characteristics of the two new mixed fuels are comparable with the higher quality solid biofuels of ESEK. It can be concluded that the mixed coffee pellets (CU10 and CS10) have greater heating value than the wood pellet. However, they have both higher ash content. It can also be seen that the CU10 has higher N content, but also higher mechanical durability compared to the other two fuels. CU10 has also higher oil content, and lower bulk density, perhaps because of the existence of leaves from prunings. In addition, it has lower shrinkage starting temperature, however the rest ash melting temperatures are higher or comparable to the other two fuels. Furthermore, CS10 sample has comparable properties to wood pellet from ESEK, with a lot higher heating value, but higher ash content as well.

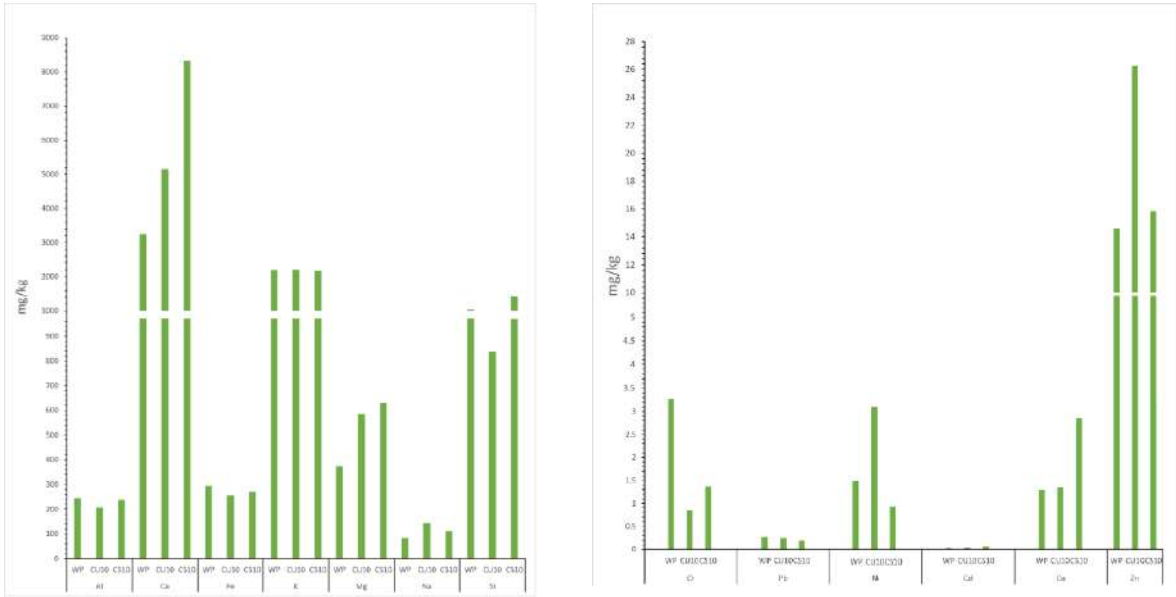


*Figure 28. Major (right) and Minor (left) elements of fuel samples*

Regarding the major elements, it can be seen that all three fuels have comparable results, with only CS10 having increased Ca content than the others. Regarding the minor elements, it can be seen that all three samples have comparable results, with CS10 sample having higher Cu content than the other two fuels and wood pellets have higher Cr content compared to the mixed coffee pellets. Finally, the CU10 sample has higher Ni and Zn content compared to the other two fuels. All pellet samples are in line with the limits of ISO 17225-2 for wood pellets (class A and B pellets) regarding minor elements.

The samplings were conducted the following dates: December 8, 2022 (wood pellet), January 19, 2023 (CU10), February 14, 2023 (CS10), using 10 minute time intervals between each individual sampling. Each procedure lasted approximately 4 hours to ensure an adequate sample size to avoid statistical errors. The samples were taken using a Testo 330 LL handheld measuring device, used for the professional flue gas analysis of furnace systems. To facilitate the sampling, three ports were drilled in the common flue gas stack of the boiler[11]. The EN 13284 standard[12] and the hydraulic diameter of the straight duct was used to determine the location of the sampling ports.

Figure 28 presents the main flue gas characteristics as they were measured during the combustion tests. All emissions are presented for 10% reference $O_2$.

*Table 26. Boiler flue gas characteristics as measured*

| Parameter | Units (dry, @10% $O_2$) * | Wood pellets | CU10 | CS10 |
|---|---|---|---|---|
| CO | $mg/m^3$ | 1,304 | 2341 | 2058 |
| λ | - | 1.5 | 1.9 | 1.7 |
| T Air | °C | 13.5 | 20.5 | 7.6 |
| FT | °C | 178 | 123 | 139 |
| qA+ | % vol | 8.3 | 6.2 | 7.1 |
| Chimney draft | mbar | -0.1 | -0.2 | -0.1 |
| η | % | 91.7 | 93.8 | 92.9 |

[11] Kougioumtzis, M. A., Kanaveli, I. P., Karampinis, E., Grammelis, P., & Kakaras, E. (2021). Combustion of olive tree pruning pellets versus sunflower husk pellets at industrial boiler. Monitoring of emissions and combustion efficiency. *Renewable Energy*, *171*, 516–525. https://doi.org/10.1016/j.renene.2021.02.118

[12] EN 13284-1, Stationary Source Emissions. Determination of Low Range Mass Concentration of Dust. Manual Gravimetric Method, 2017.

| | | | | |
|---|---|---|---|---|
| $NO_x$ | $mg/m^3$ | 265 | 354 | 287 |

**: values have been adjusted to 10% reference $O_2$*

To accord to Greek legislation, Ministerial Decree 189533/2011, 2012 revision of EN303-5, concerning central heating boilers used in the residential and service sector, new biomass boiler (automatic feeding) emissions must comply with the requirements of Class 3/EN303-5 and its related limits. All three samples were below the CO limit of 3,000 $mg/Nm^3$ for nominal capacity of boilers with less than 50 kW. Only the $NO_x$ emissions slightly exceeded the limit of 340 $mg/Nm^3$ for the urban residue – coffee mix, however that could be attributed to the higher N-content of the fuel, compared to the others. It should be also noted, that the measurements were performed with simple equipment and in a simple/non-sophisticated biomass burner and that during the change of fuels, the combustion parameters were not altered/ optimized. Thus, the performance of the three fuels at a state-of-the art biomass boiler and with optimized combustion parameters/ boiler settings, based on the fuel that is combusted, would further increase the combustion performance and results.

Furthermore, samples were also collected and analyzed from the ash that was produced after the combustion (Figure 29). The ash produced from the combustion of the fuels followed the same trend. They were mainly granular and non-melted. Thus, the ashes are easy for removal/cleaning whereas and should not cause slagging. Table 27. displays the main properties for each of the ash samples, while Figure 30. details the minor ash elements.

*Figure 29. Ash samples from: (top left) wood pellets, (top right) urban prunings with coffee residues (CU10), (bottom) sawmill residues with coffee residues (CS10)*

*Table 27. Main ash properties*

| Property | Units | Wood | CU10 | CS10 |
|---|---|---|---|---|
| Moisture | % d.b. | 5.6 | 3.4 | 2.6 |

| | | | | |
|---|---|---|---|---|
| Organic Carbon, C | % d.b. | 15.8 | 6.8 | 9.8 |
| Inorganic Carbon | % d.b. | 8.7 | 5.5 | 7.4 |
| Sulphur, S | % d.b. | 0.49 | 0.97 | 1.22 |
| Chlorine, Cl | % d.b. | 0.24 | 0.35 | 0.36 |

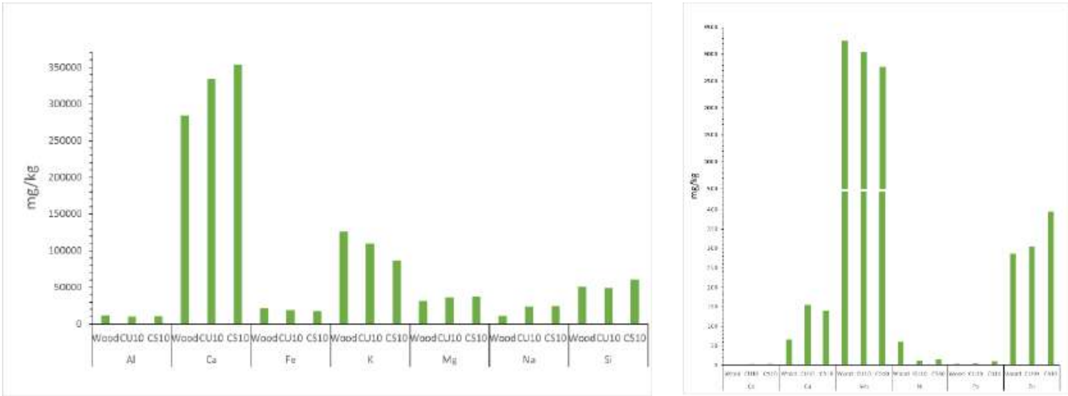


*Figure 30. Major (left) and Minor (right) elements of ash samples*

All three samples have relatively high organic carbon, with wood pellets having the highest. A high organic carbon content in the ash after biomass combustion indicates that a significant amount of carbonaceous material from the biomass fuel has not fully combusted and remains in the ash. This can be an indicator of incomplete combustion linked to the non-ideal conditions in the combustion chamber, thus better monitoring of the boiler settings should be implemented. Nonetheless, ash with higher organic carbon content may have more potential as a soil nutrient source or for carbon sequestration. Furthermore, all three samples show consistent levels of major and minor elements and it can be seen that they follow the same trend with the analyses of the fuels. Certain heavy metals that are concentrated in the ashes are recognized as pollutants (e.g. Pb, Zn, Cu, Cd, Ni). In overall, the minor elements of all fuels' ashes are in line with the requirements of the Austrian Guideline for usage of biomass ash as fertilizer in forestry and agriculture[13].

## 6.6.3 Participants and type of stakeholders attended

The stakeholders participating in the demonstration can be seen below.

*Table 28. Stakeholders attended the demonstration*

| Type of Stakeholder | Number of people | Role in BECoop RESCoop |
|---|---|---|
| Municipal Kindergarten | 2 | End- user |
| Local authorities | 1 | End-user |
| Boiler Supplier | 1 | Boiler Manufacturer/ technology provider |

[13] BMLFUW e Bundesministerium für Land- und Forstwirtschaft, Richtlinie für den sachgerechten Einsatz von Pflanzenaschen zur Verwertung auf land- und forstwirtschaftlich genutzten Fl€achen, 2011

| | | |
|---|---|---|
| Citizens | 3 | End-users/ biomass providers |
| Energy Community (ESEK) | 1 | Main initiator/ BECoop RESCoop |
| Research Organization (CERTH) | 2 | Technical support |

## 6.6.4 Lessons learned

The current demonstration was a good practice of what the new activities of the BECoop RESCoop would be like. The demonstration was a replicability of the activities proposed for the BECoop RESCoop, that of a bioenergy ESCO, that it would install biomass boilers and bring the biomass fuels, where the end-user would only pay for the heat consumed. As a result of this application, the following has been achieved:

- A comparison of three different biofuels were validated with combustion tests. Both new "alternative" fuels (coffee residues mixed with urban prunings and sawmill residues) had competitive fuel characteristics and combustion results with the wood pellets
- the lack of experience with the new fuels coupled with the absence of sophisticated boiler control systems have also played their role. The combustion of the new fuels at a state-of-the-art biomass boiler and with optimized combustion parameters/ boiler settings, based on the fuels that are combusted, would further increase the combustion performance and results
- no problems were detected while combusting the new "alternative" fuels
- In total, 4.3 metric tons of pellets have been used to heat the municipal kindergarten until now
- Satisfaction from the end-user regarding the operation of the boiler and its performance
- Another 15 metric tons of coffee pellet have been produced by ESEK, which are dedicated to meet the heating needs of the kindergarten next winter season as well as for another municipal building that will change its boiler into a biomass one in the near future
- Eliminated the building's consumption of heating oil, which was 1,300 liters
- Reduced the heating-related cost by 20%

# 7 Conclusions

Aim of the support services was to guide the BECoop RESCoops hand-in-hand and accelerate the development of their bioenergy visions, by showcasing the feasibility of the selected biomass-based activities (or part of them) of each BECoop RESCoop. Task 4.4 played a pivotal role in the project by building upon the results of Task 4.1 (cases roadmaps), Task 4.2 (technical support services) and Task 4.3 (business and financial support services). The main goal of this phase was to demonstrate the practicality and viability of the activities undertaken by each BECoop RESCoop, aligning with their bioenergy heating vision formulated in the earlier tasks.

In brief, Task 4.4 provided support services to all BECoop RESCoops by demonstrating parts of the bioenergy activities and concepts mentioned in the previous Tasks of WP4. The task tried to elaborate in a more concrete form on the proposed activities, in order for the BECoop RESCoops to better understand in practice the transition from planning to implementation stages. The demonstrations differed based on the maturity, technological readiness and specific peculiarities of each BECoop RESCoop case.

In general, several small-scale demonstrations were performed in each BECoop RESCoop, thus exceeding (in practice) the KPI of one demonstration in each pilot case, as described in the DoA. An overview of the demonstrations performed in each pilot area can be found in Table 29.

*Table 29 Overview of demonstrations performed*

| | Spanish BECoop | Polish BECoop | Italian BECoop | Greek BECoop |
|---|---|---|---|---|
| Demonstrations performed: | • Mechanized harvesting demonstration of forest residues and fuel analysis<br>• Combustion test with the local biomass and fuel analysis | • Mechanized forest biomass harvesting<br>• Sustainable forest management<br>• Biomass pellets production<br>• Biomass pellets distribution to households | • Visit woody biomass CHP district heating<br>• Three harvesting methods of forests residues<br>• Visit Biomass district heating with pellet and essential oil production | • Collection and chipping of city prunings<br>• Collection of coffee residues<br>• Mixed Coffee pellet production and fuel characterization<br>• Pellet boiler installation and emissions monitoring |
| Number of Demonstrations: | • 2 | • 4 | • 3 | • 4 |
| Total audience of stakeholders engaged: | • 36 | • 139 | • 72 | • 293 |

| | | | | |
|---|---|---|---|---|
| Major types of stakeholders attending: | • Authorities, Municipalities, BECoop partners, Biomass management companies, local citizens | • Biomass processing company, energy advisers, agricultural cooperatives, mayor of OBS commune, municipal authorities, BECoop partners, local citizens | • Mayoral authorities, BECoop partners, forest operators environmental associations, local citizens | • SMEs, NGOs, Municipal authorities, BECoop partners, local citizens, researchers |
| Other activities: | | • additional/ "light" activities performed aiming to inform/ engage local citizens | • additional/ "light" activities performed aiming to inform/ engage local citizens | |

In terms of lessons learned from each set of pilot demonstrations, several conclusions can be drawn. From the Spanish pilot BECoop RESCoop, it was exhibited that a sustainable management of the local forests and harvesting of forest residues is environmentally feasible and economical viable, where the involvement of local authorities is crucial, particularly for public forests, as they are responsible for authorizing the harvesting process. The demonstration also showcased that the demonstrated harvesting and treating processes can also produce a high-quality product that meets the requirements of the local end-users and are competitive to the solid biofuels of the market. The Polish BECoop RESCoop demonstrated a mechanized harvesting of forest biomass and focused on the sustainable management of its forests. Furthermore, it demonstrated the pelletization process via a mobile pelletizer and distributed pellets among local citizens. The "live" presentation and distribution had a much better and faster impact on the stakeholders, including the understanding of the pellets and the involvement of the end-user. It also further attracted potential consumers and helped them overcome their prejudices against bio-energy. The Italian BECoop RESCoop focused on comparing three harvesting methods of forest biomass, in terms of performance and costs. Further to this, the visits to operational biomass plants demonstrated how to operate a biomass CHP district unit and optimize the district heating process and how these activities can be combined with the production of pellets and essential oils. Finally, the Greek BECoop RESCoop monitored the collection processes of coffee residues and urban prunings and oversaw the pilot production of new "alternative" solid biofuels. The created biofuels were turned to be competitive (at certain mixes with coffee residues) to high quality biofuels and they were utilized/ validated at a biomass boiler in a municipal kindergarten for covering its thermal demands. The outcomes of these demonstrations will further provide valuable feedback to Task 4.5, informing about the lessons learned and overall insights gained throughout the demonstrated activities.

In addition to the technical and economic feasibility aspects of the demonstrations, the latter not only aimed on informing and engaging local communities but also to gain their approval and support for the proposed activities. Thus, one major issue that was achieved through T4.4 activities was the propagation of the bio-energy vision of the BECoop RESCoops to local societies and stakeholders.

To sum up T4.4 activities, across all 4 pilot cases, a total of **13 small-scale demonstrations** were conducted, **involving a total of 540 stakeholders**. These interactions that were performed between government and municipal officials, technical and scientific experts, SMEs, NGOs and citizens, also helped propagate the message of bio-energy community potential towards a more energy-sustainable and decentralized future across multiple countries.

# Annex

## Annex I: Spanish BECoop RESCoop

The following sections include additional results and data obtained during the demonstration.

### Mechanized harvesting demonstration of forest residues and fuel analysis

The option 1 was carried in several days, in which the following results regarding the working time of each day were obtained and reflected in the following table.

*Table 30. Working time spent to carry out Option 1 of the forestry demonstration.*

| Day | Nº of workers per day | Nº of hours with the skidder per day | Nº of hours with the forestry truck per day |
|---|---|---|---|
| 13/10/2022 | 4 | 8 | - |
| 14/10/2022 | 3 | 8 | - |
| 17/10/2022 | 5 | 8 | - |
| 18/10/2022 | 5 | 8 | - |
| 19/10/2022 | 5 | 8 | - |
| 20/10/2022 | 3 | 8 | 8 |
| 21/10/2022 | 5 | 6 | - |
| 24/10/2022 | 3 | 8 | - |
| 25/10/2022 | - | 8 | - |
| 27/10/2022 | 3 | 8 | - |
| 03/11/2022 | - | - | 5 |

Regarding option 2 the tariff costs are the same that have been indicated before, and the working time for each operation required in this is reflected in the following table.

*Table 31. Working time spent to carry out Option 2 of the forestry demonstration.*

| Day | Nº of workers per day | Nº of hours with the skidder per day | Nº of hours with the forestry truck per day |
|---|---|---|---|
| 25/10/2022 | 5 | - | - |
| 26/10/2022 | 5 | - | - |
| 27/10/2022 | 5 | 4 | - |
| 28/10/2022 | 5 | 8 | - |
| 31/10/2022 | 5 | - | - |
| 01/11/2022 | 5 | - | - |
| 02/11/2022 | 5 | 8 | - |
| 03/11/2022 | - | - | 3 |
| 08/11/2022 | - | - | 8 |
| 11/11/2022 | - | - | 2 |

## Combustion test with the local biomass and fuel analysis

An example of the evolution of some parameters monitored during one day of the test can be seen in the following figure.

*Figure 31. An example of the evolution of some parameters monitored during one day of the test (15/02/2023).*

# Annex II: Polish BECoop RESCoop

## Additional activities performed

Further to the abovementioned demonstrations, more "light" activities were performed under T4.4 aiming to inform/ engage local citizens about the bioenergy community activities of the Polish BECoop RESCoop. Such activities re described in the following sections.

### Demonstration of different biomass pellets and woodchips

Pellets and chips for energy purposes in households or medium central heat plants can be produced from different forestry and agricultural biomass. The most popular pellets in Poland are made of forest wood and straw. However, there are many other biomass residues that after suitable processing and valorisation can be converted into pellets. Similarly, chips are produced from wood, as well. The wood chips can be comminuted to desired size. Moreover, chips can be obtained also from other biomass residues, such as corn, miscanthus or other energy plants.


*Figure 32. Pellets and woodchips demonstration*

As a result, it was important to pay attention to the stakeholders on the various options of biomass pellets and chips that create an alternative to peat coal in terms of energy source for the domestic automated boilers. The demonstrated different biomass pellets and chips indicated, how many options possess the biomass. It means also, that the stakeholders have large choices depending on the local resources or preferences.

During the demonstration it was indicated that different pellets are characterized by different properties (bulk density, caloric value, moisture content, mechanical durability, slag formation, ash content etc.). Therefore, the selection should be performed carefully. Apart from pellets and woodchips, wood logs and briquettes are also important as they have a suitable form to replace coal in the manually fed domestic boilers that are still very popular in Poland (especially, in rural areas).

### Demonstration of peat coal replacement by biomass pellet

Coal is the dominant heating fuel in the commune of Oborniki Śląskie. Coal boilers with automatic fuel feeding system burn coal with a size of 5-30 mm (so-called pea coal). In order to ensure process automation, biomass in the form of pellets is an alternative fuel. Therefore, the demonstration of the fuel change have been presented. What's more, during the demonstration, the attention was also paid on the much lower risk of blocking the feeder by pellet (i.e. screw feeder) in the feeding system due to the very regular shape and size of the pellets. It was also indicated that such a change of fuel does not adversely affect other elements of the heating system.

It was underlined that pellets can be made of both forest and agricultural biomass, which gives the opportunity to use a wide local potential. However, the attention should be paid to the proper storage of pellets in conditions that eliminate the possibility of its moisture. Finally, other added values were indicated such as: lower emissions of pollutants into the atmosphere compared to coal, and an alternative to fertilizing the soil with ash from biomass.

### Demonstration of nut coal replacement by biomass briquette/log

Due to the large share of coal-fired boilers powered manually with large pieces of coal (so-called nut coal) with a size 25-50 mm or 40-80 mm) in the Oborniki Śląskie commune, it was important to show the possibility of replacing fossil fuel with biomass fuel. In this case, the equivalent for this type of coal is biomass compacted in the form of briquettes or piece wood (wood logs). Briquettes can be produced from forest or agricultural biomass (depending on the availability). As a result, there is no need to make any significant changes to the heating system. Alternatively, a larger boiler charge (greater batch) may be required (due to a slightly lower calorific value of biomass) or faster charging of the boiler with another portion of fuel.

The demonstration has been performed in Pęgów cottage (Oborniki Śląskie commune) in a typical single household (heated surface area: 120 $m^2$). The building is heated by the old manually fed coal boiler (12 years old). Thermal capacity of the boiler is ca. 20 kW. The basic fuel is bituminous coal. The dedicated coal assortment is nut (40-80 mm) and cube (63-200 mm). The water heating circle is open. The hot water tank for sanitary purposes has a capacity of 120 $dm^3$. Within this activity a dedicated movie has been recorded and shared via BECoop webpage and other social media.

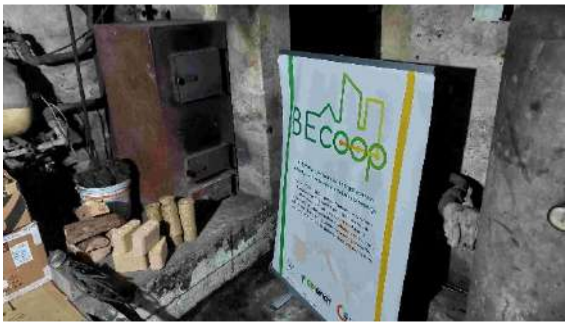



*Figure 33. Nut coal replacement by biomass briquette/log*

The added value is the use of local renewable fuel, the possibility of using ash in the garden as fertilizer, and a significant reduction in emissions of pollutants into the atmosphere (compared to coal). However, attention should be paid to the need to ensure that biomass (briquettes and pieces of wood) is stored in a dry room (or at least under a roof) and that only pieces of wood with a moisture content of less than 20% should be burned, which will ensure high combustion efficiency and heating efficiency.

### Demonstration of bulk density of different fuels

In relation to biomass storage and transportation, the bulk density of biomass is one of the most important factors influencing the storage space, required truck volume for fuel delivery and logistics costs. Considering that each fuel requires some storage space, the demonstration of the process followed for bulk density estimation has been realized. During this interactive demonstration the stakeholders could personally try to determine this parameter.

*Figure 34. Demonstrations of bulk density of different fuels with stakeholders*

The bulk density of the material was determined according to the EN 1237:2000 standard using the following formula:

$$\rho_V = \frac{m_i}{V_i} \cdot 100\%$$

where: $\rho_v$ – bulk density (kg/m$^3$), $m_i$ – mass of the investigated material (kg), $V_i$ – volume of the container fulfilled by the investigated material (m$^3$).

This practical exercise was performed as many households are not ready to store the amount of biomass for a heating season in the dry and well-ventilated storage room, especially if coal is replaced by biomass pellets or briquettes (coal can be stored also in open-air). Therefore, it is important to know how much biomass in the given form/type the final user is able to store (as the storage space is very often limited). The visual tests facilitated the understanding and importance of this factor in practice.

## Demonstration of biomass resistance on water absorption

During the pellets storage (and other biomass fuels) it is important to protect them against water access. The pellets with high water content or pellets absorbing water are losing their heating properties and mechanical durability. Too much water can lead to complete destruction of pellets. To share this knowledge with stakeholders, the demonstration of biomass resistance on water absorption was performed.


*Figure 35. Pellet water absorption exhibition*

After the tests the discussion about the biomass fuels storage was performed. Special attention was put on the preparation of the dry storage space with ventilation system to ensure the long-term high quality of pellets and efficient combustion in the fully automatic boiler.

## Demonstration of mechanical durability of pellets

For the automated fuel boilers that burn pellets, the best option is to utilize pellets characterized by high mechanical durability. Pellets with high mechanical durability insure stable and efficient combustion. Therefore, the demonstration showing the procedure of validating the mechanical durability of pellets has been presented.

The mechanical durability test of pellets was carried out in the especially constructed apparatus meeting all the requirements of the EN ISO 17831-1:2016-02 standard. The procedure of the mechanical durability test was as follows: the mass of the pellets (500 g ± 10 g for the pellets with a diameter below 12 mm or 500 g ± 50 g for the pellets with a diameter over 12 mm) was put into the working chamber. The procedure for the mechanical durability analysis consisted of randomly sampling of pellets (500 ± 10 g) from the 15 kg bags of commercial pellets. The rotational speed of the chamber was 50 rpm, whereas the operation time was 10 minutes. After the test, the entire content of the chamber was sieved through a sieve with a mesh diameter of 3.15 mm. The sieving process consisted of making 10 circular movements with a sieve containing the investigated pellets. Next, these two separated samples of the pellets were weighed using a laboratory scale with an accuracy of 0.1 g. Finally, the mechanical durability ($D_U$) index of pellets was determined using the following formula:

$$D_U = \frac{m_2}{m_1} \times 100\%$$

where: $D_U$ – mechanical durability index of pellets (%), $m_2$ – the mass of pellets left on the 3.15 mm sieve after the test and sieving (g), $m_1$ – the mass of pellets inserted into the working chamber of the apparatus (g). According to the ISO standard, the mechanical durability index for investigated pellets might be higher or lower than 97.5%. As a result, the pellets either meet the mechanical durability criterion (if DU ≥ 97.5%) or do not meet the defined criterion (DU < 97.5%).

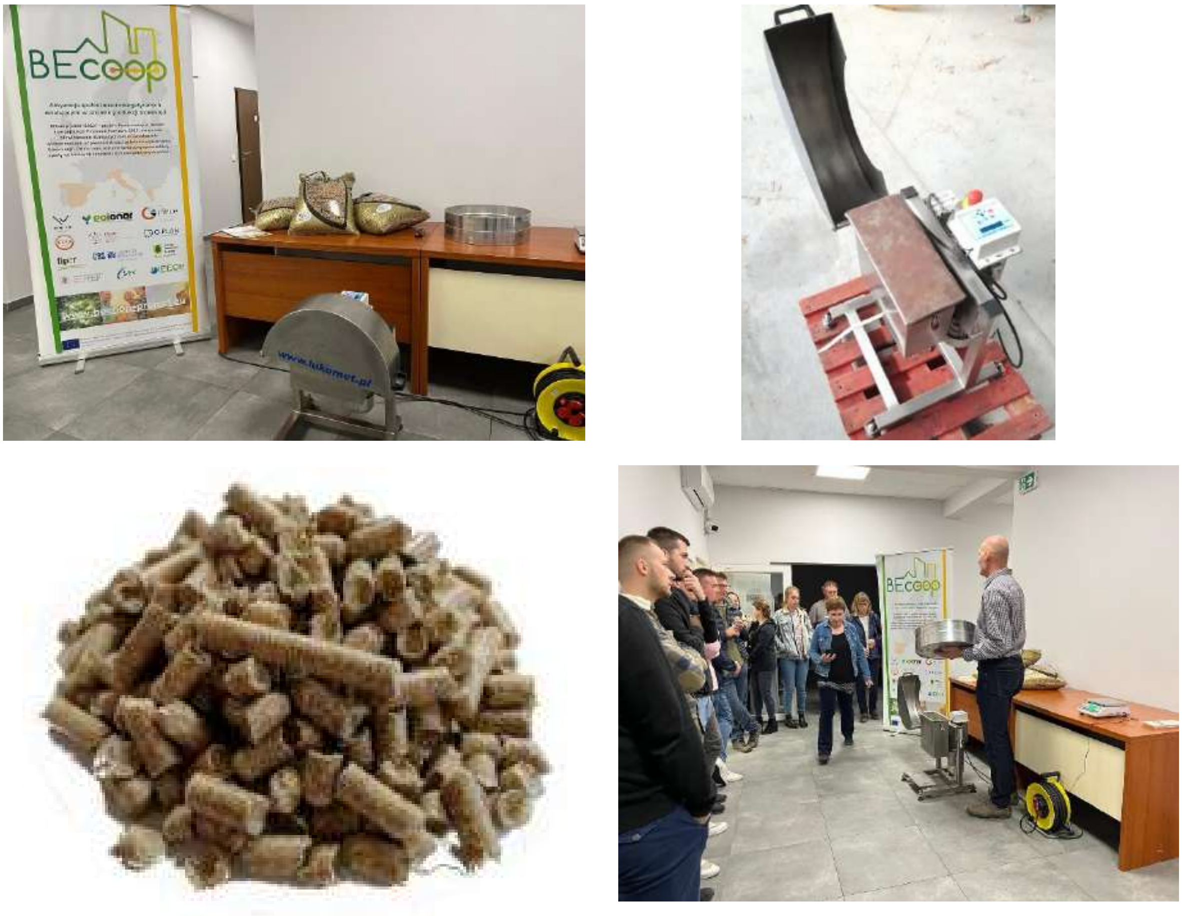


*Figure 36. Demonstration of mechanical durability of pellets*

Main attention was focused on the importance of the adequate mechanical durability of pellets and its influence on storage, transportation and combustion in the boiler. It was underlined that short logistic chain can reduce the risk of pellets destruction (defragmentation). Moreover, storage conditions also influence the mechanical durability of pellets, especially the water or moist air can lead to a significant decrease of its mechanical durability. Therefore, dry and ventilated storage room (or tank) is recommended. That information was very important for the potential pellets producers, sellers and final users. It helped to organize properly the logistics process or storage space.

## Biomass fuel analysis

The proposed logistic chain in the Oborniki Śląskie commune includes the use of biomass from forestry and agricultural resources. The main materials for pellets production are forestry wood and straw. Therefore, the knowledge about the main chemical-physical properties of these fuels is necessary. However, the municipality of the OBS considers further increase of other biomass residues utilization in the future, including bio-residues from selective collection and municipal biomass from parks cleaning, trees pruning, shrubs cutting etc.. As a result, the analysis of other biomass materials has been performed to have a better picture about the biomass potential for heating purposes in the OBS area.

*Table 32. Main fuel characteristics of various solid biofuels in the Polish area*

| Type of biomass | Lower Heating Value (MJ/kg) | Ash content, (%) | Moisture content, (%) | Volatile matter content, (%) | Carbon, (%) | Hydrogen, (%) | Nitrogen, (%) | Sulphur, (%) |
|---|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Forest wood | 17.89 | 0.66 | 3.0 | 77.8 | 47 | 6.7 | 0.11 | 0.021 |
| Straw | 15.99 | 7.27 | 10.3 | 72.8 | 40 | 6.1 | 0.69 | 0.089 |
| Grass | 18.63 | 6.76 | 1.16 | 76.91 | 46 | 7.0 | 1.7 | 0.206 |
| Pine tree | 20.09 | 1.06 | 0.81 | 81.98 | 49 | 7.3 | 0.10 | 0.021 |
| Sunflower husk | 18.25 | 2.99 | 13.8 | 71.8 | 44 | 6.4 | 0.8 | 0.131 |
| Apple pruning | 15.86 | 3.65 | 12.12 | 80.66 | 51 | 8.5 | 0.20 | 0.015 |
| Cherry pruning | 17.02 | 3.48 | 9.39 | 74.80 | 52 | 8.5 | 0.78 | 0.032 |
| Pear prunning | 17.03 | 4.19 | 8.77 | 80.22 | 49 | 8.8 | 1.2 | 0.058 |
| Digestate | 17.22 | 7.10 | 16.4 | 67.3 | 40 | 6.5 | 1.5 | 0.47* |
| Peach Seeds | 20.51 | 0.79 | 0.236 | 76.97 | 49 | 6.9 | 0.54 | 0.025 |
| Beetroot Pomace | 17.55 | 5.87 | 1.03 | 77.96 | 50 | 8.7 | 1.3 | 0.186 |
| Walnut shells | 18.73 | 1.10 | 4.32 | 81.4 | 48 | 8.0 | 3.1 | 0.015 |
| Hazelnut shells | 17.08 | 1.00 | 9.56 | 78.0 | 49 | 7.8 | 0.4 | 0.021 |
| Peanut shells | 18.45 | 2.20 | 6.32 | 78.8 | 49 | 7.9 | 1.2 | 0.074 |
| Orange peels | 17.97 | 3.25 | 4.5 | 90.6 | 48 | 7.9 | 0.68 | 0.051 |
| Lemon peels | 16.11 | 4.9 | 4.22 | 80.77 | 45 | 8.6 | 1.1 | 0.074 |
| Mandarin peels | 16.07 | 3.9 | 4.57 | 82.16 | 47 | 8.7 | 1.0 | 0.072 |

*value obtained from literature

# Annex III: Italian BECoop RESCoop

## Additional activities performed

In addition to the main activities performed in the main body of the deliverable, two other small demonstrations took place (M23):

1) provision of instructions regarding the safety and protection measures when using chainsaws in a forest site for increasing the level of safety in forestry work, attended by 15 participants (mainly citizens, families, institutions, forest operators etc.);
2) training on recognizing alpine tree species and the impact of bark beetles on wood for raising awareness of the importance of cultivating the forest to ensure carbon storage and biodiversity conservation, attended by 15 participants (mainly citizens, families, institutions, forest operators etc.).


*Figure 37: Small demonstrations on safety and protection measures when using chainsaws in forest site & Raising awareness of the importance of cultivating the forest, Italy*

Further to the main activities performed and reported in the main body of the current deliverable, more field visits were performed and organized by the Italian partners (FIPER and SEV). These visits have been also reported in DLV 4.2, but are also briefly presented in the following tables:

| ***Field Visit: The sawmill of the Magnificent Community of Fiemme*** | |
|---|---|
|  | |
| **Brief Description:** | Visit to the sawmill of the Magnificent Community of Fiemme. Lumber processing chain analysis from log to processing residue management (trimmings, wood chips, etc). All forest enterprises send their wood here. The sawmill manages 15,000 ha of public forest (50 km sourcing radius). |
| **When:** | 29th March 2023 |
| **Where:** | Cavalese, Italy |

| | |
|---|---|
| **Why:** | Explanation of chain of custody and forest and wood product certification system. |
| **No of participants:** | 15 |
| **Type of stakeholders:** | Citizens/General Public / Biomass Owners / Authorities/Municipalities / Research Centers/ Universities / Biomass management companies/ RESCoops |

| ***Field Visit: Biomethane plant Bioenergia Trentino in Cadino*** | |
|---|---|
|   | |
| **Brief Description:** | Visit to a biomethane plant that produces and sells electricity (700 kWel), biomethane (360 $Nm^3/h$) and compost (14,000 metric tons). Supply chain analysis of organic waste collection, management and processing. |
| **When:** | 29th March 2023 |
| **Where:** | Cadino, Italy |
| **Why:** | A field visit to a success case that implements a technology not investigated thoroughly by the BECoop RESCoops (biogas and biomethane production), that could be an additional technological solution for bioenergy communities. |
| **No of participants:** | 15 |
| **Type of stakeholders:** | Associations / Research Centers/ Universities/ RESCoop |

| ***Field Visit: E-Werk Prad*** | |
|---|---|
|    | |
| **Brief Description:** | Visit to a success case of RESCoop with 1,443 members. Activities of RESCoop such as production, supply and distribution of electricity and heat along with distribution of fast internet (fiber to the home). Visit to hydropump plant (3 MW), district heating plants, biogas plant |
| **When:** | 30th March 2023 |
| **Where:** | Prato allo Stelvio, Italy |

| | |
|---|---|
| **Why:** | To visit a successful example of RESCoop that combines and exploits different renewable energy sources such as solar, hydro, biomass. |
| **No of participants:** | 15 |
| **Type of stakeholders:** | Associations / Research Centres/ Universities/ RESCoop |

| ***Field Visit: Fernheizwerk Toblach-Innichen (Teleriscaldamento Termo-Elettrico Dobbiaco)*** | |
|---|---|
|    | |
| **Brief Description:** | Visit to a successful case of RESCoop with 1,000 members and a biomass District heating plant with cogeneration (16 MWth, 1.5 MWel total) that implements also ORC technology and provides fiber-optic internet to all its members. |
| **When:** | 31st March 2023 |
| **Where:** | Dobbiaco, Italy |
| **Why:** | One successful RESCoop that could be an example for replication for the Italian BECoop RESCoop activities: Biomass district heating along with ORC cogeneration. |
| **No of participants:** | 18 |
| **Type of stakeholders:** | Associations / Research Centres/ Universities/ RESCoop |

# Annex IV: Greek BECoop RESCoop

## Mixed Coffee pellet production and fuel characterization

The following sections include results on the fuel analyses of the rest samples of mixed pellets.

### Fuel Analyses of mixed biofuels: Spent coffee grounds with forest residues

**Error! Reference source not found.**, Figure 38 and Figure 39 , present the fuel characterization and major and minor elements of the coffee pellets mixed with forest residues at different ratios.

*Table 33. Main fuel characteristics of coffee pellets mixed with forest residues*

| Property | Units | CF0 | CF10 | CF30 | CF50 | CF70 | CF90 |
|---|---|---|---|---|---|---|---|
| Moisture | %, a.r.[14] | 8.4 | 8.7 | 8.8 | 9.5 | 10.7 | 10 |
| Ash | %, d.b. | 5.5 | 5.2 | 4.9 | 3.3 | 3.1 | 2.5 |
| Volatiles | %, d.b. | 76 | 75.3 | 75.7 | 75.4 | 75.7 | 76.3 |
| C | %, d.b. | 48.57 | 49.12 | 49.26 | 50.66 | 50.57 | 50.77 |
| H | %, d.b. | 5.66 | 5.67 | 5.73 | 6.05 | 6.13 | 6.22 |
| N | %, d.b. | 0.51 | 0.78 | 1.43 | 2.26 | 2.53 | 2.96 |
| S | %, d.b. | 0.05 | 0.06 | 0.11 | 0.16 | 0.18 | 0.2 |
| Cl | %, d.b. | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| HHV | MJ/kg, d.b. | 18.65 | 18.86 | 18.65 | 20.02 | 19.18 | 20.53 |
| LHV | MJ/kg, a.r. | 15.75 | 15.87 | 15.68 | 16.7 | 15.68 | 17.02 |
| Bulk density | kg/m3, a.r. | 684 | 687 | 701 | 695 | 666 | 725 |
| Mechanical Durability | %, a.r. | 94.3 | 95.5 | 93.4 | 93.4 | 91.9 | 91.1 |
| SST | °C | 994 | 1028 | 1024 | 1073 | 1089 | 1138 |
| DT | °C | 1266 | 1223 | 1251 | 1266 | 1246 | 1294 |
| HT | °C | 1211 | 1261 | 1277 | 1343 | 1351 | 1539 |
| FT | °C | 1225 | 1280 | 1284 | 1373 | 1404 | >1550 |

[14] *d.b.: dry basis; a.r.: as received

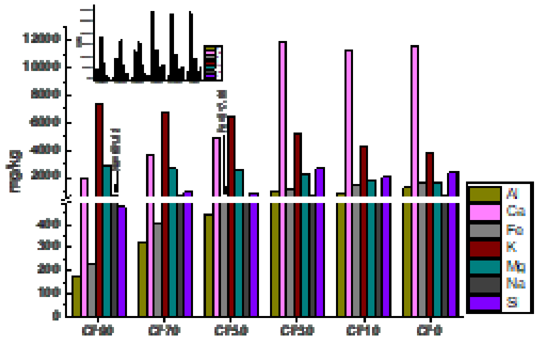


*Figure 38. Major elements (mg/kg d.b.) of coffee pellets mixed with forest residues*

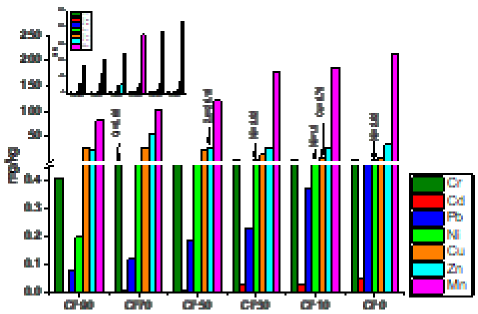


*Figure 39. Minor (down) elements (mg/kg d.b.) of coffee pellets mixed with forest residues*

Overall, the produced pellets have a range of LHV from 15.75-17.02 MJ/kg (a.r.) and ash content from 2.5-5.5% (d.b). From the results, it is demonstrated that as the content of coffee residues increases in the fuel mixture, the heating values, bulk density, carbon, and hydrogen content increases, whereas the ash content decreases significantly (from 5.5% to 2.5%) and the chlorine content decreases slightly. The ash decrease could be possibly attributed to the lesser forest residues in the fuel mixture, thus less leaves and soil contamination. On the other hand, by increasing the coffee residues in the mixture leads to increasing the nitrogen and Sulphur content and decreasing the mechanical durability of the pellet.

Regarding the major elements, it can be surmised that by increasing the content of coffee residues in the mixture, the potassium (K) increases from 3,747 mg/kg (CF0) to 7,356 mg/kg (CF90), along with Magnesium (Mg). Nonetheless, increasing the content of coffee residues in the fuel mixtures, the content of calcium (Ca) and silica (Si) decreases significantly. This is possibly attributed since less forest residues in the mixture means also less soil contamination, and thus less Ca and Si. Other major elements such as Iron (Fe) and Aluminum (Al) also decreases, whereas the rest have no major differences when the ratio of spent coffee ground changes. Regarding the minor elements, by increasing the coffee residues in the fuel mixtures, the Cu content increases. On the other hand, by increasing the spent coffee ground, the content of Mn decreases significantly, along with Cr, Pb, and Ni. All the rest minor elements are either reduced or they have negligible alterations. In overall, all pellet mixtures are in line with the limits of ISO 17225-2 for wood pellets regarding minor elements, apart from Cu (limit of 10 mg/kg d.b. for class A and B pellets). The limit is surpassed for pellet mixtures with 30% coffee residues (Cu at 14.3 mg/kg) and above.

## Fuel Analyses of mixed biofuels: Spent coffee grounds with urban prunings

**Error! Reference source not found.**, Figure 40 and Figure 41 present the fuel characterization and major and minor elements of the coffee pellets mixed with urban prunings.

*Table 34. Main fuel characteristics of coffee pellets mixed with urban prunings*

| Property | Units | CU0 | CU10 | CU30 | CU50 |
|---|---|---|---|---|---|
| Moisture | %, a.r.[15] | 10.3 | 11.1 | 11.4 | 10.9 |
| Ash | %, d.b. | 4.2 | 1.6 | 3.7 | 3.4 |
| Volatiles | %, d.b. | 68.6 | 77.9 | 75.8 | 75.8 |
| Carbon, C | %, d.b. | 49.64 | 50.35 | 50.11 | 50.48 |
| Hydrogen, H | %, d.b. | 5.86 | 6.01 | 5.99 | 6.09 |
| Nitrogen, N | %, d.b. | 0.51 | 0.8 | 1.6 | 2.11 |
| Sulphur, S | %, d.b. | 0.04 | 0.05 | 0.11 | 0.13 |
| Chlorine, Cl | %, d.b. | 0.02 | 0.02 | 0.02 | 0.02 |
| HHV | MJ/kg, d.b. | 19.42 | 19.87 | 20.23 | 20.53 |
| LHV | MJ/kg, a.r. | 16.02 | 16.23 | 16.5 | 16.85 |
| Bulk density | kg/m3, a.r. | 688 | 648 | 671 | 664 |
| Mechanical Durability | %, a.r. | 96.8 | 96.2 | 94.6 | 93.1 |
| SST | °C | 1017 | 748 | 771 | 1053 |
| DT | °C | 1358 | 1335 | 1313 | 1311 |
| HT | °C | 1523 | 1527 | 1451 | 1475 |
| FT | °C | 1531 | 1536 | 1468 | 1486 |

[15] *d.b.: dry basis; a.r.: as received

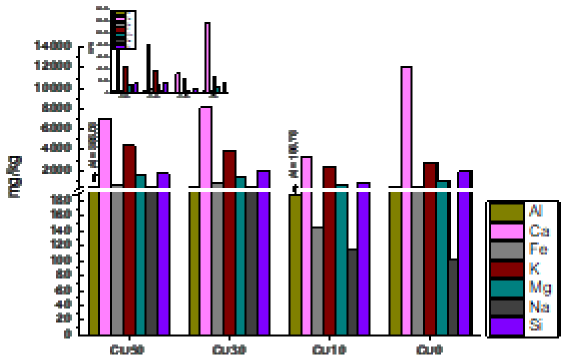


*Figure 40. Major elements (mg/kg d.b.) of coffee pellets mixed with urban prunings*

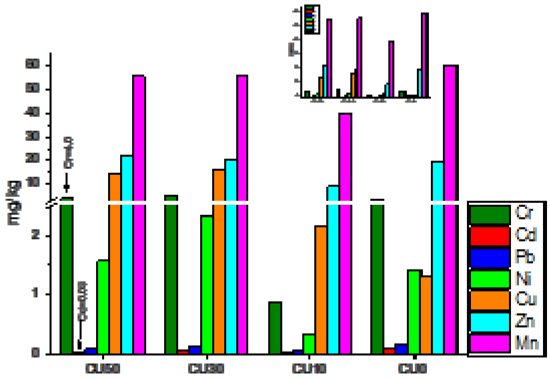


*Figure 41. Minor (down) elements (mg/kg d.b.) of coffee pellets mixed with urban prunings*

The produced pellets have a range of LHV from 16.02- 16.85 MJ/kg (a.r.) and ash content from 1.6- 4.2 % (d.b). As exhibited by the results, when the content of coffee residues increases, the heating value, carbon, and hydrogen content increases. Furthermore, by increasing the coffee residues in the mixture, the ash content decreases in the produced pellets. More specifically, the produced pellet from only urban prunings had 4.2 %, d.b. ash content, whereas, by mixing it with 50 wt% coffee residues (CU50) the ash content was reduced to 3.4 %, d.b. However, as it was identified in the previous solid biofuels mixtures, the increased coffee residues also increases the nitrogen (from 0.51 wt% in CU0 sample to 2.11 wt% in CU50) and Sulphur content and decreases the mechanical durability of the pellet. Finally, the properties of this mixture comply with the class B limits set by ISO 17225-2 for wood pellets with up to 10% coffee residues (CU10), apart from LHV where the limit is at 16.5 MJ/kg and that of CU10 pellet is at 16.23 MJ/kg.

Regarding the major elements, by increasing the content of coffee residues in the mixture, the potassium (K) increases from 2,747 mg/kg (CU0) to 4,435 mg/kg (CU50), along with Magnesium (Mg). However, by increasing the content of coffee residues in the fuel mixtures, the content of calcium and silica decreases significantly. More specifically, the content of calcium (Ca) drops from 12,043 mg/kg (CU0) to 7,020 mg/kg (CU50). This may be attributed to the fact that increasing the coffee residues, the leaves and soil contamination from urban prunings is reduced, and thus the content of calcium and silica. Regarding the minor elements, by increasing the coffee residues in the fuel mixtures, the Cu content increases significantly. More specifically, the Cu content increases from 1.3 mg/kg (CU0) to 14.1 mg/kg (CU50). All the rest minor elements are either reduced or they have negligible alterations. Pellet mixtures with 10% coffee residues and 90% urban prunings are in line with the limits of ISO

17225-2 for wood pellets (class A and B pellets) regarding minor elements. The rest pellet mixtures also comply with the limits, apart from their Cu content that is higher (Cu at 16.5 mg/kg for CU30 and 14.1 mg/kg for CU50).

### Fuel Analyses of mixed biofuels: Spent coffee grounds with maize residues

Table 35, Figure 42 and Figure 43 present the fuel characterization and major and minor elements of the coffee pellets mixed with maize residues.

The produced pellets have a range of LHV from 13.51- 16.45 MJ/kg (a.r.) and ash content from 3.9-15.2 % (d.b). From the results, it is demonstrated that when the content of coffee residues increases, the heating value increases significantly by 23% (CM90 compared to CM0). As in the previous solid biofuels mixtures, carbon and hydrogen content increases as well. Furthermore, by increasing the coffee residues in the mixture, the ash content decreases in the produced pellets significantly. This may be attributed to the high ash content of the agricultural residues. More specifically, the produced pellet from only maize residues had 15.2 %, d.b. ash content, whereas, by mixing it with 90 wt% coffee residues (CM90) the ash content was reduced by 74%. However, as in the previous solid biofuels mixtures, it can be seen that the increased coffee residues also increases the nitrogen (from 0.9 wt%, d.b. in CM0 to 3.1 wt% in CM90) and Sulphur content (from 0.10 wt%, d.b. in CM0 to 0.17 wt% in CM90). On the other hand, by increasing the content of coffee residues the chlorine content is reduced as also the mechanical durability of the pellet. The high ash content of the produced pellets and high N, S, Cl content don't comply with the limits set by ISO 17225-2 for wood pellets or Biomasud Plus® for pellets for commercial/residential applications.

*Table 35. Main fuel characteristics of coffee pellets mixed with maize residues*

| Property | Units | CM0 | CM10 | CM30 | CM50 | CM70 | CM90 |
|---|---|---|---|---|---|---|---|
| Moisture | %, a.r.[16] | 7.4 | 11.6 | 8.4 | 10.7 | 9.9 | 11.7 |
| Ash | %, d.b. | 15.2 | 13.5 | 12.4 | 8 | 5.8 | 3.9 |
| Volatiles | %, d.b. | 68.6 | 69.6 | 69.7 | 72.9 | 74.1 | 75.2 |
| C | %, d.b. | 41.75 | 43.05 | 43.91 | 46.76 | 48.84 | 50.25 |
| H | %, d.b. | 5.05 | 5.23 | 5.36 | 5.66 | 5.96 | 6.14 |
| N | %, d.b. | 0.9 | 1.16 | 1.99 | 2.15 | 2.76 | 3.14 |
| S | %, d.b. | 0.1 | 0.1 | 0.14 | 0.14 | 0.16 | 0.17 |
| Cl | %, d.b. | 0.28 | 0.25 | 0.18 | 0.12 | 0.07 | 0.04 |
| HHV | MJ/kg, d.b. | 15.89 | 15.78 | 17.02 | 16.97 | 18.24 | 20.28 |
| LHV | MJ/kg, a.r. | 13.51 | 12.65 | 14.31 | 13.8 | 15.02 | 16.45 |
| Bulk density | $kg/m^3$, a.r. | 740 | 662 | 716 | 708 | 715 | 682 |

[16] *d.b.: dry basis; a.r.: as received

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mechanical Durability | %, a.r. | 95.4 | 97.6 | 92.5 | 95.3 | 93.6 | 92.7 |
| SST | °C | 836 | 828 | 1210 | 1179 | 1076 | 1040 |
| DT | °C | 1241 | 1257 | 1254 | 1210 | 1130 | 1135 |
| HT | °C | 1299 | 1321 | 1321 | 1270 | 1192 | 1205 |
| FT | °C | 1316 | 1335 | 1338 | 1296 | 1216 | 1228 |

Regarding the major elements, it can be seen that by increasing the content of coffee residues in the mixture, the potassium (K) decreases significantly from 16,349 mg/kg (CM0) to 6,452 mg/kg (CM90). In brief, all major elements were decreased by increasing the content of the coffee residues in the fuel mixture with maize residues, thus improving the “quality” of the fuel. This may be attributed to the fact that increasing the coffee residues, the soil contamination from maize residues was reduced, and thus the content of calcium and silica was reduced. The same trend is followed by the minor elements as well. By increasing the coffee residues in the fuel mixtures, all minor elements were reduced apart from Cu content that was slightly increased. More specifically, the Cu content increases from 14.0 mg/kg (CM0) to 23.8 mg/kg (CM90). For this set of pellets produced, all mixtures did not comply with the limits of ISO 17225-2 for wood pellets (class A and B pellets) regarding minor elements due to the Cu content that was above limit for all ratios. Other than Cu, the CM0, CM10, CM30 samples were above the limit for the Ni content. However, by increasing the coffee residues in the fuel mixture, the Ni content was decreased and the produced pellets with 50 wt% and more coffee residues were within the limits.

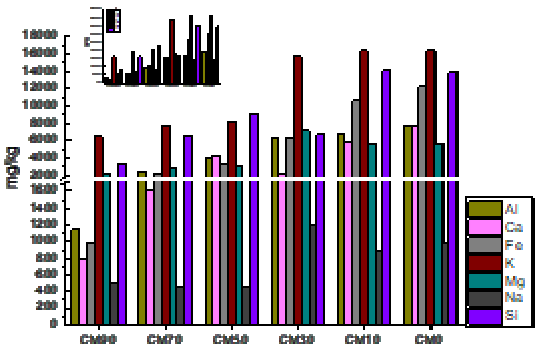


*Figure 42. Major elements (mg/kg d.b.) of coffee pellets mixed with maize residues*

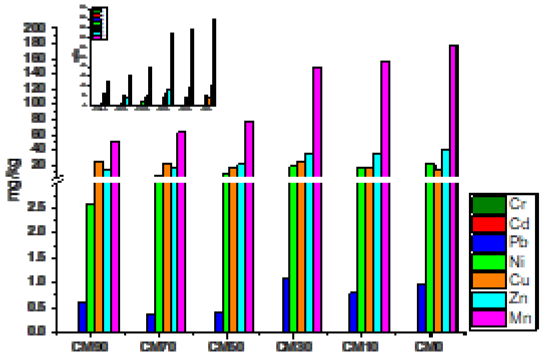

*Figure 43. Minor (down) elements (mg/kg d.b.) of coffee pellets mixed with maize residues*

## Fuel Analyses of mixed biofuels: Spent coffee grounds with peach prunings

Table 36, Figure 44 and Figure 45 present the fuel characterization and major and minor elements of the coffee pellets mixed with peach prunings.

*Table 36. Main fuel characteristics of coffee pellets mixed with peach prunings*

| Property | Units | CP0 | CP10 | CP30 | CP50 | CP70 | CP90 |
|---|---|---|---|---|---|---|---|
| Moisture | %, a.r.[17] | 6.6 | 9 | 9.2 | 8.3 | 9.4 | 8.9 |
| Ash | %, d.b. | 5.1 | 4.7 | 4.3 | 3.6 | 3 | 2.4 |
| Volatiles | %, d.b. | 68.6 | 69.6 | 69.7 | 72.9 | 74.1 | 75.2 |
| C | %, d.b. | 48.21 | 48.47 | 49.11 | 49.58 | 50.14 | 50.48 |
| H | %, d.b. | 5.05 | 5.23 | 5.36 | 5.66 | 5.96 | 6.14 |
| N | %, d.b. | 1.15 | 1.22 | 1.84 | 2.3 | 2.71 | 3.02 |
| S | %, d.b. | 0.06 | 0.07 | 0.11 | 0.14 | 0.17 | 0.19 |
| Cl | %, d.b. | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 |
| HHV | MJ/kg, d.b. | 18.52 | 19.06 | 19.49 | 20.07 | 20.46 | 20.38 |
| LHV | MJ/kg, a.r. | 15.98 | 15.98 | 16.31 | 17.01 | 17.12 | 17.13 |
| Bulk density | kg/m$^3$, a.r. | 679 | 630 | 652 | 706 | 668 | 714 |
| Mechanical Durability | %, a.r. | 97.8 | 96.5 | 94.3 | 91.3 | 91.9 | 90.9 |
| SST | °C | 1084 | 1071 | 1054 | 1059 | 1187 | 1208 |
| DT | °C | 1317 | 1317 | 1318 | 1326 | 1368 | 1322 |

[17] *d.b.: dry basis; a.r.: as received

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| HT | ºC | 1524 | 1481 | 1520 | 1543 | 1508 | 1540 |
| FT | ºC | 1529 | 1503 | 1537 | 1555 | 1538 | >1550 |

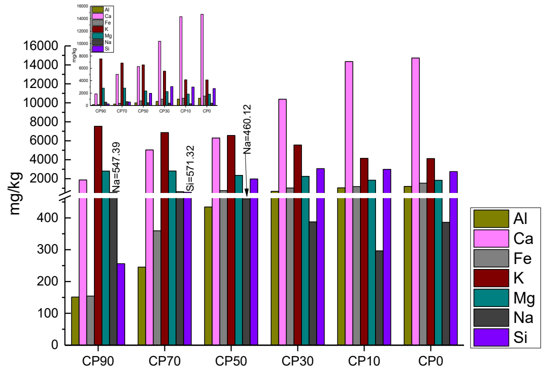


*Figure 44. Major elements (mg/kg d.b.) of coffee pellets mixed with peach prunings*

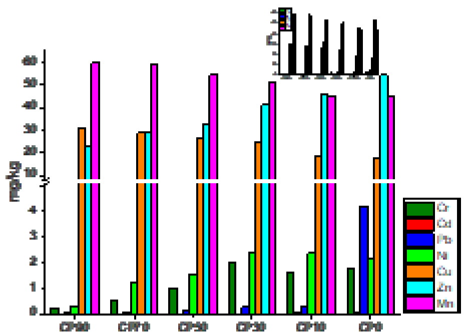

*Figure 45. Minor (down) elements (mg/kg d.b.) of coffee pellets mixed with peach prunings*

The produced pellets have a range of LHV from 15.98- 17.13 MJ/kg (a.r.) and ash content from 2.4- 5.1 % (d.b). From the results, it can be seen that when the content of coffee residues increases, the heating value, carbon and hydrogen content increases. More specifically, by adding 90 wt% coffee residues, the LHV was increased by 7.2%. Furthermore, by increasing the coffee residues in the mixture, the ash content decreases in the produced pellets. The produced pellet from only peach prunings had 5.1 %, d.b. ash content, whereas, by mixing it with 90 wt% coffee residues (CP90) the ash content was reduced by 52.9%. The significant decrease of ash content may be attributed to fewer leaves or soil contamination through the peach prunings. Moreover, the increased coffee residues also increased the nitrogen (from 1.15 wt% in CP0 sample to 3.02 wt% in CP90) and Sulphur content (from 0.06 wt% in CP0 sample to 0.19 wt% in CP90) and decreased the mechanical durability of the pellet. Finally, the high ash content of the produced pellets and high N, S, Cl content don't comply with the limits set by ISO 17225-2 for wood pellets for commercial/residential applications or other solid biofuel certification schemes e.g. Biomasud Plus® for agripellets.

Regarding the major elements, the same trend is followed as in the pellet samples with maize residues. In brief, all major elements were decreased by increasing the content of the coffee residues in the fuel mixture with peach prunings, thus improving the "quality" of the fuel. This may be attributed to the fact that increasing the coffee residues, the soil contamination and/or leaves from peach prunings is reduced, and thus the content of calcium and silica was reduced. Almost the same trend is followed by the minor elements as well. By increasing the coffee residues in the fuel mixtures, all minor elements, apart from Mn and Cu, were reduced. More specifically, the Cu content was increased from 17.2 mg/kg (CP0) to 31.0 mg/kg (CP90). For this set of pellets produced, all mixtures did not comply with the limits of ISO 17225-2 for wood pellets (class A and B pellets) regarding minor elements due to the Cu content that was above limit for all ratios. Other than Cu, the rest minor elements were within the limits.

## Fuel Analyses of mixed biofuels: Spent coffee ground with miscanthus

Table 37, Figure 47 and Figure 29 present the fuel characterization and major and minor elements of the coffee pellets mixed with miscanthus.

*Table 37. Main fuel characteristics of coffee pellets mixed with miscanthus*

| Property | Units | CMI0 | CMI30 | CMI50 |
|---|---|---|---|---|
| Moisture | %, a.r.[18] | 9.5 | 8.1 | 8.6 |
| Ash | %, d.b. | 11.2 | 9.2 | 6.8 |
| Volatiles | %, d.b. | 72.9 | 73 | 73.9 |
| C | %, d.b. | 43.79 | 45.57 | 47.66 |
| H | %, d.b. | 5.33 | 5.55 | 5.77 |
| N | %, d.b. | 0.37 | 1.32 | 1.94 |
| S | %, d.b. | 0.05 | 0.1 | 0.11 |
| Cl | %, d.b. | 0.16 | 0.13 | 0.08 |
| HHV | MJ/kg, d.b. | 17.11 | 18.16 | 18.84 |
| LHV | MJ/kg, a.r. | 14.21 | 15.38 | 15.86 |
| Bulk density | kg/m3, a.r. | 617 | 597 | 567 |
| Mechanical Durability | %, a.r. | 94.8 | 92.2 | 91 |
| SST | °C | 859 | 1021 | 954 |
| DT | °C | 1175 | 1189 | 1589 |
| HT | °C | 1216 | 1239 | 1266 |

[18] *d.b.: dry basis; a.r.: as received

| | | | | |
|---|---|---|---|---|
| FT | °C | 1258 | 1261 | 1286 |

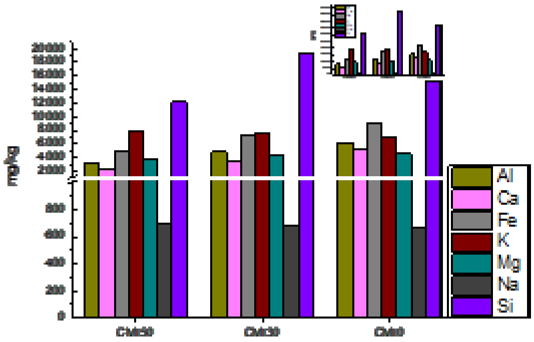


*Figure 46. Major elements (mg/kg d.b.) of coffee pellets mixed with miscanthus*

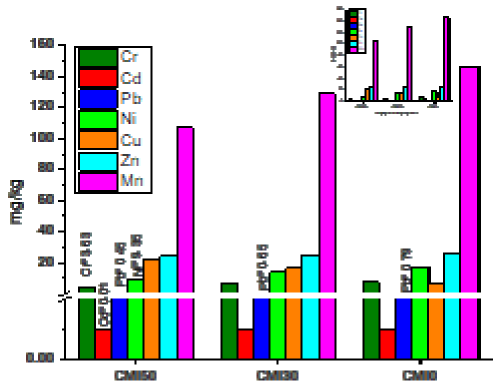


*Figure 47. Minor (down) elements (mg/kg d.b.) of coffee pellets mixed with miscanthus*

Miscanthus was mixed with coffee residues at three different ratios: 0 wt%, 30 wt% and 50 wt% coffee residues. The produced pellets had a range of LHV from 14.21-15.86 MJ/kg (a.r.) and ash content from 6.8- 11.2% (d.b). The addition of 50 wt% coffee residues (CMI50) increased the LHV of the fuel by 12%, compared to just miscanthus. Furthermore, though the pellet with only miscanthus (MI0) had high ash content, by mixing it with 50 wt% coffee residues (MI50) reduced the ash content by 39%. As it was also seen in the previous results, increasing the coffee residues in the pellets with miscanthus, it also increased the content of H and C. On the contrary, the increased coffee residues content didn't result to an increased bulk density. Instead, the higher the amount of residual coffee in the mixture, the lower was the bulk density of the pellets. Lastly, the increased coffee residues also increased the nitrogen (from 0.37 wt% in CMI0 sample to 1.94 wt% in CMI50) and Sulphur content (from 0.05 wt% in CMI0 sample to 0.11 wt% in CMI50) but reduced the chlorine content (from 0.16 wt% in CMI0 sample to 0.08 wt% in CMI50). Finally, the high ash content of the produced pellets and high N, S, Cl content, along with the low heating value of the fuels do not comply with the limits set by ISO 17225-2 for wood pellets for commercial/residential applications or other solid biofuel certification schemes e.g. Biomasud Plus® for agripellets.

Regarding the major elements, most major elements were either reduced or had slight alterations by increasing the content of coffee residues in the mixture. Only the Potassium content (K) increased from 7,023 mg/kg (CMI0) to 7,921 mg/kg (CMI50), along with a slight increase in the Sodium (Na) content (4% increase). Again, the content of calcium (Ca) drops from 5,272 mg/kg (CMI0) to 2,263 mg/kg (CMI50) and silica from. 15,123 mg/kg (CMI0) to 12,178 mg/kg (CMI50). This may be attributed to the fact that increasing the coffee residues, the soil contamination from miscanthus is reduced, and thus the content of calcium and silica. Regarding the minor elements, by increasing the coffee residues in the fuel mixtures seems to result in the reduction of most minor elements, apart from Cu. More specifically, the Cu content increased from 7.4 mg/kg (CMI0) to 22.5 mg/kg (CMI50). All of the rest minor elements are either reduced. Other minor elements such as Mn, Cr and Ni were reduced significantly while increasing the coffee residues content. Pellet mixtures are in line with the limits of ISO 17225-2 for wood pellets (class A and B pellets) regarding minor elements, apart from the Cu and Ni content. Only the pellet mixtures with only miscanthus (CMI0) were below the limit of Cu but were above the limit for Ni content. The only pellet mixture that was below the Ni content was that of CMI50, where the coffee residues resulted to a significant decrease in the Ni content.

# Pellet boiler installation and emissions monitoring

The following sections include results and information on the pellet combustion tests performed that were not added in the main body of the deliverable.

## Results of the small-scale demonstration

Through the emission measurement tool, several parameters were measured. The following equations were utilized to calculate boiler efficiency and other parameters, as described in the manual of the tool:

$$CO = \frac{21\% - \mathrm{O}_{2\mathrm{ref}}}{21\% - \mathrm{O}_2} \times CO \times 1.25$$

$$\lambda = \frac{\mathrm{CO}_{2\mathrm{max}}}{\mathrm{CO}_2}$$

$$qA = ((FT - AT) \times (\frac{\mathrm{A}_2}{21\% - \mathrm{O}_2} + B)) - \mathrm{K}_\mathrm{k}$$

$$\eta = 100 - qA$$

$$\mathrm{NO}_\mathrm{x} = \frac{21\%\text{-}\mathrm{O}_{2\mathrm{ref}}}{21\%\text{-}\mathrm{O}_2} \times \mathrm{NO}_\mathrm{x} \times 2.05$$

Where:

CO (carbon monoxide), mg/m$^3$

λ, air ratio

qA, flue gas loss

η, boiler efficiency

$NO_x$, nitrogen oxide

FT, flue gas temperature

AT, ambient temperature

$A_2$/B, fuel-specific parameters

21%, oxygen level of air

$O_2$, measured oxygen level in %

$K_k$, calculated value allowing for regained condensate heat if dewpoint level is reached

qA, calculated flue gas loss