Promoting the penetration of agrobiomass in European rural areas

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Agricultural woody biomass for energy: agricultural prunings, plantation removals and hedgerow prunings

Authoritative Guide

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About this document

The publication “**Agricultural woody biomass for energy: agricultural prunings, plantation removals and hedgerow prunings**”, made by Fundación Circe - Centro de Investigación de Recursos y Consumos Energéticos (CIRCE) with the assistance of Association d’Initiatives Locales pour l’Energie et l’Environnement (AILE) and Centre for Research and Technology Hellas (CERTH), is part of a series of authoritative guides prepared within the framework of the AgroBioHeat project that aim to provide a systematic knowledge about the utilization of different types of agrobiomass resources.

In particular, the present Guide focuses on woody biomass assortments that are generated from trees that are integrated in the agricultural landscape: orchards and hedgerows. Compared to forest woody biomass most commonly used in bioenergy applications, such biomass fractions may display interesting similarities but also differ in several important aspects. Although there is a significant potential of agricultural woody biomass assortments in several European countries or regions, for the most part they are underutilized for energy purposes. Therefore, there is still significant potential for the development of new biomass-to-energy value chains using these types of “agricultural wood”.

The AgroBioHeat project aims to produce a mass deployment of improved and market ready agrobiomass heating solutions in Europe. Agrobiomass is a large, underexploited and indigenous resource, which can support the achievement of the European Energy and Climate targets, while promoting rural development and circular economy. The project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No 818369.

For more information about the project, please visit: **www.agrobioheat.eu**

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Cover photo

Harvested pile of olive tree prunings and integrated harvesting/shredding system in Puglia, Italy. Source: Manolis Karampinos.

AgroBioHeat consortium

Logo	Description
CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS	Centre for Research and Technology Hellas (CERTH) is one of the leading research centres in Greece. Its areas of expertise include – among others – renewable energy sources, solid biofuels production and utilization, energy savings and environmental protection. www.certh.gr
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INASO-PASEGES INSTITOUTO AGROTIKIS & SYNETAIRISTIKIS OIKONOMIAS	INASO-PASEGES is a civil non profit organisation, established in 2005 in Athens by the Panhellenic Confederation of Unions of Agricultural Cooperatives (PASEGES). www.neapaseges.gr
ZEZ Zelena Energetska Zadruga	The Green Energy Cooperative (ZEZ) was established in 2013 as part of the project "Development of Energy Cooperatives in Croatia" implemented by the United Nations Development Program (UNDP) in Croatia. www.zez.coop
GREEN ENERGY Romanian Innovative Biomass CLUSTER	The Cluster's main purpose is to develop the bioenergy sector in Romania and raising the interest towards the production and utilization of the biomass. www.greencluster.ro

UABIO Bioenergy Association of Ukraine	UABIO was established in 2013 as a public organisation. The purpose of the Association's activity is to create a common platform for cooperation on the bioenergy market of Ukraine. www.uabio.org
Aile initiatives énergie environnement	AILE is working on renewable energies and energy savings in agricultural and rural areas of Western France. www.aile.asso.fr
WHITE RESEARCH	White Research is a social research and consulting enterprise specialising in consumer behaviour, market analysis and innovation management based in Brussels. www.white-research.eu
Agronergy	Agronergy is a French ESP (Energy Service Provider) dedicated to Renewable Heating. www.agronergy.fr

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Introduction

The utilization of agricultural residues as a source of biomass is an opportunity for supporting the expansion of the bioeconomy and renewable energy production in Europe. Several agricultural residues are of the herbaceous type, like straw. However, it is also possible to source **various types of woody biomass from the agricultural sector**: agricultural prunings from permanent crops (vineyard, olive groves, and fruit orchards), prunings from hedgerows and biomass by orchard plantations at the end of their lifetime.

The potential of such biomass resources in Europe is significant, especially in some member states. For example, the technical potential of prunings from permanent crops in the EU-28 was estimated to be 12.51 Mt of dry matter per year[1], while the potential of agricultural prunings together with plantation removal biomass was estimated to be more than 20 Mt of dry matter per year[2]. Prunings from hedgerows also represent a significant biomass potential in several European regions.

The use of such woody biomass fractions from agriculture for renewable energy production is a real possibility. There are several success cases in Europe that prove this. However, they are still scarce and isolated at the moment. The widespread utilization of agri-wood for energy appear stuck for multiple reasons which are related to technical barriers, but also - and more importantly - to non-technical constraints such as cultural attitude, current regulatory framework, market prices of fossil or other biomass fuels.

The aim of this Guide is to provide an introduction in those alternative sources of agri-wood for energy, highlighting the differences between the “traditional” sources of woody biomass and explain how they can be mobilized in the framework of biomass-to-energy value chains.

[1] Dyjakon, A., García-Galindo, D. 2019. “Implementing Agricultural Pruning to Energy in Europe: Technical, Economic and Implementation Potentials”. Energies 2019, 12(8), 1513; https://doi.org/10.3390/en12081513

[2] García-Galindo, D., Rezeau, A. et al. 2016. “Setting up and running sustainable supply of woody biomass from agrarian pruning”. European Biomass Conference and Exhibition. Pages: 1760 – 1765. Amsterdam: 6-9 June 2016.

1. Woody biomass from agricultural prunings

Agricultural prunings are generated from pruning operations frequently performed in productive tree orchards. There are several reasons why farmers prune trees: to maintain their health, to form a shape that is more suited to fruit harvesting, to enhance productivity and others. The frequency and type of pruning depends on several factors, including farmer preferences and applied techniques, crop requirements, etc.

For farmers, the management of prunings can be considered as a “waste” disposal issue. The value of the material is relatively low, but its volume is significant and needs to be handled before the farmers can move on to other agronomic practices in their orchards. Based on analysis from the EuroPruning project[3], the energetic utilisation of agricultural prunings in modern energy conversion system (e.g. efficient furnaces, boilers or gasifiers) usually corresponds to less than 5 % of the management practices. The use of firewood can be relevant locally in some rural areas where thick parts of pruning wood are valorized by part of local inhabitants, generally not an extended practice, thus in general lower than 20% of final use), but in general its use can be considered small at EU scale. However, the main management methods of the pruning biomass is its open-air burning, its disposal at field side where it is abandoned, or its use in form of shredded pieces widespread on the soil plantation.

Separated olive tree prunings from two olive trees in Southern Greece.

The largest pile in the back had a weight of 126.65 kg (fresh matter) and consisted of the smaller branches and most of the leaves. Their utilization for energy production would require their size reduction and the use of modern biomass heating systems. At the moment though, most farmers would dispose off those prunings with open fires or mulch them.

The thicker prunings in the front had a weight of 37.15 kg. Most farmers use such branches as firewood.

Figure 1: Olive tree prunings separated by size. Source: CERTH / uP_running project

A key factor that affects the organization of the biomass supply from agricultural prunings is the fact that production of biomass per hectare is low in comparison to forestry wood, and thus operations of

[3] EuroPruning, “Mapping and analysis of the pruning biomass potential in Europe”, Deliverable report D3.1, 2014, Available at: www.europruning.eu

collection, handling and processing at field are usually subject of relevant costs per unit of material processed. The agricultural pruning biomass productivity ranges from lower than 0.5 t/ha (dry matter) to 10 t/ha (in some extreme cases). The lowest productivities correspond to annual pruning of crops grown in dry areas without irrigation, or in areas of poor soils under low input agronomics. Annual pruning from crops in good climatic and agronomic conditions can usually produce from 0.5 to 2.0 t/ha (dry matter). Biennial pruning, as in case of olive groves can often range from 2 to 4 t/ha (dry matter), whereas less frequent operations like toppings or re-shaping of tree forms can produce even larger amounts.

The agricultural pruning biomass productivity depends on multiple factors, as described by García et al.[4]: type of crop, variety and age, form of the tree, density, type of pruning (pre-pruning, graft pruning, maintenance, topping, etc.), climate and soil conditions, and other agronomic operations relevant. As a result, it is inadvisable to use standard literature values of APPR biomass productivity when scoping a new initiative. Evaluation through direct measurements is always recommended and a manual is already available on the uP_running Observatory[5]. Alternatively, data from the Observatory tool can be useful for a first guess as this GIS (Geographic Information System) platform collects biomass productivity values from hundreds of field measurements in relation to the aforementioned factors.

Size and layout of the plantations as well as their territorial dispersion are two additional factors to be considered. In many cases, vineyards, olive and fruit plantations are organized in small parcels and distributed in the territory. In several cases (for example, several olive groves and vineyards in Southern Europe) the terrain has high slopes and features that may limit the capacity of a machinery to operate. Excessive maneuvering time can also occur due to the simple fact that a machine needs to operate in a field with a presence of trees that should not be damaged. Finally, moving machines from field to field requires additional time. All these aspects impose limitations on the types of collection systems that can be utilized and can increase operational costs. Moreover, in order to mobilize large volumes of biomass, an involvement of a large number of farmers and plantations is necessary, which increases the coordination and logistics costs. Farmers usually want to dispose residues from their fields quickly; the risk is that, when delays occur due to weather, or to unavailability of a service for biomass collection, farmers or plantation managers may opt for disposing the residues as usual, e.g., through open air burning, mulching, etc.

One additional factor that needs to be considered is that the fuel properties of agricultural prunings differ compared to conventional woody biomass fuels, such as forest wood chips. The energy content itself is quite similar – according to internal results obtained in the EuroPruning project, one kilogram of APPR biomass is equivalent to 1.03 kg of forestry wood, at same water content. However, thre are important differences in homogeneity of particle size and shape, as well as in ash content. More information on these aspects is provided in Chapter 5 of this Guide.

[4] García-Galindo, D., Rezeau, A. et al. 2016.

[5] uP_running, "Observatory map of biomass from agrarian pruning and plantation removal", 2017.: http://www.up-running-observatory.eu/

2. Woody biomass from plantation removals

Wood from plantation removal is usually produced when vines, olive or fruit trees are cleared out at the end of the lifetime of a plantation. In some cases, the termination of a plantation is driven by changes in the food market (for example, in order to grow a new fruit or grape variety), by agricultural policies (for modernization and reconversion of plantations) or by other particular reasons (plague/disease, farmer or exploitation manager). As for prunings, the wood from plantation removals is mostly under-utilized in Europe[6,7], although traditional use of firewood from the aerial part of the tree may be common in some areas. In such cases, the stump and roots, as well as thin branches remain unutilized. In many cases, the whole tree is just up rooted, piled with others, and fired in the open air.

The biomass productivity from plantation removals can easility reach 5 to 10 t/ha dry matter or even exceed it. These values are comparable to forestry exploitations which can easily reach above 40 t/ha dry matter of stem-based wood. Provided that there is a regular frequency of uprooting operations in a given area, new value chains using specialized machinery for the handling of plantation removal biomass may emerge.

Figure 2: Cutting of aerial part of peach trees in Sudanell, Spain. Source: CIRCE / AgroBioHeat project

[6] uP_running deliverable D2.1, "Sector Analysis and Action Plan for the Demo Regions", 2017, available at: http://www.up-running.eu/project-materials/

[7] uP_running deliverable D2.2, "Sector Analysis and Strategic Plan at national and EU level", 2018, available at: http://www.up-running.eu/project-materials/

Figure 3: Shredding of of aerial part of peach trees in Sudanell, Spain. Source: CIRCE / AgroBioHeat project

3. Woody biomass from hedgerow prunings

Considered a form of agroforestry, the hedges are landscapes with marked cultural and ecological characteristics. Hedges and groves are special environments for flora and fauna, for the quality of the water and the soil. It is human activities, farming activities in particular, that shape these landscapes[8].

The hedgerow pruning wood considered in this Guide comes from the trees growing around cultivated plots, meadows and pastures but also in valley bottoms and wetlands areas, groves and spinneys, along verges and roadsides, rivers, etc. These hedgerows have significant cultural and historical value and provide many functions and benefits within the landscape, including sheltering crops and livestock, supporting wildlife and linking habitats, controlling erosion and visually enhancing the landscape.

Hedgerows, like forests, play a dual role in the context of climate change. They store carbon in soil organic matter and through tree growth. In addition, the trees in the hedges, as well as the scattered trees within the plots, create a microclimate around them and contribute to reducing climatic extremes.

Hedgerow networks such as the hedgerow landscapes are the dominant type of semi-natural habitat in France, Finland, Ireland, Portugal, England, Netherlands, Lithuania, Latvia and northern Germany.

Management of hedgerows is necessary to maintain their basic functionalities, but it is complicated. Lack of time and means stimulates the choice of overly aggressive management methods (shears, cutters, pruning on three sides to uniform them in height, etc.) with the aim of containing the hedge, and not increasing its productivity. These methods, which are hostile for hedges functionalities, are anyway not appropriate to reach effective cost production and high quality of wood energy feedstock.

Historically, in hedgerow regions, the wood resource generated from hedgerow management allowed self-sufficiency to cover at least domestic needs. The transition from the use of log wood to chipped wood makes it possible to reduce the difficulty of the exploitation and use of hedgerow prunings for energy. Energetic use of hedgerow pruning allows hedgerow management to become from a net expense to a generator of savings through the substitution of fossil energy used for various heating applications: municipal buildings, livestock farms, etc.

Despite the significant potential of hedgerow pruning biomass in some European countries and regions, the use of this resource remains much lower compared to forestry wood or recycled. For example, in Brittany region (Western France) – an area well-known for its hedgerows – hedgerow prunings represent around 65,000 tonnes out of the 500,000 tonnes of woody biomass consumed in boiler rooms annually.

[8] J. Baudry, A. Jouin. De la haie aux bocages. Organisation, dynamique et gestion. 2009.

Like the agricultural prunings and plantation removal biomass described in the previous setions, specific aspects of hedgerow pruning management like logistic aspects, mobilisation, harvest, fuel preparation and use, justify this guide to underline the importance of professionalizing the actors who wish to mobilize this resource.

Figure 4: Example of hedgerow in Brittany. Source: AILE.

Regarding the hedgerow pruning energy uses, the wood energy sector is a lever for developing the hedgerow, but it is not the only one. The other economic valuations on a farm are large. For example, in case of low storage capacity necessary to dry wood energy, the farmer can use a surplus of annual production for the mulching of new plantations on the farm, but also by the sale of product on his commune.

The management of hedge row in a region is an opportunity for sustainable development[9],[10] on environmental issues (landscape, biodiversity, health, energy, carbon storage, soil quality, etc. …), social (non-relocatable local employment, resilience of systems, well-being, etc.) and economic (positive economic balance, strengthening of the value chain anchored in the territory, substitution of imported non-biobased materials, etc.). By making the best use of this resource, two conditions are necessary: the articulation of public policies and the integration of the precepts of the circular economy into the biomass management cycle. To carry out the ecological transition, the challenges of biomass mobilizing have been connected with other territorial issues.

Based on this will of bringing value agro biomass for energy use, it is legitimate to ask the question of the best way to take into account the two conditions mentioned above (transversality of public policies and circular economy) to support the wood energy sector development in a sustainable way.

To set up and organise an efficient hedge pruning management on a region (local scale), it is then necessary to make the link between the operators in charge of managing these various tools locally for the benefit of the primary stakeholders, which are the farmers. To do this, it is necessary to carry out awareness-raising work on the issues covered by the subject of the hedgerow pruning sustainable management and its energy recovery in the territory and highlight the vigilance aspects and excessive sampling.

[9] Ministère de l'Agriculture et de l'alimentation. Le programme national de la forêt et du bois (PNFB) 2016-2026. [Online] 2016.

[10] Ministère de l'Agriculture et de l'Alimentation. plan national de développement pour l'agroforesterie 2015. [Online] 2015. https://agriculture.gouv.fr/un-plan-national-de-developpement-pour-lagroforesterie.

The productivity of hedgerow is a decisive aspect in the production and valorisation of the hedgerow maintenance by-products. It allows to determine the frequency of intervention in relation to a given utilization mode, to organize works accordingly, and to estimate the profitability of an intervention taking into account means deployed and the production obtained. In addition, productivity is also decisive to estimate the carbon storage potential of hedges.

The diversity of the type of hedge resulting from various pedoclimatic contexts and different species, agricultural practices and uses, makes the approach to hedge productivity complex. Maintenance practices and the duration of rotations are decisive. Other difficulty is due to the absence of a dendrometric reference for trees constituting hedgerows, like the existing tools in forest silviculture.

In France, the renewed interest of rural actors in the management and enhancement of the roles of hedgerows has led to the creation of a national typology of hedgerows. This tool offers an approach to standardize the hedge, although each one is original, in order to be able to propose suitable management itineraries but also in the long term to identify different production potentials according to the pedoclimatic conditions of the plots.

Because of this lack of information, several hedgerow tree professionals in France, federated around AFAC agroforestry, have launched the Resp'haies project, which aims to improve knowledge on the hedge and in particular to consolidate the already existing typology and produce references on hedge productivity[11].

For example, the Bouvier 2008 study used in several French national publications[12]:

Table 1. example of productivity references for hedge types

Typology from Bouvier 2008	Productivity (dry cubic meter /km/year)	Productivity (dry tons /km/year)
Mixed coppice-standard hedges	15	3,7
High forest hedges	10	2,5
Coppice	20	5
“Productive” shrub hedges	8,5	2,1

Table 1 shows an example of a chestnut coppice type of hedge (type 4.B of the AFAC agroforestry typology): for sustainable management, cutting takes place every 12 years and will produce 5 tons of dry biomass per kilometer and per year i.e., 60 tonnes accumulated at the end of the rotation at the time of the coppicing operation (a little less if the recommended selection stem is carried out).

[11] AFAC agroforesterie. [Online] https://afac-agroforesteries.fr/resphaies/

[12] D., Bouvier. Estimation de la productivité des haies de l’Ouest de la France, Recherche de références pour l’amélioration de la valorisation énergétique des haies, 85 pages. s.l. : CRAB, 2008.

But, for this, the cooperation of stakeholder's determinate the success of boiler projects. Thus, the role of project leaders is to involve all the stakeholders in the project at each level (wood fuel suppliers, installers, design offices, communities, maintenance agent, citizens, heat customers for district heating).

Finally, the wood energy sector does not exclusively use hedgerow wood. If a supplier can decide to work with a single resource, most of the time suppliers produce their fuel from a mix of materials (for economic and qualitative reasons). Owners and operators of forests, farmers and landscape management companies are therefore called upon to work together. One of the examples is the constitution in collective interest cooperative society of wood fuel members which have developed in the Western part of France. They integrate most of these actors.

The use of hedgerow can bring certain benefits to the community: the use of local biosourced energy as a substitute for fossil energy imported into the territory allows to reduce the territory's trade balance deficit: the substitution of 200 tonnes of oil equivalent by 1,000 tonnes of wood represents almost €100,000 reinjected into the territory.

On the other hand, the creation of not relocatable local jobs must be taken into account from operation in the boiler room to the territorial supply chain: the mobilization of 1000 tonnes of wood in the boiler room on the territory allows to consolidate 1 equivalent job full-time in the sector distributed from upstream to downstream of the wood fuel sector.

But can hedgerows create quality fuel? The quality of wood fuel is determined by its shape, its density, its grain size, its moisture content, its calorific value and its ash content. The answer is different depending on fuels and uses targeted. The origin (forest, non-forest, wood industry, etc.) is not necessarily a guarantee of quality, it is indeed the quality of the mode of operating and the logistics chain which will be decisive. Hedgerows are composed of linear plant formations exposed to sunlight on both sides, which induces more greater lateral branching than in the forest. In addition, most of the hedges are filled with leafy species, mostly mixed with shrubby and arboreal species, with hard and soft wood. The wood resulting from cutting of hedges will therefore be composed of heterogeneous material and will have a potentially variable quality.

The most suitable way for the use of hedgerow for energy is as wood chips. On the hand because it is complex (not profitable) to produce both log wood and chipped wood on the same site unless this chipped wood is used as mulch. On the other hand, because it allows to mobilize the entirety of the material (strong and thin branches).

The production of wood fuel hedgerows has several comparative advantages compared to other biomasses: it is by definition close to rural uses (farms, livestock, rural heating networks); it is very accessible between two crops, when it is not already on the side of a road; it is a by-product resulting from the necessary maintenance of the hedges.

Nevertheless, it has drawbacks too. Despite its accessibility, it is a scattered resource around the plots. Furthermore, the branch chipping yields are not as high as those of the strong woods. Finally, the increase in ramifications favours the risk of chipping irregularities (overlengths). This explains the need to process branches with machines equipped with smaller calibration grids than for strong wood chipping, with also lower work rates.

Despite these difficulties, farmers and communities find solutions to produce a fuel compatible with the requirements of boilers, but more broadly of boiler rooms (silo, transfer, ash removal). They have developed advanced skills, both in the choice of trees to use, site preparation, chipping adjustment, product mixing/sorting and tips throughout the preparation chain.

4. Mobilising agricultural woody biomass

4.1. Agricultural prunings

One of the main challenges for using agricultural prunings in energy applications consists in finding the most appropriate system to collect the biomass. Collection systems affect the biomass quality, and thus its value, but also have a direct influence in the organization of the logistics and handling operations downstream. Furthermore, collection is a critical stage as it can have an impact up to 60 % in the total costs for pruning mobilization, based on some preliminary economic analysis performed in the past by uP_running project [13].

Before the collection of wood, a first step is needed in which this pruning biomass must be prepared and tailored for the further operations. For the collection of wood produced from pruning operations, three main configurations can be proposed:

1. Hauling branches and shredding/chipping/baling at field side
2. Collection integrated with shredding/chipping/baling
3. Pre-pruning with integrated shredding/chipping

In the two first methods, the pruning wood is collected from the soil, whereas the third case allows a direct collection from the tree during the mechanical pruning operations. In the next sections, more details are given for each one of these collection methods.

4.1.1. Preparing the pruning wood before collection

The preparation of the prunings is not technically complex. It can be carried out manually or mechanically (by means of windrowers). Windrowers or pruning sweepers are usually coupled to the hydraulic circuit of tractors, mounted in front or at rear, either in both or in one side, depending (respectively) if they work to bring all pruning to center or only work nearby one of the tree rows. The sweepers are usually made of flexible, but highly resistant plastic bars, rubber blades or wires. Some examples are provided in Figure 5.

Windrower with plastic bars (image from EuroPruning project[14])

Windrower with rubber blades (image from EuroPruning project)

Windrower with wires (*acordonador-girolivo.blogspot.com*)

Figure 5: Different types of windrowers

[13] uP_running "Biomass from agricultural pruning and plantation removals". http://www.up-running.eu/wp-content/uploads/2018/09/1st-Monograph_vDEF-2.pdf

[14] EuroPruning, 2015. "Current and innovative technologies for harvesting agricultural pruning wood". Deliverable report D3.4. Available at: www.europruning.eu

The preparation of the pruning is a crucial part of the work. High losses have a double impact in the viability of the biomass collection: (1) the costs per ton obtained are higher; and (2) the farmer or plantation will have to perform an additional, probably manual, operation for removing the branches remaining. This causes an additional cost to the plantation owner and thus, put in risk the economic savings of the biomass producer.

4.1.2. Hauling the branches and shredding/chipping/baling at field side

Figure 6: Example of vineyard pruning after withdrawal, with stones (uP_running demonstrations in Spain)[13]

This method consists in hauling the branches out of the field, where they stay temporary piled. The branches can be moved manually in case of small orchards. In such cases, the branches shall be only partially contaminated with soil particles and stones. When the haulage is performed mechanically (tractors equipped with a rake or a fork), then more inorganic materials is collected. In case of vineyards, the number of stones can be particularly large. Figure 6 provides an example of this problem experienced in uP_runnining project demonstrations.

After the haulage to the side of the field, the branches can be directly loaded on a truck to be transported to the final consumer or to a biomass hub or logistic platform. This alternative is feasible in local uses and short distances since the branches inside a truck occupy an important volume[15] and the final weight transported is low in comparison to chips or bales (which density is much higher).

An alternative option is to perform the processing at the field side with implements of different size and power, depending on the volumes to be processed and the availability of machinery or companies ready to provide the service (see Figure 7). Chipping machinery includes blades or knifes that can be rapidly deteriorated if they process wood with abrasive inorganics, such as stones and soil particles. Since branches are usually contaminated with such inorganics, the application of chipping is not typical for the handling of pruning. Shredders with hammers are preferable since they are better suited to the comminution of unclean wood.

[15] Bulk density of branches may range 90-120 kg/m^3 (dry basis), while bulk density of chips uses to range 200-300 kg/m^3 (dry basis).

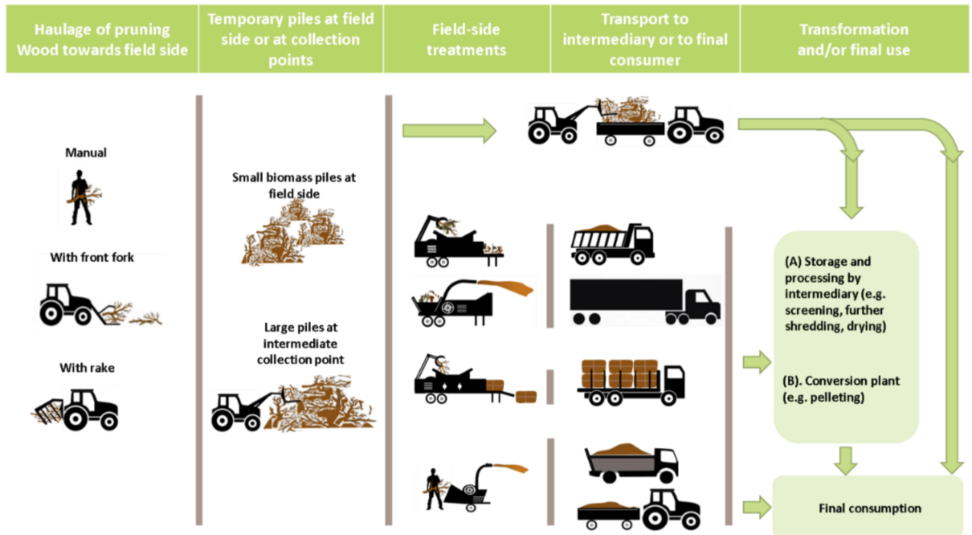

Figure 7: Alternatives for implementing the supply chain when prunings are hauled to the field side. Source: uP_running[13]

4.1.3. Harvesting with integrated shredding/chipping/baling

In this case, the branches are collected from the soil, within each field row. An effective operation with these types of implements requires that the prunings are aligned in windrows (either manually or mechanically prepared). These machineries integrate the collection and the treatment, that can be a shredding, a chipping or a baling of the branches collected.

The system can be mounted in front of the tractor and then it avoids driving over the branches (see Figure 8 cases 'a' and 'b'). However, when mounted at the rear, the tractor drives over the branches (see Figure 8 cases 'c' to 'f'). In such cases, it is recommended to adapt the tractor with some protections underneath to avoid damages in electric connections, hydraulic systems or other systems exposed to the contact with the branches. There exist few self-propelled machineries, even though they are unusual, and thus not depicted in Figure 8.

The material collected and transformed into shredded wood or woodchips is sent either to a trailer towed behind (cases 'a' to 'c'), to a big-bag (case 'd') or to an integrated deposit (able to tilt and discharge, as cases 'e' and 'f'). In these last cases, it is important to avoid forming a pile of chips and letting it on soil (case 'e'): it negatively affects quality and costs, as it will need an operation of loading to a trailer or truck. The preferred practice should be the direct discharge on trailer, container or truck.

Another option of the integrated systems is to collect the pruning branches from the soil and baling them in form of round or square bales (see Figure 9). The baling operation is as quick and effective as shredding or chipping (allows a similar velocity of advance). There exist already commercial balers (colored green in Figure 9) for prunings able to produce either round or squared bales.

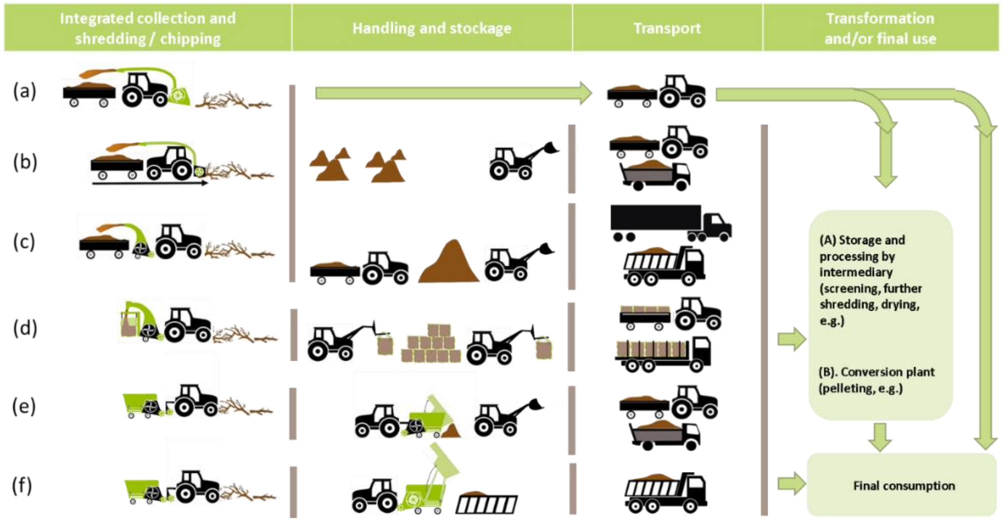

Figure 8: Alternative paths for implementing the supply chain when collection and shredding/chipping of prunings is integrated in the same machinery. Source: uP_running[13]

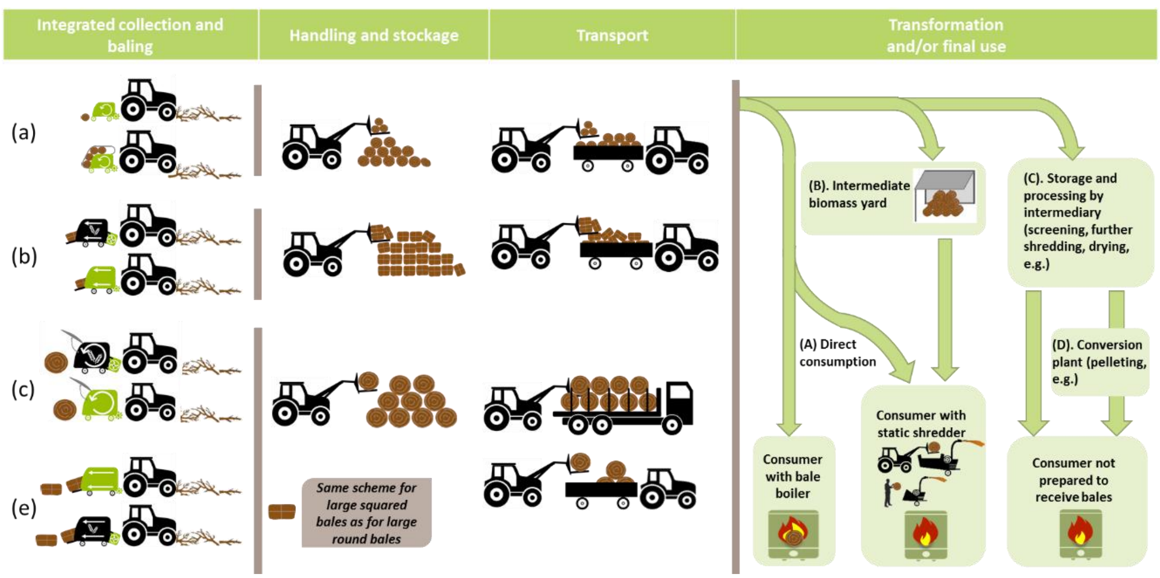

Figure 9: Alternative paths for implementing the supply chain when collection and baling of prunings is integrated in the same machinery. Source: uP_running[13]

4.1.4. Pre-pruning with integrated shredding/chipping

Although this last option has not been implemented until now in existing chains, it is introduced due to its great potential to reduce costs and collection performance. As the modernization of fruit, olive and grape plantations proceeds, the mechanization is penetrating and incorporated more in the agronomical practices**Error! Bookmark not defined.**. The mechanized pruning is a method quite extended for vineyards, which a llows a cutting of a relevant part of the vineyard shoots. An attempt to implement a vineyard pre-pruner integrated with biomass collection has been already carried out in the framework of the Life+ project Vinyards4heat[16].

Figure 10 compiles two technical solutions that are either in development or not very widespread yet (although commercially available, in case of Favaretto).

	*Vineyard pre-pruning integrated with collection and mulching/chipping* A prototype has been developed and tested in the framework of the Vineyards4heat project. Source: Vineyard4heat [16]	
	*Pre-pruning integrated with collection and mulching/chipping in an automotive machine* A commercial machine (Speedy cut) is offered by the Italian manufacturer Favaretto. Source: EuroPruning [17]	

Figure 10: Examples of implements designed to perform the integrated pre-pruning, collection and treatment the biomass. Source: uP_running[13]

4.1.5. Comparison of the different pruning collection methods

A comparison of advantages and disadvantages is detailed in Table 2.

Table 2 Comparison of the three pruning collection methods. Source: uP_running[13]

<table>
<tr><th></th><th>Hauling branches and shredding at field side</th><th>Harvester with integrated shredding/chipping</th><th>Harvester with integrated baling</th><th>Pre-pruner with integrated shredder</th></tr>
<tr><td rowspan="2">PROS</td><td rowspan="2">• Easiness for the farmer
• Branches can dry out without fermentation
• A local company shall provide the shredding/ chipping service.</td><td colspan="2">• Limited contamination of the biomass with exogenous (stones, soil, etc.)</td><td>• No additional cost (pre-pruning + collection integrated)
• No contamination (biomass does not touch the soil)</td></tr>
<tr><td>• Material already processed (some consumers may be capable of using it directly)</td><td>• Storage is simple
• Wet branches dry properly in form of bales</td><td></td></tr>
<tr><td rowspan="2">CONS</td><td rowspan="2">• Usually significant contamination of biomass during hauling (stones, soil, etc).</td><td colspan="2">• Windrowing / pruning preparation necessary
• Collection time may be large
• Driving over pruning requires installing tractor protections</td><td>• Non-existing value chains. Few prototypes / implements available
• Percentage of losses may be high during collection</td></tr>
<tr><td>• Moist shred material undergoes degradation during storage
• Chipping sensitive to stones</td><td>• Bales tend to change shape with time
• Lower density than straw bales</td><td></td></tr>
</table>

[16] Life project Vineyard4heat, 2015-2017. Available at: http://vineyards4heat.eu/

[17] EuroPruning, 2015. "Current and innovative technologies for harvesting agricultural pruning wood". Deliverable report D3.4. Available at: www.europruning.eu

Hauling branches and shredding at field side	Harvester with integrated shredding/chipping	Harvester with integrated baling	Pre-pruner with integrated shredder
	• Shredding usually not fine and needs further processing • Case of big-bags: additional handling time, cost of big bags	• Handling is time consuming • Need to shred if final consumer cannot burn bales	

4.2. Plantation removal wood

The vineyard and fruit trees plantation have to be renovated with a certain frequency. Whereas fruit tree plantations are usually subject of a shorter lifetime (10 to 20 years in market orientated plantations), vineyards and olives usually have a longer lifetime (circa 30 years for modern vineyards, 40 for olive trees under intensive management, or about 15 for olive trees under super-intensive management).

From a global point of view, the methods to collect and mobilize wood from plantations removal may be classified into three different approaches:

1. Whole tree uprooting, shredding and further processing
2. Felling the trees to be processed by crushing, shredding or chipping
3. Integrated felling with shredding / chipping

In all of them a keystone is the shredding or chipping device. As these systems must process a tree in a piece, they are systems of large power, either forestry chippers of large capacity, or large crushers or shredders as those generally utilized by treating industrial/demolition wood or other residues.

It must be taken into account that stumps and roots will remain in the field after these different techniques, which usually need to be cleaned in order to start a new plantation.

4.2.1. Whole tree uprooting, shredding and further processing

The typical operation when a plantation is terminated consists in up-rooting with bulldozers or excavators. The residues are usually piled to be dumped or burnt in the open air to be eliminated. When aiming to make a change in the final fate for these residues in coordination with the farmers or plantation owners, it should be considered that they usually prefer to perform the practice as usual. The challenge is then to obtain a biomass with sufficient quality for the consumers.

This practice obtains together the whole tree wood (both the aerial part, and stump with part of the roots). The material must be piled at the field side, and then either transported bulk to the processing plant (Figure 11.a) or treated “in situ” (Figure 11.b). As the material contains substantial amounts of soil and stones stuck to the roots, and due to the haulage carried out, it is recommended to shake the uprooted trees before its comminution. The mechanical systems better adapted to treat the biomass are crushers (low rotating velocity) or shredders (hammer shredding at high rotating velocity). Both produce respectively large pieces and inhomogeneous shredded material.

Except for the case that the material processed is directly sent to a final consumer with capacity to directly use or process it (Figure 11.c) the material should be transported to an intermediate point (biomass hub or logistic platform) where it can be object of screening and further shredding/chipping. In general, the wood produced from such a scheme is of lower quality in comparison to the methods where the aerial part of the tree is treated separately.

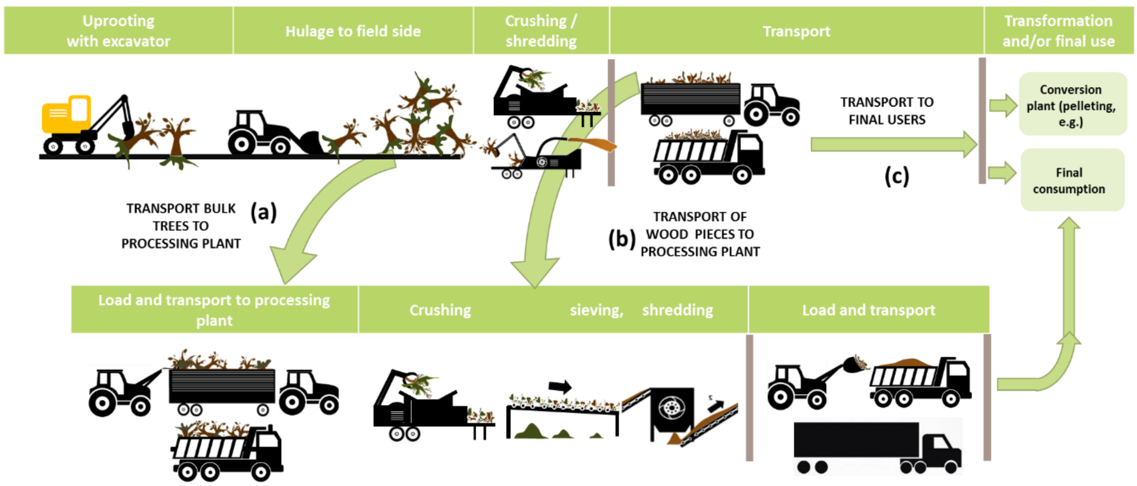

Figure 11: Alternative paths for implementing the supply chain of plantation removal wood when the whole tree is up-rooted and processed. Source: uP_running[13]

4.2.2. Felling the trees to be processed by crushing, shredding or chipping

An option to reduce the need of processing downstream the field side operations, improve the biomass quality, and thus, have a more competitive feedstock, consists in the processing of the aerial part of the tree. Trees can be felled manually by farmers or workers with chainsaws, or mechanically, with cutting discs or shears mounted on a hydraulic arm (see Figure 12). This method leaves stumps on the field. It has the disadvantage of the felling operation, which is an additional cost compared to the plantation up-rooting operation described in the previous section.

As observed in Three principal alternatives can be discerned:

(a) Once the trees are felled, they can be treated directly without haulage, obtaining a better-quality wood - Figure 12 (a).
(b) Another option is the direct transportation of whole aerial part of the trees to the processing plant. Figure 12 (b).
(c) A third option is performing a chipping or shredding (Figure 12 c.1) or crushing (Figure 12 c.2) at field side.

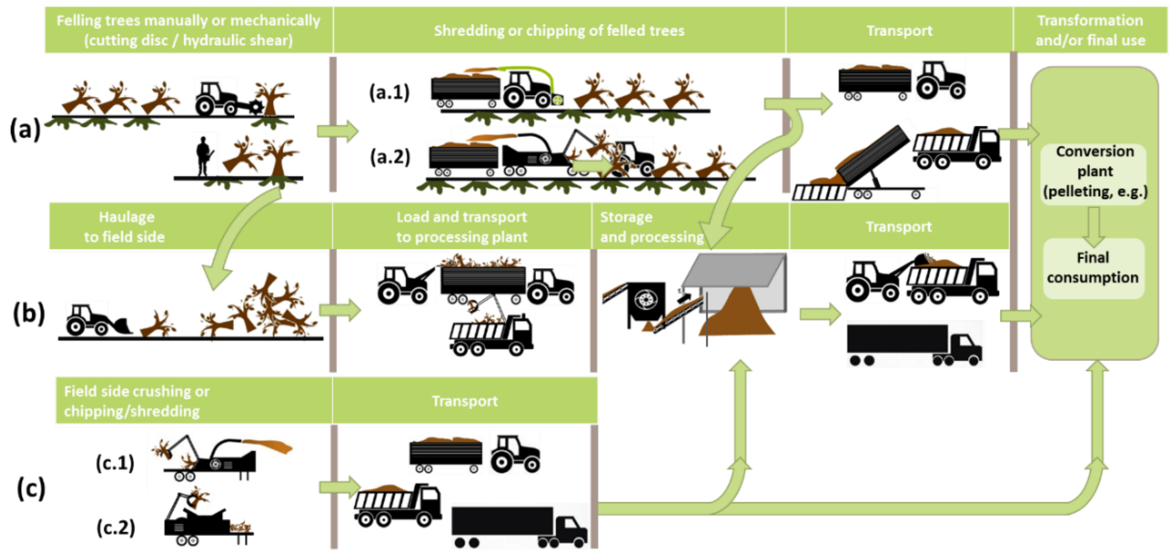

Figure 12: Alternative paths for implementing the supply chain of plantation removal wood when the trees are felled to obtain the aerial part of the tree. Source: uP_running[13]

4.2.3. Integrated felling with shredding or chipping

An alternative to optimize the processing is to carry out the operations in a single stage (see Figure 13). The process requires a tractor of high power with a large shredder installed in front. As the tractor advances in the line of trees, these are bended and/or cut and as they fall the shredder/chipper reaches the stem and start processing. Similar to the operation with forestry chippers or large shredders or crushers, the investment is high.

The main difference is that in the 2-stages process, the value chain actors to be involved in the area may already possess with the necessary machinery. Thus, the use for plantation removals is a way to extend the hours that the machinery is utilized every year (and accordingly, to reduce the amortization costs).

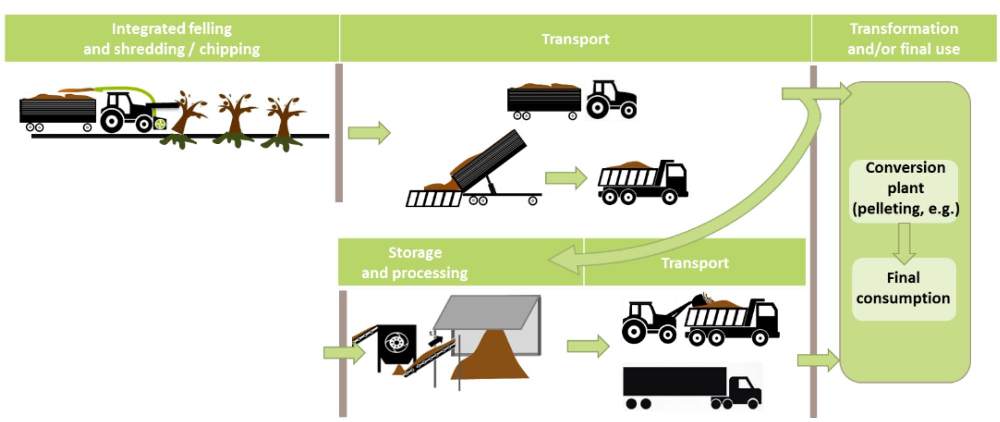

Figure 13: Alternative paths for implementing the supply chain of plantation removal wood when an integrated felling and shredding / chipping is performed. Source: uP_running[13]

4.2.4. Management of stumps

Stumps and roots remain in the field when only the aboveground part of the biomass is processed. Farmers usually need to clean these remaining parts of the tree in order to start a new plantation cycle. Wherever the burning in piles on the open air is the usual practice to manage the residues of plantations removed, farmers are reluctant to agree upon a new management where a third actor gathers the aboveground part of the tree. Stumps and roots do not burn properly, and thus, the disposing method fails. In such areas farmers prefer to uproot the whole tree, since then all residues (above and underground parts) are burned and converted to ash. An option is to integrate a service of felling and obtaining the aboveground part of the tree, with the up rooting of stumps and roots, and restoration of field soil.

The diagram is similar to the case of up-rooting the whole tree (see Figure 14).

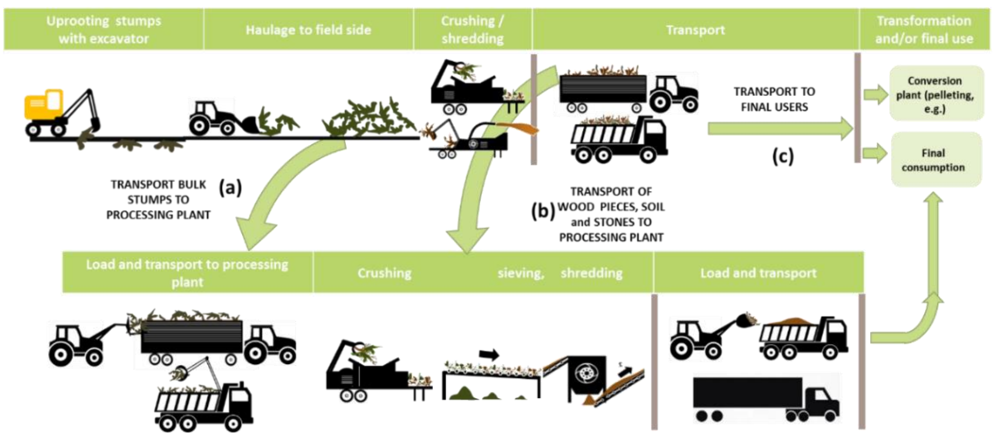

Figure 14: Alternative paths for obtaining stumps and roots and provide them to a final consumer. Source: uP_running[13]

4.3. Hedgerow prunings

The issues related to the mobilization of hedgerow wood are threefold:

- Draw sustainably from the resources of the hedge without over-exploiting it and aiming for positive amenities useful for the territory,
- Mobilize efficiently to be competitive on the wood energy market and profitable for the farmer or the community managing the hedges,
- Mobilize to produce biofuel with steady quality over the time and compatible with the existing boiler facilities.

These must be present at each stage of the supply chain, from sampling and harvesting operations to the boiler feeding.

4.3.1. Harvesting

Cutting programming, marking of trees to be pruned, trees to be felled or stumps to be coppiced, identification of the presence of undesirables (barbed wire, fence posts, rock flush with the ground, diseased trees, etc.) are preliminary steps for good harvesting efficiency.

This pre-selection must consider the resumption of growth following previous cuts, the quantitative and qualitative needs, an assessment of the section (diameter) of the branches and trees to be sampled. There are several ways for operating this stage, depending on the actor involved: Operation can be carried out directly or through a service provider, but it can also be entrusted to a wood fuel supplier who offers a turnkey service: select, cut and transform the harvested biomass. Please note that the owner of the hedge is always responsible of the result and must clearly specify his expectations in terms of the quality of the intervention (intensity of sampling, quality of the cuts, respect for the trees, etc.). The turnkey choice doesn’t mean a release from the hedge manager's responsibility.

The harvesting method is decisive because it makes it possible to manage the hedge according to the expected uses and to organize the sites for optimal efficiency, both from an economic point of view (time spent) and to tackle the qualitative requirements (preservation of hedge functionalities and product quality).

Whatever the choice of the hedge manager, several preliminary steps should be considered to facilitate this harvesting step.

Also, the choice of the place, the access, and the bearing capacity of the plot with in particular the risk of poor water flow and compaction of the agrarian soils is another parameter to be taken into account which can impact the good productivity of the arable crops that litter the hedgerows and require adaptations of the method of cultivation.

Apart the small cuttings to shape the tree carried out at the beginning of the life of the tree operated every year or every two years, the maintenance is delayed, if possible, to allow the production of branches of diameters greater than 7cm obtained approximately after 8 to 12 years old.

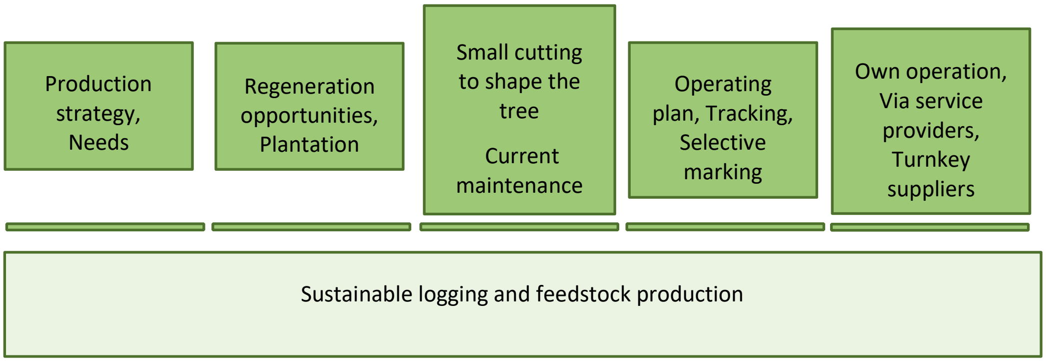

Figure 15: Feedstock production stages to provide sustainable feedstock for wood energy market. Source: AILE.

The routine maintenance of the hedges sometimes deemed necessary after three or four years of growth by a lateral pruning makes it possible to contain the hedge in width[18]:

- Along the roads, this is carried out regularly to free up the tread and ensure the safety of road users, and also to limit the influence on the electrical wires infrastructure.
- In agricultural plots, this is carried out before cultivation to avoid any loss of arable area. This practice is reinforced when there is no economic use of the wood in the hedge.

		
Knife blade	Saw blade	Cutter bar with pruner

Figure 16: Mechanised lateral tools for hedge. Source: AILE

It is indeed technically possible to use tools such as blade cutters or pruning shears to roughly cut branches with a diameter under 7cm by operating after three or four years of vegetation. Reputed to be fast, secure

[18] Chambre d'agriculture Pays de la Loire, Chambre d'agriculture de Bretagne. 2020, Guide gestion durable du bocage, 32p. [Online] 07 2020. https://pays-de-la-loire.chambres-agriculture.fr/fileadmin/user_upload/National/FAL_commun/publications/Pays_de_la_Loire/2020/2020_Guide_gestion_durable_des_haies.pdf.

and inexpensive, they appear to hedge managers but often act to the detriment of tree growth and the durability of hedges, with increased risks of disease and risk of dieback.

A such statement, mainly tabular in form, showing the order and extent of all work of any nature to be carried out for one year (the annual programme of work) or a few years. This management considers each tree in the hedge to provide it with appropriate treatment relating to its stage of development, its potential and its function. This may require the farmer or the road manager to sometimes take the chainsaw again, a practice that is often forgotten, and at the very least, that he provides an additional effort compared to routine maintenance on the linear: training to work in safety and respecting the tree, find the necessary time, understand, and plan the operations. But here again it is possible to call on a qualified service provider who can also offer a turnkey project.

The impulse can come from the wood energy sector, in particular the buyer, who can through the certification of the Label Haie[19] (29), draw up a charter of best practices for its farmer members who produce woodchips. For its part, the supplier also take commitment.

Thus, the farmer or the so-called "manager" community engages in a progression scheme in the way of logging the hedge, from Level 1 (Essential indicators: preserve the integrity of the hedge and respect the balance of the levy, without over-exploitation) and after 10 years of reaching Level 3 (improvement indicators: gain in biodiversity, landscape, air/water/soil supply protection, climate mitigation).

We will focus on some recommendations from the "manager" specifications:

- Plan the HP in accordance with the operating plan: Mark, select the trees, Observe the diseased trees to remove them then carry out the disinfection of the chainsaw.
- Ensure safety: Safety shoe, helmet, glasses. Make sure you are alone or away from others.
- Logging: Perform the slaughter, cleanly with a flat clean cut for good healing. Do not hesitate to make small notches on the gnarled tree heads to facilitate shredding. Cut the trunks if necessary, according to the recommendations of the shredder used.

[19] Label HAIE. [Online] https://labelhaie.fr/.

Figure 17 : Flat clean cut for, recovery of the cut if necessary with the chainsaw. Source: Mission Bocage and AILE

Figure 18: The intervention of an excavator equipped with a harvester head. Sources: Cuma Calvados Innovation and AILE

The intervention of an excavator equipped with a harvester head is possible and is envisaged in sites grouped together with good accessibility and preferably on meadows or with plots with grassy strips guaranteeing good bearing capacity of the soil.

Several types of harvesting head exist with greater or lesser precision and sharpness of logging. Disc or chain equipment tends to split stems and uproot trees less than clamp systems. A recut with the chainsaw is necessary when the cut is too high.

The advantage of this equipment is of course safety and efficient storage. Excavators equipped with tracks will have a lesser impact on soil compaction.

Figure 19: Clamp harvester head (left) and Chain disk harvester head (right). Source: AILE

4.3.1. Transformation

The harvesting from hedges generally makes it possible to obtain a mix composed of pruning wood and stumps whose diameter varies from 4-5 cm and 15-20 cm in diameter, and also whole trees composed of a trunk and branches.

Shredding or chipping can take place at different points in the logging chain:

- In the field after storage
- On the side of the road after skidding
- On a platform after storage, before or after drying.

This last practice is particularly well suited for the logging of wood from the bottom of valleys, riparian hedges, and other wetlands (willow, alder, poplar).

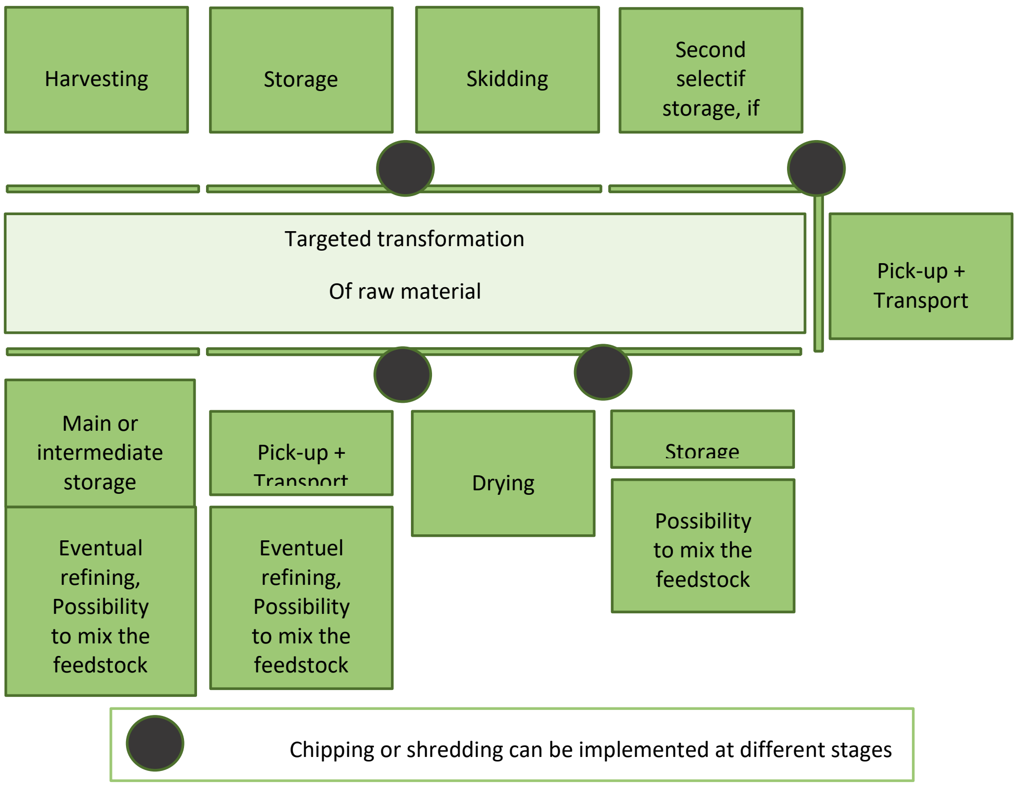

Figure 20: Transformation stage of raw material to produce wood chips

After drying, hardwoods are particularly more difficult to chip and can cause premature wear of equipment and increased fuel consumption.

This supply chain has already been the subject of scientific research in the past to try to identify the elements that can impact the quality of the fuel produced. If we focus on the chip's particle size repartition, it appears that the shredding/chipping stage is decisive.

4.3.1.1. Chipping

The work rate depends on several factors related to the pile of branches, including:

- quality of the storage of the branches: not too high, better to spread
- presence of exogenous materials (blocks of stone, fork finger, barbed wire, etc…)
- diameter and length of the branches to be shredded, the presence of leaves or thorns
- number of heaps, the distance to move between the heaps and their accessibility
- number of trailers with the adapted capacity to the distance to the place of delivery
- flow rate of the chipper, the functions of the tractor and the ability of the driver (adjustments, driving, maintenance of the machines) in real conditions of use

For the same site, the yield can vary from simple to double. It is considered that the cost of shredding should be between 8 and 12 €/t to guarantee the profitability of the sale of fuel.

Figure 21: Branches too thin, in leaf = poor yield (clogging) and poor chip quality in combustion. Source: AILE.

The chips come from chipping machines carried out using knives that cut the incoming product perpendicular to the thread line of the wood. The cutting device of a chipper is a full or empty drum fitted with several discs. There are chippers with changeable knives, others with reusable knives after sharpening. Similarly, manufacturers now offer machines with manual feed but also with semi-manual feed where the driver can operate a grapple from the chipper or from the cab of the tractor, carrier truck or self-propelled machine.

The regularity of the granulometry of the wood chips from the hedgerows can vary because the inputs potentially fluctuate from a simple branch to the whole tree, and rarely from logs only. But the settings and the compatibility with the tractor (post-reversed or not in particular) also have a major role to play. The production of fine particles (0 to 3.15mm), large particles, fibrous product and in general the difficulty in obtaining the desired fraction is often accompanied by premature wear of the equipment and can have an increased impact on chipper maintenance.

Table 3: Hypotheses on the factors influencing the appearance of small particles or non-standard particles

Small particles (0 - 3.15 mm)	Coarse or non-standard particles depending on the particle size class concerned: "Chipping tails"
• The infeed conveyor does not go fast enough, and the operator tends to force the incoming product with the grapple. • Too many knives on the rotor and the rotation speed of the rotor are too high. • Grid too far from the rotor and insufficient load increase due to lack of incoming product. • The blower is too powerful and cuts the pieces of wood or too many blades on the blower. • - Conversely, if the blower does not evacuate enough wood, there is a risk of jamming.	• The knives and/or counter knives are not sharpened. • Design of grid(s) allowing the wood chips to come out too easily. • Large diameters when the tractor lacks power at the PTO. • - the chipper feed block is not equipped with vertical side rollers of the horizontal feed rotor and a horizontal roller to press the wood on the feed belt, despite the possibility of inclination of the power supply on some models.

The adjustment recommendations indicated in the manuals are sometimes imprecise and considered insufficient by the operators and are not in line with the tractor used or quite simply impossible because they are dependent on the tractor and the options and functions available to it. Trials and exchanges of practices are sometimes necessary to fine-tune these settings and training can be useful for groups of farmers and/or driver service providers concerned with limiting premature wear and tear on equipment and improving their practices to meet the expectations of their customers. These moments are an opportunity to involve chipper manufacturers and dealers to encourage the professionalization of HP chiping for wood fuel.

A key step before chipping is to prepare the pile of branches. Depending on the species, you should wait before shredding:

- Fir, cedar, and other conifers should be left in a pile for between six months and a year to allow the needles to drop.
- Willows, alders and poplars having grown in humid areas, it is also necessary to wait between four and six months.

Storage is carried out by carrying the branches:

- All the branches must be arranged in the same direction and must not be tangled together or placed in all directions.
- 15m from the hedge to allow the passage of the sets: tractor/shredder and tractor/trailer.
- The bottom of the HP in the direction to the hedge and the top in the direction to the field
- Ideally carried out using a grapple, carrying the branches and avoiding picking up dirt and grass to limit the wear of the shredder knives.

4.3.1.2. Shredding

Figure 22. grinding, drying and use in animal litter – source AILE

In the special case of the shredded material, it is produced using a rotor equipped with hammers which allow defibration of wood with a diameter of less than around 7cm. This type of material is still very underdeveloped. The shredded material can be used as mulch or litter after prior drying. Fresh, it can be spread on the ground as amendement (RSW: ramial shredded wood (10). It is not adapted for small wood fuel boilers using screw.

4.3.2. Drying, Refining, Storage

HP wood suppliers mainly deliver small to medium capacity boiler rooms requiring dry wood, and to a lesser extent high power boiler rooms (over 1MW).

The natural drying carried out for a period of 4 to 8 months in a concrete and ventilated shed makes it possible to obtain a humidity on the raw product from 60 to 20 % depending on the level of requirement of the boiler. Artificial drying generates additional costs (€10 to €15 per outgoing ton) and often also transport/recovery stages impacting the carbon balance. This, unlike the natural drying that can be carried out by most farmers, is more rarely present, often this process uses waste heat from cogeneration (biogas engine for example) or hot air generators running on shredded wood.

The material mixing consists of mixing chipps of several hardwood species (hard, soft) and softwood of variable density and/or with different moister ranges. In fact, the quantities of wood transported by the transfer screws of small and medium-sized boilers and large boilers equipped with belt feed are very precise volumes which do not take into account the weight of fuel. Thus, mixing the species makes it possible to smooth out the operation over the entire heating season and to avoid making adjustments at each delivery. For large boilers, the woodchip-shredded material mix makes it possible to produce fuel at a lower cost or to reduce the humidity level of the fresh woodchip thanks to very dry shredded pallet material, for example. This is not compatible with screw transfer because the shredded material is not suitable.

Screening consists of separating wood chips or shredded wood into several size fractions. Generally, two fractions are produced in addition to the main fraction which is sought: the fine fraction (0 to 12mm) and the coarse fraction (>150-250mm). Screening is mandatory after composting unsorted and shredded green waste, in order to extract the composted by-products that can cause poor combustion. Regarding naturally dried wood chips, screening is more like a "catch-up" when the particle size classification is deemed insufficient or non-compliant with customer expectations. It is carried out on dry wood around 25% humidity on gross mass at the initiative of the supplier or the operator of the boiler room.

There are several screening providers, often involved in the composting sector. As for artificial drying, an additional cost of around €15 to €20/t is to be expected for screening in addition to the loss of materials. Depending on the settings and the rate of exogenous materials, this loss of material can vary from 10 to 25%. It then becomes necessary to find other recovery channels for these co-products (resale of the small fraction for litter/spreading of effluents/co-composting, mulching of young plantations, etc.).

Figure 23 : Trommel screaning producing two fractions – source AILE

Figure 24: Photo :: Stars screaning producing three fractions – source AILE

4.3.3. Marketing, delivery and recovery of the ashes

The cost of this fuel being particularly high, it is obviously important to clearly explain the multiple interests of developing the hedges and that everyone is concerned, but also it is imperative to contain transport costs to stay competitive. This means that this biofuel, essentially mobilized by farmers or agricultural work companies, should be a local fuel.

Labeled HP wood forsees a greater remuneration to the farmer “manager” and therefore a higher cost of fuel in the boiler room. The distributors who market this labeled product must also comply with the distribution specifications of the Label Haie, also respecting the criterion of a maximum of 1 km traveled per cubic meter of woodchips delivered: from the logging site, via the drying platform, to the boiler facility. The Label Haie thus regulates both hedge management practices and HP wood distribution channels to supply local boiler facilities.

The recovery of ashes by the wood supplier is a service that can be appreciated by collective boiler operators who wish to move towards more circular economy, and all the more so if this is carried out in partnership with local farmers who have produced the fuel and use the ashes for agronomic amendement.

5. Fuel properties and quality standards

5.1. Properties of agricultural wood as a solid biomass fuel

Agricultural woody biomass – whether it originates from vineyard, olive and fruit prunings, plantation removals or hedgerow prunings – is characterized by good energy content, but with some particular differences in comparison to forest biomass.

Forestry system-based wood chips, which represents the best quality and are a "reference" fuel for several installations, usually have an ash content around 1 % on dry basis. This type of biomass is not contaminated with soil, dust or stones and does not contain twigs, pieces of branches, leaves or bark, which have a higher ash content than pure stem-based wood. Accordingly, agricultural woody biomass therefore requires boilers with higher requirements in the systems dedicated to withdrawing ashes or to clean the flue gases.

Table 4. Characteristics of different types of agricultural pruning biomass after mechanical collection (by harvesting with integrated shredder) and processing (data from EuroPruning[20]). Comparison with pine wood chips of class B (norm EN-ISO 17225).

Fuels	Pine chips Class B	Almond pruning	Peach tree pruning	Olive pruning	Vineyard pruning
Water (% wt, ar)	**≤ 35.0**	34.4	37.5	27.6	41.5
Ash (% wt, db)	**≤ 3.0**	4.6	3.7	4.8	3.5
LHV (MJ/kg, ar)	-	10.6	10.5	12.5	9.2
LHV (MJ/kg,db)	**18.2**	17.4	18.3	18.2	17.4
ar: as received; db: dry base.					

According to EuroPruning project, S2Biom[21] and Biomasud Plus[22] agricultural pruning ash content usually ranges from 3 to 5 % of ashes (dry basis). However, depending on the management operations, their ash content may reach levels of 10 % in dry basis, or even more. This is the case of pruning that are hauled out of the fields with tractors equipped with front forks. Then, the content of inorganic matter increases due to incorporation of soil and stones and may cause problems to the operation of a combustion systems (e.g., blockages of grates, increased particle matter emissions, etc.).

Inadequate management of agricultural woody biomass can cause a biomass initially below 5 % of ash to have more than 10 %, including gravel or stones, which difficult the operation for most boilers.

[20] EuroPruning, 2016. Internal results. Unpublished data

[21] S2biom, 2016. "Explanatory note accompanying the database for standardized biomass characterization (and minimal biomass quality requirement for each biomass conversion technology)". Annexes. Deliverable D2.4 report. Available at: http://www.s2biom.eu/

[22] Biomasud Plus, 2018. "Selected biofuels characterization results and quality assessment report". Deliverable report D3.2. Available at: http://biomasudplus.eu

5.2. Quality standards and fuel quality certification schemes

A quality standard is basically a table where the fuel specifications of a biomass (i.e., wood pellets: ISO 17225-2) are defined and classified. For example, ash content for wood pellets should be under 0.7% to reach the quality standard class A1; to be classified as class A2, less than 1.2%; and to fall into class B, less than 1.5%.

Standards for solid biofuels are nowadays quite extended already and cover most of the biomass assortments. There are no specific standards for agricultural woody biomass, though they can be classified according to other existing standards, depending on their trade format and quality as follows:

- ISO 17225-2, if the material is processed into pellets;
- ISO 17225-4, if the material is intended to be marketed as residential wood chips
- ISO 17225-9, if the material is intended to be used for industrial wood chips or hog fuel.

The type of original material, and the valorisation processes applied, determine the shape and characteristics of the solid biofuel obtained, and therefore, the alternative standards that could cover it (among those mentioned above), and the chances to fit any of their quality classes.

Differently to standards, **quality certification** implies more requirements besides fulfilling the thresholds of a certain quality class in the quality standard. It is more similar to an ISO 9000 quality implementation, and it mainly includes:

- An audit by an independent auditor where a sample will be collected and send to a laboratory to see if it fulfils quality of a certain class as per the standards and review all other requirements beyond quality fulfilment.
- A Quality Management System implemented (QMS) which basically includes:
    - Self-inspections. Analysis every shift of certain basic parameters
    - Production procedures
    - Maintenance and cleaning plan
    - Adequate equipment
    - Claim management system
    - Malfunctioning management
    - Training of the staff

With the projects Biomasud (Interreg SUDOE IV-B) and Biomasud Plus (H2020) a certification system was created, with the same name "BIOmasud®" to cover several biomasses typically present in Mediterranean countries (olive stones, dry nut shells, etc.). Among these biofuels, some types of agricultural prunings were added to the system; nevertheless, there are some formats that are not included such as the hog fuel.

Quality standardisation and certification of solid biofuels brings several advantages to the whole bioenergy value chain:

- Confidence for boiler users
- To maintain air quality at acceptable conditions set by legislation
- A more transparent market
- To preserve the environment through the optimal use of natural resources, energy efficiency and the reduction of Greenhouse Gases (GHG).
- In order to establish standardised operation of combustion equipment (production of adapted boilers)

Following Table 5 describes which standards and certification schemes cover each of the types of fuels depending on the different trade formats used. Of course, the quality may vary depending on the biomasses and for being covered by the standards and certifications, they must have a minimum quality. For example, even if theoretically Hedgerows pellets could be certified ENplus® or BIOmasud®, the most tolerant class, with lower requirements on ash content, is Class B, for which the ash content should be less than 1.5 %. This value is typically difficult to be achieved with branches and residues of the hedgerow maintenance.

Table 5: Standards and certifications for different types of solid biomass fuels from agricultural wood

Type of fuel	Trade format	Standard	Certification scheme
Hedgerow biomass	Wood chips	ISO 17225-4 (residential quality) ISO 17225-9 (industrial quality)	BIOmasud® (only if it fulfils quality requirements for residential use)
	Pellets	ISO 17225-2	EN*plus*® / BIOmasud®
	Hog fuel	ISO 17225-9	Not available currently
Olive tree prunings / plantation removal wood	Wood chips	ISO 17225-4 (residential quality) ISO 17225-9 (industrial quality)	BIOmasud® (only if it fulfils quality requirements for residential use)
	Pellets	ISO 17225-2	BIOmasud®(own standards)
	Hog fuel	ISO 17225-9	Not available currently
Vineyard prunings / plantation removal wood	Pellets	ISO 17225-2	BIOmasud®(own standards)
	Hog fuel	ISO 17225-9	Not available currently
Other fruit tree prunings / plantation removal wood	Wood chips	ISO 17225-4 (residential quality) ISO 17225-9 (industrial quality)	BIOmasud® (only if it fulfils quality requirements for residential use)
	Pellets	ISO 17225-2	Not available currently
	Hog fuel	ISO 17225-9	Not available currently

5.3. Making pellets out of agricultural woody biomass

Pellets are a densified form of biomass that are produced through a controlled process. Pellets have a low moisture content (typically below 10 %) and higher density than wood chips, something which provides multiple benefits: easier feeding, lower transportation costs, reduced storage requirements, easier combustion control, etc.

Wood pellets made out of sawmilling residues and other forest wood residues fractions are a premium biomass fuel with very low ash content that makes it suitable for small-scale heating solutions – both boilers and stoves. Fuel quality, coupled with ease of use and a competitive price over many types of fossil fuels have made wood pellets a very popular heating solutions for consumers in multiple European countries.

Considering the popularity of wood pellets, several entrepreneurs have considered using agricultural woody biomass as a raw material for pellet production. As a matter of fact, pellets can be produced from various types of biomasses and the technical feasibility of producing pellets from agricultural woody biomass fractions (e.g. prunings) has been demonstrated both in research projects as well as by commercial actors.

The main issue in pellet production from agricultural prunings is related to the resulting fuel quality. The moisture content and the mechanical durability of the pellets can be controlled by the operator of the pelletization process. However, the chemical fuel parameters (e.g. ash, nitrogen and others) of the produced pellets are dependent on the parameters of the raw biomass material. Typically, agricultural woody biomass has less favourable characteristics than the forest biomass fractions that are most commonly used in wood pellet production.

The high bark content of agricultural wood is a significant reason for this. For example, hedges typically do not contain softwood tree species (conifers), but hardwood trees with stronger branches that cannot be mechanically debarked. In addition, the hedgerow prunings contain small pieces of wood (< 7 cm in diameter) in quantities that can reach 40 % of the total biomass. Thes small branches also have a higher rate of bark.

For agricultural prunings, apart from the small branches with high bark content, the contamination of biomass with soil or leaves is also a reason why higher ash contents are typically found in agricultural pruning pellets.

For these reasons, agricultural woody biomass is not used at the moment in significant quantities in the pellet sector, with few isolated examples. Nevertheless, with the increase in pellets demand and with improvements in logistics operations and biomass combustion technologies, pellets from agricultural prunings might grow in importance in the future.

6. Energy production from agricultural woody biomass

Historically, the use of agricultural woody biomasss for energy production was constrained to simple devices (i.e. open fireplaces, simple wood stoves, traditional wood ovens) used to cover local heat demands of farmers and small communitities. Although such uses may still persist in rural Europe, advances in the bioenergy conversion technologies mean that agricultural woody biomass can now be used effectively in modern biomass combustion systems with a high degree of automation and efficiency and with much lower emissions.

In such modern bioenergy systems, the most common form of utilizing woody biomass fuels is in the form of chips / hog fuel or pellets. As explained in the previous chapter, production of pellets from agricultural woody biomass remains niche market, so it is **wood chip fired systems** that are of most relevance. Such combustion installations typically have the following distinct components, as shown in Figure 25: biomass storage; feeding system; energy conversion system (burner and heat exchanger); ash collection; gas cleaning; chimney; control panel and safety system.

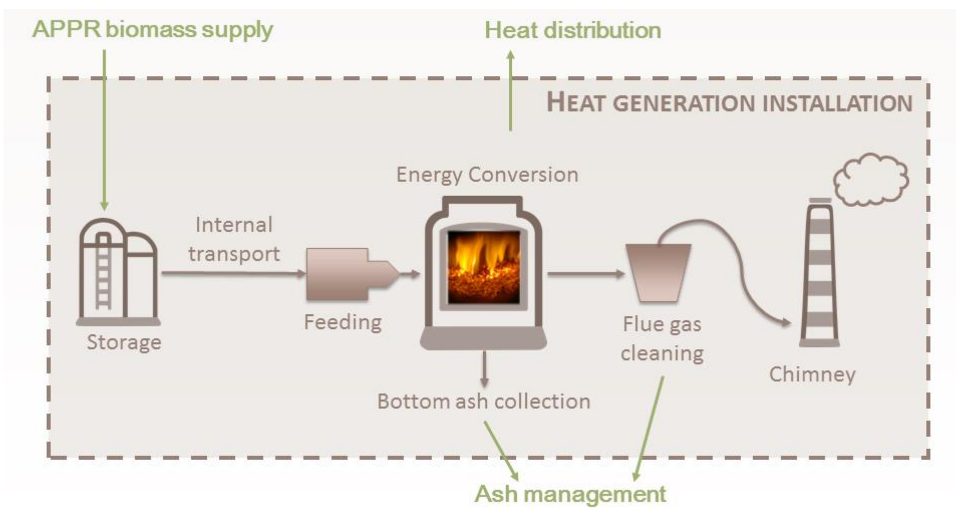

Figure 25: Scheme of a biomass installation for heat generation. Source: uP_running[13]

Agricultural woody biomass fuels are not that dissimilar to forest wood chips and in principle, the technological principles for their conversion to energy are the same. However, the devil is in the details and there are particular aspects, such as a typical higher ash content, the presence of exogenous materials and irregularities in particle size distribution that need to be properly considered in any conversion system. In order to adapt to these properties, the conversion systems include improvements in three essential aspects: a feeding system able to break the larger pieces, a combustion system (usually a fixed or moving grate) that can handle heterogeneous biomass, and an ash cleaning system that may work with high ash content biomass. Therefore, biomass conversion systems tailored for the use of agricultural woody biomass may need to consider using a more robust feeding system, include a larger ash bin or devices used for controlling impurities more frequently than forest woody biomass systems.

The use of agricultural woody biomass can be carried out in existing facilities not initially designed for such fuels. Depending on how much the fuel parameters of these new biomass fractions differ from the standard ones, entry in this market may be more or less difficult. One possible strategy is to mix the agricultural woody biomass with other biomass assortments up to a level that does not compromise the boiler operation nor the product and service warrantee offered by the boiler manufacturer or maintenance service team. If the use of agricultural woody biomass comes with significant cost savings compared to the standard fuel assortments, then the boiler operator may consider retrofitting investments that would allow them to use higher shares of such materials.

Alternatively, agricultural woody biomass can be utilized in facilities initially designed and prepared with this fuel in mind. In such cases, the new consumer is suggested to adopt mature and proved technologies able to use the biomass in form of more heterogeneous material, as it will allow a cost reduction of the on-field and field side operations, and thus will reduce the final cost of the fuel supply.

The main technologies already ready in the market for agrobiomass heating are detailed in the public deliverable D4.2 of AgroBioHeat[23]. This report summarizes in a condensed form information on modern, efficient, reliable and clean technologies for agrobiomass heating in small sized facilities. The report provides an overview of the technological systems and sub-systems used for agrobiomass heating applications: fuel feeding, combustion, heat exchangers, control systems ash removal and flue gas cleaning systems.

The following sections of this chapter focus on some special considerations regarding the use of agricultural woody biomass, in particular related to fuel feeding and storage systems. These considerations are based on AILE's experience on hedgerow prunings, but in principle they are relevant also for agricultural pruning and plantation removal biomass in the form of wood chips or hog fuel.

Considerations for energy conversion systems using hedgerow prunings

The chemical composition of hedge wood is quite close to forest wood, so this wood fuel can be used in any wood boiler room, without adding a treatment device.

This material comes from a dispersed resource requiring manual exploitation most of the time or mechanized with special precautions, which makes it an expensive resource to mobilize. The branches are abundant and do not offer the best chipping yields. These elements make it a wood fuel whose price on the market is in the upper range of the prices observed on other wood chip energy.

Therefore, it will be difficult for this fuel to position itself competitively on the industrial boiler market in the face of fossil fuels that are often much cheaper given the levels of consumption and the wholesale rate applied. Nevertherless this biomass is completely adapted to the market of small and medium-sized boiler rooms (<1MW) replacing more expensive fossil fuels. This target with customers who are willing to pay for the biomass (higher price than in industrial sector) allowed the chain to be more profitable.

[23] Deliverable D4.2 AgroBioHeat "*Agrobiomass fuels and utilization systems*". https://agrobioheat.eu/wp-content/uploads/2020/10/AgroBioHeat_D4.2_agrobiomass-fuels-and-utilization-systems_v1.0.pdf

When they accept the purchase of this type of fuel, customers aim at the same time to provide support for the maintenance of hedgerows landscapes and all the stakes connected to it.

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Figure 26: Olive tree pruning hog fuel [Image source: CERTH] [23]

Figure 27: Olive tree pruning pellets fuel [Image source: CERTH / AGROinLOG project] [23]

Figure 28: Pile of vineyard pruning hog fuel [Image source: CIRCE] [23]

Figure 29: Vineyard pruning pellets [Image source: Pelets de la Mancha[24]] [23]

6.1. Fuel delivery

When it is used in rural areas, wood fuel from hedge can be delivered by agricultural tipper, by truck equipped with hook-lift type tipper or by semi-trailer. This will depend on the level of consumption of the size of the silos. Beyond 30 km of transport distance, the agricultural tipper is no longer considered effective, which corresponds to the Label Haie standard (1m^3 max/km traveled[19]).

The silos must therefore be able to accommodate different types of delivery. Given the possibilities, note the need to be vigilant about the maneuvering areas and access to the silo. For example, the silo edges

[24] Pellets de la Mancha, http://www.peletsdelamancha.com

must be as low as possible to allow the possibility of delivery by agricultural tipper (lower ground clearance than a hook-lift type tipper carrier).


Figure 30 : Example of problematic silo edge configurations - source AILE

6.2. Designing fuel feeding systems to handle heterogenous particle size

In most wood production sites from hedgerows, the biomass comes from pruning wood or tree coppicing with more developed branching than in the forest:

- The proportion of wood chips with an elongated shape is greater than on a forest log chipping site. The fuel produced is then less fluid. The presence of overlengths is also a risk, in particular when the fuel is convoyed by screw systems.
- Similarly, the presence of fines (particle size fraction < 3.15 mm) is also greater than on a forest log chipping. The hedge wood fuel reach a fine content between 5 and 10% (F10), against less than 5% on forest logs.

Wood fuel suppliers have solutions to limit these risks. But this refining represents an additional cost. The ideal way is therefore to design boiler rooms that are not sensitive to this type of fuel. The main risks of malfunction identified relate to silage emptying and transfer to the boiler.

It is therefore important to avoid narrow silos. Boiler rooms most frequently delivered with hedge wood have a thermal power lower than 400 kW and the main silage removal system used is the rotary silage unloader.

Figure 31: example of rotary silage unloader at the bottom of the silo with extraction screw (left) / example of vertical accumulation of wood showing the not very fluid character of wood chip (right). Source AILE.

The action of this type of mechanism on wood chips with less fluidity is hampered when the silage unloader is not wide enough in relation to the storage height. A vault phenomenon then appears above the silage unloader.

This phenomenon is accentuated with silo filling systems combining hopper and vertical screw: on the one hand because the silos are often higher so the height of stored wood chips causes greater pressure on the device and on the other part because the wood is projected inside the silo causing a compaction effect.

In these cases, it is necessary to avoid having a width/height ratio of the silo lower than 1 or to choose alternatives:

- Choose a wood fuel from hedgerows but refined with greater fluidity
- Install an transversal unraveling screw into the silo

It is also important to favour a simple and direct mode of transfer. The transfer modes most commonly used on the boiler powers targeted (<400kW) by this type of wood fuel are equipped with endless screws. Manufacturers of boilers equipped with conveyor screws recommend wood chip fuels with a grain size between P16S to P31S[25] which means sensitivity to particles larger than 15 cm.

[25] AFNOR. NF EN ISO 17225-1 - Biocombustibles solides. 2021.

Consequently, given the profile of the fuel, in the absence of particular refining, it is necessary to design the boiler rooms and their conveying devices in such a way as to limit these hazards as much as possible. The main recommendation is to favor conveyor systems that have no more than two screws maximum:

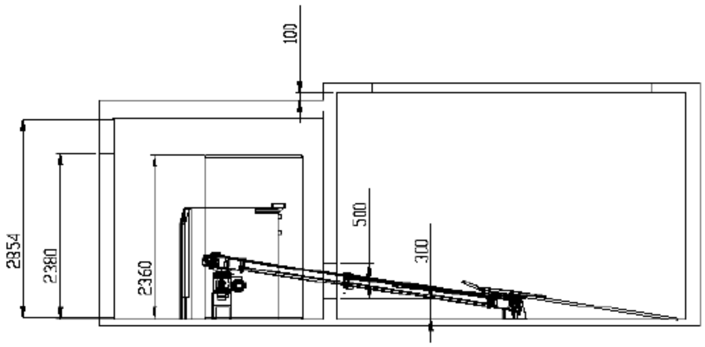

Figure 32 : example of implantation of oblique screws at more than 45° to be avoided to encourage the use of hedge wood - source AILE

Figure 33 : example of screw conveyor very simple to recommend - source AILE

An unloader screw and an introduction screw avoiding the addition of an intermediate transfer screw. This configuration avoids multiplying the number of passing from one screw to another, an area that is often a source of jamming in case of overlengths and coarse and non-standard particles.

A passage is still necessary between the silage and introduction screw, so in this case, for this type of wood, the installation of an anti-jamming device is recommended.

This type of configuration requires the placement of the silo floor at the level (or even a few tens of centimeters below) of the boiler room floor. To be able to be delivered, these boiler rooms are generally installed against a natural slope (slope of the land) or artificial (development of a delivery ramp) or equipped with a delivery hopper.

These recommendations make it possible to avoid the installation of transfer screws on a slope and to see the appearance of another type of sensitivity, that of sensitivity to the accumulation of fines at the bottom of the screw. However, if these arrangements are not possible, it is imperative, in the absence of refining of wood chips, to prohibit the implementation of transfer screws at a slope of more than 45° between the extraction system at the bottom and the system introduction at the top and prohibiting the installation of screws longer than 4m.

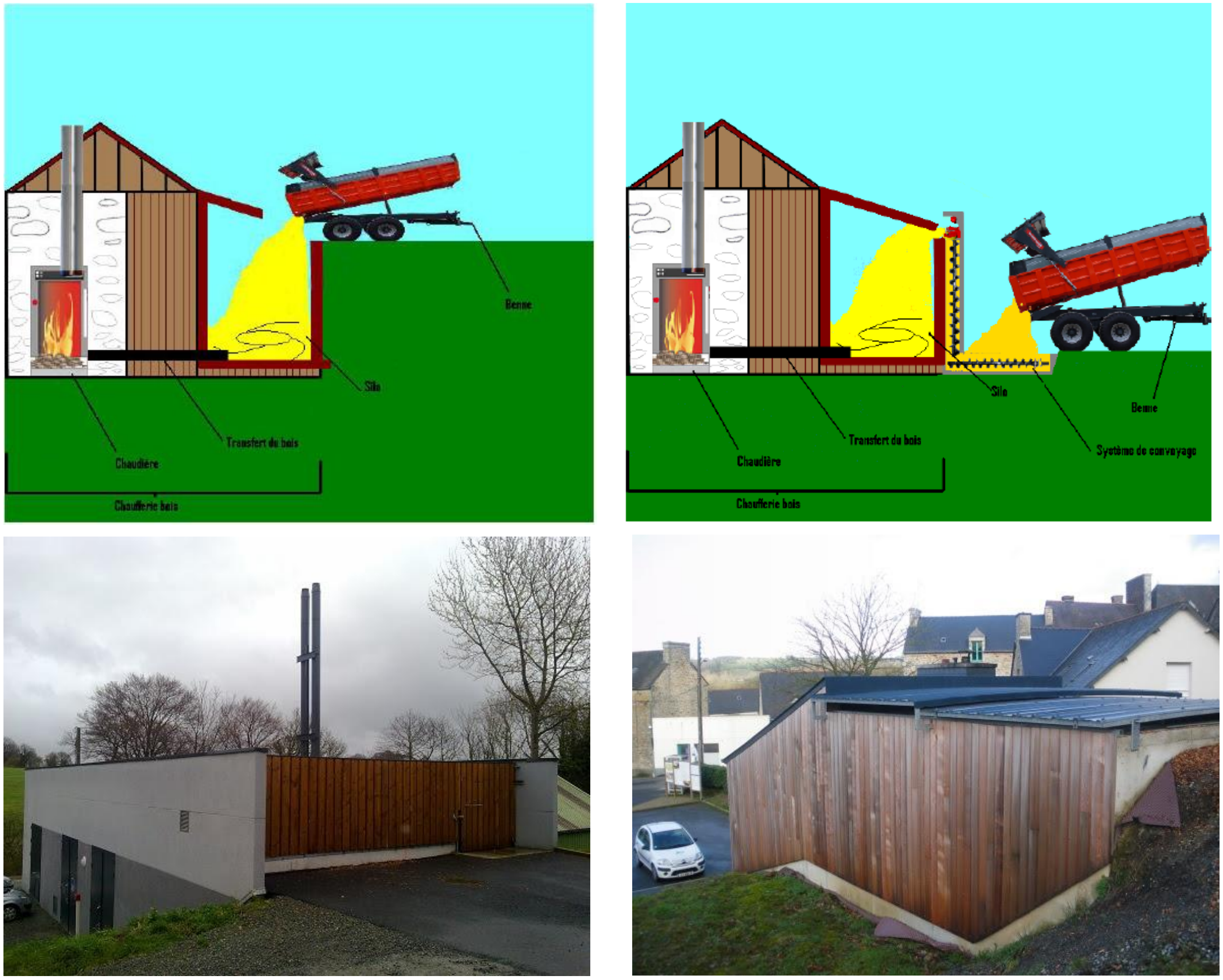

Figure 34 : examples of boiler rooms with silo and boiler on the same level - source AILE

7. Success cases and lessons learnt from previous experiences

7.1. The uP_running project flagship success cases

uP_running was an European project, funded by Horizon 2020, with the aim to promote the development of new bioenergy value chains based on biomass from Agricultural Prunings and Plantation Removals ("APPR" for short).

The uP_running project identified several existing cases of APPR biomass utilisation in Europe, out of which it selected 10 emblematic and best practice ("flagship") cases of APPR biomass utilization for bioenergy production (flagship cases), that covered a wide range of business models, technical implements, types of APPR biomass, end uses and other parameters. In each case, the success factors and obstacles faced by the prime movers were quite different, depending on the local or national frameworks conditions.

The uP_running project selected different flagship cases in which the APPR were transformed into different products: (1) heat, (2) marketable fuels and (3) power. Table 6 shows the main details of these flagship cases. Further information can be found in the public Deliverables 6.3 and 6.4 of the uP_running project [26,27].

Table 6. Summary of uP_running flagships. Source: uP_running 3rd Monograph [28]

	Flagship case	Year of initiation	Prime mover type	Type of crops involved	Biomass form (initially)	End-users
Heat from APPR biomass	**Domaine Xavier Muller (FR)**	2010 (pruning), 2016 (vine stocks)	Farmer / small agro-industry	Vineyards (APPR)	Chips & pellets	Own biomass boiler (household)
	Vilafranca del Penedés (ES)	2016	Municipality	Vineyards (AP)	Hog fuel	Municipal heating boiler & local wineries
	ITC Shabo (UA)	2015	Agro-industry	Vineyard (AP)	Hog fuel	Industrial biomass boiler
Marketable fuels from APPR biomass	**Gospodarstwo Sadownicze (PO)**	2013	Farmer	Fruit trees (AP)	Bales	Municipal buildings
	EAMEB (GR)	2011	Agro-services company	Fruit trees (PR)	Chips	Various end-users, including power plant
	AgriToppi (IT)	2016	Agro-services	Olive trees (AP)	Pellets	Domestic & industrial multifuel boilers
	Triada-MK (UA)	2017	Farming company / agro-services line	Fruit trees (PR)	Pellets	Municipal heating boiler
	Pelets de la Mancha (ES)	2011	Pellet plant	Vineyards (AP)	Pellets	Various industrial end-users & biocommodities market

[26] Deliverable 6.3 *Flagship success cases update v1*. uP_running project H2020 691748. http://www.up-running.eu/wp-content/uploads/2017/10/uP_running_D6.3-Flagship-cases-report-v1_.pdf

[27] Deliverable 6.4 *Flagship success cases update v2*. uP_running project H2020 691748 http://www.up-running.eu/wp-content/uploads/2019/10/uP_running_D6.4-Flagship-cases-report-v2_.pdf

Power from APPR biomass	**FIUSIS (IT)**	2010	Power plant	Olive trees (AP)	Hog fuel	Power plant
	ENCE Merida (ES)	2013 (plant start-up), 2016 (start of APPR utilization)	Power plant	Various (APPR)	Various	Power plant

These experiences allow to collect some main lessons learned, already detailed in the 3rd Monograph of uP_running project[28]. According to this, eight parameters were determined to be crucial for the optimal utilisation of agricultural prunings and plantation removal biomass for bioenergy:

1. Versatility
2. Biomass productivity
3. Locality
4. Social impacts
5. Adaptation and evolution
6. Disrupting vision and perseverance
7. Overcoming the initial scepticism
8. Changing farmer attitudes and agronomic practices

A compilation of these lessons learnt is summarized in Table 7, in which the main key lessons should be followed in order to achieve the development and implementation of new value chains based on such biomass fractions.

Table 7. Compilation of lessons learnt for the optimal utilisation of agricultural pruning and plantation removal biomass for bioenergy. Source: uP_running [28]

	Key lessons	Remarks
Versatility	Each value chain must be customized to their individual conditions and limitations, opportunities and market developments	• Variety of value chains deployment to meet local conditions and demands. • Suitable for direct energy production (heat, electricity), upgraded energy carriers (pellets, chips) or bio-commodities to other markets.
Biomass productivity	APPR biomass productivity has a significant impact on the value chain, but a low value is not prohibitive for many applications	• Low productivity does not necessarily imply unfeasibility of the value chain, especially when fossil fuels are replaced, and biomass fuels are sourced cheaper. • Productivity is more critical when economics might be more restrained to keep cost low and reduce payback (eg. the feed level in tariff or the amount of biomass needed to amortize the equipment)
Locality	The locality is a clear feature for prime movers, since the APPR biomass cannot be transported economically over long distances. Its impact and implications for the success of the initiative should be fully understood.	• Biomass as harvested has a low energy density. Distance from the sourcing radius (distance from the point of production till the conversion site) should be less than 50 - 80 km. • If APPR biomass is upgraded into pellets, they can be transported to final end-users much longer distances with fewer limitations.

[28] *uP_running 3rd Monograph "Agricultural pruning and plantation removal biomass value chains. Lessons learnt from flagships cases".* http://www.up-running.eu/wp-content/uploads/2018/09/1st-Monograph_vDEF-2.pdf

	Key lessons	Remarks
Social impacts	APPR value chains often should enlist the support and acceptance of the local population, demonstrating the clear and general benefits for the area.	• Job creation, especially permanent positions, is an important feature in rural areas, in which most of the agricultural-related vacancies are seasonal. • Avoiding polluting practices (eg. open-field burning) that increase the quality of life, in addition to promote the sustainable image of the local community.
Adaptation and evolution	The value chains must adapt to changing local and market conditions by modifying their approach, if needed.	• It might be a bit discouraging for the primer movers to implement these re-adaptations, but this emerges quite naturally as the actors gain experience. • Generally, prime movers have a great sense of initiative and innovation, so they are well suited to meet new challenges.
Disrupting vision and perseverance	APPR biomass use is not extended, pioneering actors behind a new initiative must be moved by their vision and instinct, not fully by the market opportunities	• Having a clear vision that the current practices of management of the biomass resources should be improved in favour of the local community, the climate and the sustainability. • Possible changes in the framework (market, policy) shall create a more favourable environment to adopt bioenergy solutions based on APPR biomass. When the framework does not vary, the motivation and perseverance of the pioneers is a key issue for the success.
Overcoming initial scepticism	Most local actors tend to assume that the new APPR value chain will fail. Campaigns to abate the scepticism and to align actors are necessary.	• The prime movers are mobilized by a disrupting vision which runs contrary to the general thoughts and established practices of other farmers or companies.
Changing farmer attitudes and agronomic practices	Starting new APPR biomass value chains cannot happen without the collaboration of farmers, who should change their usual practices.	• The demonstration of the feasibility of the new agronomics in practice, and the clear illustration of the benefits are crucial. Farmers always choose the option that better fits to their personal interests and profitability.

7.2. Projects to promote knowledge on hedgerow pruning utilization

Despite its omnipresence in rural areas, and the existence of experiences with more than 20 years of hindsight, hedgerow pruning wood is still struggling to establish itself as an essential solution to contribute to the energy transition. This observation has been slowly improving over the past ten years but must accelerate to achieve the objectives of energy transition policies.

This section offers a review of some initiatives that have been implemented in recent years to improve skills on HP and develop its use.

Knowledge about the hedgerow exists but is scattered and sometimes obsolete. The practices are for the most part forgotten and must be adapted to the new configurations (size of the plot and the plots themselves). Research players and agricultural advisers have every interest in pooling their resources if they want to capitalize on new references, disseminate good practices to farmers and communities and encourage them to promote hedgerow wood.

Since 2015, it is mainly through the development of agroforestry in France, by the Agroforestry Rural Network on the one hand, continued by the network Réunir AF 2020-2025 that actions are carried out in favor of the hedgerow. It should allow an increase in the number of advisers, but also nurserymen and new logistics supply chains: plant material, mulching, etc.).

The Mixed Technological Network (RMT) Agroforesteries 2021-2024, has opened a new work of reflection specific to the valorization of trees outside the forest and a resource center with a documentary base and projects related to agroforestry[29]. Dedicated to the scientific and technical partnership set up and supported by the Ministry of Agriculture, the RMTs are designed to be places of exchange and synergy of skills, bringing together actors in research, training and development around priority themes for the development of the agricultural and agri-food sectors, to carry out collaborative work and promote innovation.

7.2.1.1. Examples in Britanny

In Brittany, a strong desire to place trees at the center of transitions can be seen:

- air quality: Air Breizh, particle plan
- water quality: Breizh Bocage 3
- energy: Brittany Wood Energy Plan 2021-2026

More information can be found on the website: https://www.planboisenergiebretagne.fr/

7.2.2. New references production

7.2.2.1. About the hedge: Resp'Haies (2019-2022)[30]

In order to continue the work undertaken on the typology of hedges and faced with the observation that a need for support in the assessment of the growing stock is necessary to strengthen knowledge of hedges, the Resp'Haie program (RESilence and PERformances of agricultural holdings linked to HEDGES), supported by the Ministry of Agriculture and Food, aims to:

- establish a methodological guide for assessing production by volume and annual productivity of hedges,
- to capitalize on the ecosystem services of hedgerows and their contribution to the technical and economic performance of agricultural production systems,
- to develop tools to promote the commitment of farmers and local managers in the sustainable management of hedgerows, to provide technical arguments to advisors and trainers to help farmers in their decisions.

[29] AFNOR. NF EN ISO 17225-9 - Biocombustibles solides — Classes et spécifications des combustibles — Partie 9: Plaquettes et broyat de bois à usage industriel.
[30] AFAC agroforesterie. [Online] https://afac-agroforesteries.fr/resphaies/.

7.2.2.2. About wood recovery : Bocag'Air 2 (2020-2022)[31]

Resulting from the Agr'Air 2017 call for projects, supported by ADEME and the ministry in charge of ecology and in collaboration with the ministry in charge of agriculture, the Bocag'Air program aims to reduce emissions atmospheric pollutants from the agricultural sector, in particular the emissions of particles linked to the combustion of wood and the mobility of agricultural machinery (fossil combustion).

Following on from Bocag'Air 1, this project focuses more specifically on the subject of combustion, hedgerow wood and questions about the influence of the small fraction rate (particle size <3,15mm present in the wood chips) on the operation of boiler facilities and atmospheric emissions, and more specifically the interest of further refining the product:

- Screen to remove this fine fraction after natural drying (6 months).
- Carry out an accelerated artificial drying reducing the degradation of the material by fermentation.

Indeed, screening and artificial drying involve new logistics chains and direct additional costs. The hypothesis that these can be compensated for in the long term by a more efficient and less costly maintenance operation of the boiler facility (reduced maintenance and major maintenance, improved efficiency) and smoke emissions (particles, NO_X and CO) and less harmful for the atmosphere, must be based on references and an appropriate protocol, halfway between in-situ and laboratory analyses.

The results show that it is possible to achieve an under boiler-room ash rate < 2% and without exceeding 3-4% volatile ash rate:

Also, the results on the particle size quality of the under- boiler room ashes show that the proportion of unburned matter (particles > 8 mm) can be zero and a very low proportion of the 3.15 – 8 mm fraction with and without screening of HP wood.

Moreover, the recent standart evolution ISO 17225-9[32] on biofuels highlights the lack of data on the chemical composition of the HP wood. Thus, it is planned to better characterize them by initiating a test campaign in Brittany to encourage the use of this fuel in the same way as other types of biofuels

Chemical analyzes will be carried out in 2022 to try to assess whether the presence of minerals in the wood is linked to the place in which the hedgerow hedge has grown (edge of meadow/river/sea, agricultural plot with intensive cultivation routes, in conventional agriculture, organic agriculture, etc.)

31 AILE- Bocag'AIR 2. [Online] 2021-2022. https://aile.asso.fr/le-bois-de-bocage-en-combustion-zoom-sur-les-particules-fines/#more-4285.

32 AFNOR. NF EN ISO 17225-9 - Biocombustibles solides — Classes et spécifications des combustibles — Partie 9: Plaquettes et broyat de bois à usage industriel.

7.2.3. Projects to support development of new recoveries

7.2.3.1. Bocag'Air 1 (2018-2020)

This program is also the result of the Agr'Air 2017 call for projects. Routine linear maintenance (hedges but also fruit orchards) or log production sites. It is about crushing and returning to the soil by amendment, a practice forgotten or to be rediscovered. This project has made it possible to develop a collective activity in Cuma in the Côtes-d'Armor, by financially supporting investment in a small branch shredder, by setting up monitoring and comparative analysis of construction sites and the dissemination of this technique with farmers and communities[33].

7.2.3.2. Carbocage (2018-2020)[34],[35]

The Carbocage project aims to measure and enhance the carbon storage potential of the hedgerow through a local carbon market by:

- based on existing references and field samples and showing that a hedge maintained in a sustainable and regenerated way allows additional carbon storage in the soil and biomass.
- providing a management guide and technical itineraries guaranteeing this additionality.
- evaluating the values of the hedge, commercial by sale of wood (heating, timber, etc.) and non-commercial, carbon storage but also its associated co-benefits (biodiversity, water, fight against erosion, landscapes, etc.). Regional workshops involving local authorities, companies and farmers have made it possible to define the conditions for membership of the actors, for such a market and the methods of implementation to make it attractive. At the same time, on April 23, 2019, the Ministry of Ecology launched a low-carbon label, a tool to reward and promote local actions in favor of the climate.

Reminder: The establishment of hedges, their growth favored by good management, and their recovery in energy makes it possible to carry out carbon sequestration thanks to:

1. Aerial and root growth of the tree (photosynthesis),
2. Soil life,
3. The cascade of uses that can accompany the production of energy, ashes in the hearth of course, but also animal litter and Ramial Shredded Wood (RSW) which ultimately contribute to enriching the soil with carbon thanks to an increase organic matter content.

[33] AILE - FBIA - Bocag'AIR. Bocag'AIR - Réduction des émissions de particules liés à la combustion du bois et la mobilité en agriculture. AILE. [Online] 2018-2021. https://aile.asso.fr/projet-rd/bocagair/.

[34] Chambre d'agriculture des pays de la Loire. PROJET CARBOCAGE. [Online] 2020. https://pays-de-la-loire.chambres-agriculture.fr/innovation-rd/energie-climat/recherche-developpement/projet-carbocage/.

[35] Carbocage. Guide de gestion durable des haies. 2020.

This effect was characterized by the Carbocage project and is the subject of the development of the Haie method, which complies with the reference system of the "Low-Carbon" label described in the decree of November 28, 2018.

- Carbon sequestration in unexploited aerial biomass (0 to 4.85 TeqCO2/km/year)
- Carbon sequestration in the root biomass (0.4 to 3.2 TeqCO2/km/year)
- Carbon sequestration in the soil (0.77 to 3.94 TeqCO2/km/year)

In the case of the RCW and the tests carried out in Belgium in 2005, between 30% and 50% of the carbon in the wood becomes SOM (soil organic matter) and therefore causes a significant and rapid increase in the humus rate of the soils (+ 1% in 10 years against 67 years for manure).

7.2.3.3. Agrobranche (2018-2020)

This project focuses on industrial sectors established in the field of green chemistry (molecules) or biosourced products (biocomposite materials, insulation, panels, etc.). Unlike the plants commonly used in the production of these materials, agroforestry, which makes it possible to combine, unlike perennial lignocellulosic crops, sustainable agricultural production, does not compete directly with agricultural land dedicated to food.

This new recovery path could make it possible to strengthen the economic model of agroforestry by improving the recovery of intermediate biomass from pruning and thus mobilizable throughout the life of the trees.

After having qualified the potential of this agro resource, identified the HP method in line with the types of fibers and molecules targeted and compatible extraction processes and material tests were implemented at the scale laboratory and/or pilot.

8. Sustainability aspects of agricultural wood utilisation

Generally, the continuous removal of crops from the field, being straw or fruit tree prunings, results in lower carbon and other nutrients levels in the soils. Thus, responsible management of the crops shall be performed, to maximize the yield of the crops at the same time that we maintain the ideal levels of carbon and other nutrients in the soil.

Taking into account the overall activities of farmers who invest in fruit tree plantation management, maintaining soil quality and fertility plays a crucial role, with significant impacts in both the short and long term. The concept of ecological sustainability states that the use of natural resources that benefit agricultural production processes and the yield of the crops should be consumed in sync with the rate at which they are naturally regenerated. Full compliance with this ecological principle is the key to implementing good agricultural practices and agricultural success. The aim is to avoid any risk of prejudicial effects on soil fertility and the ecosystem as a whole, this way supporting the full achievement of the plant yield. Removing prunings from the orchard implies taking away resources that should be returned to it, avoiding detrimental effects and soil impoverishment – as APPR can be used as soil organic amendment. The main criterion for the management of fruit tree plantation is the balance so that soil characteristics remain the most adequate. The energy conversion of pruning is not in contrast with sustainable soil management and long-term soil quality and fertility.

Other important facts of pruning use regarding sustainability are the improvement of air quality and pollutants if burnt in modern and appropriate combustion systems. In terms of climate change impacts, the pruning-to-energy path performed better than the pruning-to-soil. The reason is that the pruning-to-soil path also involves a series of emissions. In the case of the pruning-to-energy path, it is needed to compensate for the soil effects that would have been obtained through the alternative pruning-to-soil, for example with the use of biochar or biofertilizers. Finally, pruning-to-energy leads to reduced consumption of fossil fuels, and thus a direct and large reduction of GHG takes place.