BRINGING AGRO-BIOMASS TO REALITY: KEYS FOR NEW SUSTAINABLE VALUE CHAINS BASED ON AGRICULTURAL PRUNING AND PLANTATION REMOVAL BIOMASS

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ABSTRACT: The utilization of agro-residues as a source of biomass is an opportunity for supporting the expansion of the bioeconomy in Europe. Among the multiple agro-residues, those produced from vineyards, olive groves and fruit plantation represent a relevant potential for many EU countries. Specifically, the woody biomass residues from Agricultural Pruning and Plantation Removal (APPR in short) is a paradigm of agro-residues being produced year after year, and in most of the cases, not utilized as a resource for added value activities like the production of energy, biochemical or other biocommodities. In this paper, the uP_running project provides a vision to understand the current status of APPR biomass utilization in Europe and gives some recommendations for establishing new value chains based on this fuel. In addition, the document describes how to make the APPR biomass value chains a reality: how the different stages of the value chain and logistics can be carried out, which are the main keys to make the value chain operative, how to ensure that the final user finds an added value in the APPR biomass they receive, and how to preserve the quality and market value.
Keywords: agricultural residues, logistics, harvesting, value chains, quality.

1 INTRODUCTION

The utilization of agro-residues as a source of biomass is an opportunity for supporting the expansion of the bioeconomy in Europe. Among the multiple agro-residues, those produced from vineyards, olive groves and fruit plantations represent a significant potential for many EU countries. Specifically, the woody biomass residues from Agricultural Pruning and Plantation Removal (APPR from now onwards) is a paradigm of agro-residues being produced year after year, and, in the vast majority of the cases, not utilized as a resource for added value activities like the production of energy, biochemical or other biocommodities.

The use of APPR biomass is possible. It is a fact. There are multiple examples along Europe that prove it can be utilized. However, even though there is a large potential in Europe to be exploited (estimated more than 25 Mt of dry matter per year [1]), the cases of success in establishing a value chain for APPR biomass are scarce, occurring isolated. At the moment, further expansion of the mobilization of APPR biomass for the bioeconomy appears halted. There are multiple reasons for it, 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 competing biomass fuels.

The uP_running project (www.up-running.eu) is a Horizon 2020 initiative bringing together 11 partners from 7 European countries, allied with the same objective: to promote the take-off of APPR biomass in Europe. uP_running illustrates the collaboration between technology and research centers, universities, agrarian associations, agrarian chambers and clusters to drive a real change towards an increased utilization of APPR biomass, by promoting the start-up of new initiatives, but also by promoting a more favorable framework and social perception.

The aim of the present paper is to provide the reader with a general overview on the difficulties to start up new initiatives and with a specific insight into the organization of the value chain operations: how the different stages of the value chain and logistics can be carried out, how to preserve the value and characteristic of the APPR biomass, and what should be regarded when facing its utilization to produce heat and/or electricity.

2 STATUS OF APPR BIOMASS IN EUROPE

2.1 Existing value chains

The degree of penetration of the APPR biomass on the European market is, in general, much lower than conventional biomass like forestry wood or even other agro-residues like straw, despite the fact that the wood from APPR is being produced periodically and it is subject of agronomic practices for its use or disposal.

The energy use of agricultural pruning is rather low in Europe [2]. The energetic utilization of APPR biomass in modern energy conversion system (e.g. high-efficiency 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. The main management 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.

Wood from plantation removal is obtained 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 (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 is the case with prunings, the wood from plantation removals is mostly under-utilized in Europe [3,4], although traditional use of firewood from the aerial part of the tree may be usual 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.

Notwithstanding this general situation, there are successful cases of modern value chains at local or regional level based totally or partially on APPR biomass. More than 20 cases have already been identified by the uP_running project and are recorded in the uP_running "Observatory", the web-based tool developed for recording APPR biomass experiences [5] (see a screenshot in Figure 1). Most of the value chains identified are relevant to the self-consumption model, where farmers or small agro-industries use the APPR biomass they produce for heating their own houses, facilities or for their processes. However, there are examples of APPR biomass utilization in larger agro-industries, for the heating of municipal buildings or decentralized heating systems, for large-scale pellets or chips production and for power generation, either as exclusive fuels for the plant or as part of a broader fuel mixture.

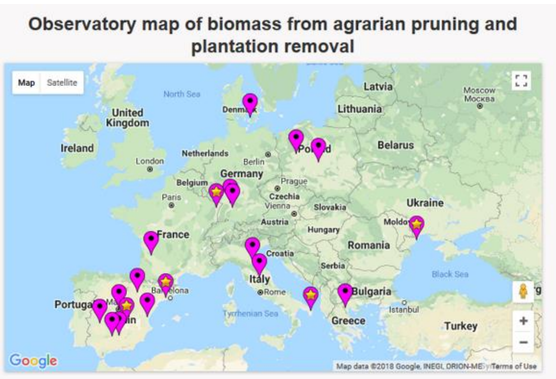

Figure 1: Screenshot of uP_running Observatory [5] displaying identified APPR biomass value chains and flagship cases (until May 2018) - http://www.up-running-observatory.eu/.

2.2 Barriers detected

Despite the fact that there are several successful cases of APPR biomass use to energy, initiating new value chains based on APPR biomass has been found empirically to be more difficult than starting new value chains based on forestry wood, or even other biomass types. On one side, there are diverse technical factors that may limit or bring difficulties when starting a new initiative to use APPR biomass, as for example: availability of mature, efficient and adapted machinery, logistic and monitoring systems prepared for the sourcing for APPR biomass or availability of boilers ready to use APPR wood). However, under the vision of uP_running project, beyond these technical issues what really retains the huge, unexploited APPR biomass potential in Europe are non-technical barriers.

These non-technical barriers have been revealed through direct consultations with more than 600 stakeholders in workshops celebrated in Spain, Italy, Greece and Ukraine. uP_running has already gained much knowledge on the barriers constraining the development of APPR biomass sector, but also about the driving forces capable of unblocking the current situation. The analysis started from the local dimension of the problem by performing 19 workshops and 36 direct interviews held in several European regions: Aragon (Spain), Apulia (Italy), Macedonia and Trace (Greece), Peloponnese (Greece) and Vinnytsia (Ukraine). The different information and visions collected were integrated in form of 4 Regional Action Plans, accompanied by an aggregated document from a wider European perspective [3]. Additionally, uP_running has performed 7 national country analysis based on collected information and visions of numerous national players, finally leading to 7 national strategic plans and a European integrated plan for the promotion of APPR biomass [4].

In principle, when considering the sector (see stakeholders type in Figure 2) with respect the use of APPR biomass, it is observed that there are much more weaknesses than strengths, or in other words, that the position of value chain actors to participate in new value chains is not well developed, and that the sector has more deficits than capacities. In contrast, when observing the external factors (opportunities and threats), the opportunities stood over the threats. This talks of multiples successful and unsuccessful stories. At the light of the multiple opportunities, an entrepreneur in an area shall take action guided by its intuition. Then the entrepreneurs will look for other cases they can replicate, or shall ask for technical advice. Prospering or not depends on the capacity of the entrepreneur to successfully design and set into gear the new APPR biomass value chain and business. If the decisions are adequate, and if constant care is taken to steer the initiative and adapt to changes, then the new value chain will prosper. The new value chain will bring the expected benefits to the value chain actors involved, generally tangible (economic saving, incomes) and intangible (brand, image, strengthen position), and thus the opportunity that guided the entrepreneur, will become materialized.

From a global point of view, both the barriers and the driving forces may be related to (a) cultural attitude, (b) know-how and technology, (c) economic and finance, or (d) governance and policy, see Table I. An important point is that for most countries there is a general interest in driving forces such as greening the economy, reducing GHG emissions, diversifying the rural economy is quite general. However, in practical terms there are no mechanisms or instruments actually favoring APPR use as one of the alternatives in line with such general interests. Some of the driving forces could trigger by themselves a sudden change in the national paradigms, e.g., a sustained increase of the fossil fuels prices or a public initiative to use APPR biomass through public procurement.

Table I: Drivers and barriers for APPR mobilization.

Drivers	Barriers
Greening the economy	Spatial distribution and layout of plantations
Circular economy	Low economic value of APPR biomass
Large potential	Tight profit margin
Diversifying rural economies	Unstable energy policy
Improvement of local air quality	Low fossil fuel prices

Drivers	Barriers
Reduction of CO_2 emissions	Lack of market driven incentives
Public initiatives	General skepticism of market actors
	Secondary interest for society and policy makers

Under the absence of relevant driving forces, APPR biomass remains underdeveloped. Breaking the situation at national scale becomes complex, as the situation is stuck in a vicious circle. At local scale, when trying to start a new value chain, a “chicken and egg” problem has also to be solved: a consumer is interested in APPR biomass will usually find no providers and lots of uncertainties and risks to be faced. When a biomass producer decides to collect APPR wood he finds usually no consumer, and much distrust about the quality and properties of the APPR biomass. Additionally, they find no example or model to follow, while informed counsel is also difficult to be obtained.

3 UNDERSTANDING APPR VALUE CHAINS

3.1 APPR biomass dispersion and productivity

Collecting the wood from pruning or plantation removals poses a series of difficulties to the logistics due to several factors. Among the main ones are the following: its dispersion in the territory, the size and layout of the plantations and the variable biomass productivity.

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 cost. 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 APPR biomass collection, farmers or plantation managers may opt for disposing the residues as usual, e.g. through open air burning, mulching, etc.

A third factor conditioning the organization of the biomass supply from APPR residues is the fact that production of biomass per hectare is low in comparison to forestry wood, and thus operations of collection, handling and processing at field are usually subject of relevant costs per unit of material processed. The APPR biomass productivity ranges from 0.5 to 10 t/ha (dry matter). The lowest productions 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 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 biomass productivity from plantation removals can reach 5 to 10 t/ha dry matter or even exceed it. In comparison, forestry exploitations can easily reach above 40 t/ha dry matter of stem-based wood.

APPR productivity depends on multiple factors, as described by García et al. 2016 [6]: 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. Alternatively, the uP_running Observatory (http://www.up-running-observatory.eu/en/) can be useful for a first guess as it collects biomass productivity values from hundreds of field measurements (more than 360 as of May 2018) in relation to the aforementioned factors.

3.2 APPR biomass as fuel

APPR from vineyard, olive groves and fruit trees is a woody biomass with good energy content, but with some particular differences in comparison to forest biomass. It is worth mentioning that several projects have provided evidences of these particularities. For example, according to the results of EuroPruning [7], one kilogram of APPR biomass is equivalent to 1.03 kg of forestry wood, at same water content (see Table 1). The main difference lies in particle size distribution and in the ash content.

Table II: Characteristics of different types of APPR biomass after mechanical collection and processing (data from EuroPruning [7]) and comparison with pine wood chips of class A2 (EN 14961-4:2012).

	Water	Ash	LHV	
	(% wt, ar)	(% wt, db)	(MJ/kg, ar)	(MJ/kg, db)
Pine chips Class B	≤ 35.0	≤ 3.0	-	18.2
Almond prunings	34.4	4.6	10.6	17.4
Peach prunings	37.5	3.7	10.5	18.3
Olive prunings	27.6	4.8	12.5	18.2
Vineyard prunings	41.5	3.5	9.2	17.4

Forestry stem-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 stemwood. This type of biomass therefore requires boilers with higher requirements in the systems dedicated to withdraw ashes or to clean the flue gases.

According to EuroPruning [7], S2Biom [8] and Biomasud [9] APPR wood 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 prunings 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.).

3.3 Collection and mobilization of pruning wood

One of the main challenges for using the pruning biomass to energy consists in finding the most appropriate system to collect the APPR biomass.

Collection systems affect the APPR 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 of more than half of the total costs for APPR mobilization.

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.

3.3.1 Preparation of pruning wood for collection

When pruning operations are performed, the branches removed fall on the plantation soil, in a circle around the tree trunk. Three main scenarios exist, depending on how the prunings are then arranged:

1. to windrow or to organize them in the center of the lane between tree rows; this is the ideal option in cases of pruning collection or even when a mulcher is used, since it minimizes the working time of the tractor;
2. to leave them as they are and pass with the treating machinery nearby, even though it may require to pass with the machinery 2 or 3 times along each lane. This option is also more complicated since the presence of branches on the standing trees may limit the movement of tractors / machinery.
3. to collect them in piles in the middle of the rows; this option could be acceptable if a static chipper is employed.

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 (used for this purpose). The sweepers are usually made of flexible, but highly resistant plastic bars, rubber blades or wires.

The preparation of the pruning is a crucial part of the work. Firstly, this operation can be partly facilitated by the farmer or plantation manager. The preparation or windrowing needed may differ from the usual methods of the farmer; therefore, a negotiation may be needed. The correct preparation of the branches (alignment, width of the windrows) has a direct impact on: the performance in ha/h (and thus on economics) and on losses (amount of material not collected). It is to be highlighted that high losses have a double impact in the viability of the biomass collection: firstly, the costs per ton obtained are higher; and second, 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. Or, it may result in an arrangement that is simply not agreeable with the farmer.

3.3.2 Hauling the branches and shredding / chipping / baling at field side

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 amount of stones can be particularly large.

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 and the final weight transported is low in comparison to chips or bales (which density is much higher). An alternative 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. The material can be shredded into pieces of large size (e.g., G150 or G300), can be shredded in form of heterogeneous material (usually called hog fuel, G100 or smaller), or it can be baled. The different options are depicted in Figure 2.

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 prunings. Shredders with hammers are preferable, since they are better suited to the comminution of unclean wood.

As case example, uP_running performed several demonstration of pruning collection, showing that the haulage can be performed appropriately. In Spain, both cases took place. Pruning from large branches taken from peach tree plantations were hauled with tractor, and piled manually, and its final ash content was as low as 1.5 % (dry basis). This percentage is really low as compared to the values presented in Table II. However, in another experience with vineyards the amount of stones inside the piles of pruning shoots collected were so high, that it was needed several cleaning operations before the prunings collected could be processed with a large shredder able to cope with contaminated wood, but not with such large amount of stones.

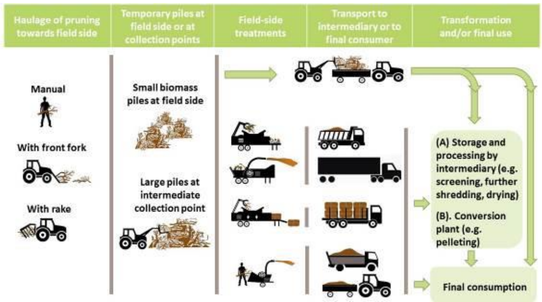

Figure 2: Alternatives for implementing the supply chain when prunings are hauled to the field side.

According to uP_running experience, farmers are usually eager to suggest this method, as it implies lower costs for them, no investment, and no need to negotiate or coordinate with an external company to enter in the field (as the material remains outside in piles). However, when the haulage incorporates important amounts of inorganics, the material obtained is not of good quality and may need additional operations to separate stones, gravels or soil. An additional advice is to leave the biomass drying in piles before the treatment, as it will get drier and facilitate its handling. Additionally, rains shall partially contribute to remove part of the inorganics collected.

3.3.3 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 type of implements requires that the prunings are aligned in windrows (either manually or mechanically prepared, as discussed in 3.3.1). These machineries integrate the collection and the treatment, which 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 3 cases 'a', '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 machinery, even though they are unusual, and thus not depicted in Figure 3.

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 lase 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.

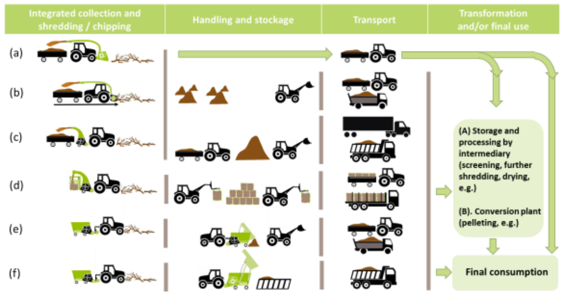

Figure 3: Alternative paths for implementing the supply chain when collection and shredding/chipping of prunings is integrated in the same machinery.

The different implements shown in Figure 3 are offered by multiple brands with shredding technologies. The simplest shredding systems utilize hammers without any sieve, and thus produce an inhomogeneous woody materials consisting on pieces of branches partially defibered, as they are comminuted by impacts of the hammers. More evolved shredders combine hammers with sieves and other teeth shredding or cutting systems, producing a very fine shredded material. These type of systems are less common, usually more sensitive to stones and with higher maintenance costs. On the positive side, the material produced, still not comparable in shape to woodchips, is more homogeneous and thus it is more likely to find direct consumers for it.

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, as can be seen in Figure 4. The baling operation is as quick and effective as shredding or chipping (allows a similar velocity of advance). There exist already commercial balers for prunings able to produce either round or squared bales. Balers for pruning are colored green in Figure 4. In some cases, the prunings can be baled with regular hay balers by incorporating some modifications. These implements are shown colored in black in Figure 4. Normally the bales are more irregular, less compressed and more instable than bales produced with specific pruning balers, though this is not necessary a main issue, depending on how the value chain is organized.

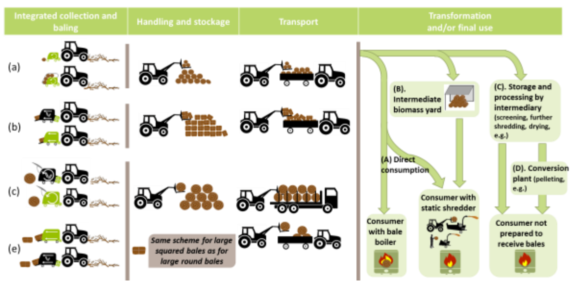

Figure 4: Alternative paths for implementing the supply chain when collection and baling of prunings is integrated in the same machinery.

In respect to Figure 4, as observed, the principal differences are the bale size and the shape, either squared or round. In case of small bales, the loading, transport, storage operations are more time consuming. The use of forks, shovel or grabber to handle the bales usually cause them to partially change in shape, especially when handling bunches of small bales. The systems denoted with (a) are small round bales prepared for pruning, especially for vineyards. Its use has been demonstrated to be appropriate for self-consumption and local consumption (with particular advantage that bales can be handled manually). Small squared balers (b) are also usually prepared for vineyard pruning. Large balers producing round (c) and squared (d) bales are more appropriate for producing larger volumes of biomass or in farms where there is already a boiler capable of handling large bales.

The advantage with bales is the better storage and the lower tendency of the wood to decompose when stored.

However it involves a series of disadvantages to be taken into account, as they condition the subsequent logistic operations and costs: after being produced, bales have to be picked-up and hauled to a place at plantation side; loading and unloading involves longer time and additional costs than bulk shredded wood or woodchips; the pruning bales tend to be less stable than straw bales, and usually lose its initial shape; finally, unless the final user already has a baler boiler, the bales have to be shredded before consumption. Baling is, however, a practice carried out already in some success cases like in Domaine Muller (France), Cantine Giorgio Lungarotti (Italy) or Wienawia (Poland). Further details on these cases can be found in the uP_running observatory [5].

3.3.4 Harvesting with integrated shredding / chipping / baling

Although this option has not been implemented until now in existing chains, it is introduced in this paper 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 [2]. The mechanized pruning is a method quite extended for vineyards, which allows 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 (http://vineyards4heat.eu/).

Another existing implement is a self-propelled integrated harvester capable of performing both pruning and pruning residue harvesting in a single pass in tree alignments, and thus applicable to reconverted intensive fruit and olive plantations. A multiple-disc cutting bar is mounted on a hydraulic boom hinged on the right side of the carrier, which performs the cutting, and the pieces fall on a belt conveyor that feeds the shredder.

The implements mentioned, and briefly described in Figures 5 and 6 are technical solutions that are either in development or not very widespread yet. Therefore, as for the moment, no pruning biomass value chain based in this collection method has been detected.

Figure 5: Vineyard pre-pruning integrated with collection and mulching/chipping (left). Prototype developed by the Vineyards4heat project (right).

Figure 6: Pre-pruning integrated with collection and mulching/chipping in an automotive machine. Commercial machine (Speedy cut) offered by Favaretto (right).

3.4 Collection and mobilization of plantation removal wood

The vineyard, olive 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 intensive, or about 15 for olive 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 cornerstone is the shredding or chipping device. As these systems have to 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. When selecting a system, it is fundamental to take into account the following items:

1. Transporting the whole tree is not efficient, and thus, except for short distances, the solution is to perform a first comminution of the material at field side. In contrast, the logistics and operation of chippers and shredders of large capacity is not always possible or simple. Moreover, the costs involved are high. Thus, a first decision is whether to perform the comminution at field side or to transport the bulk unprocessed trees to an intermediate facility where it can be more optimally processed.
2. Degree of contamination with soil and stones: chippers are only adequate when processing the aerial part of the tree. It roots and stumps are included, then a crusher or a shredder should be utilized.
3. The balance between particle size and processing performance: even though it is interesting to perform as few processing steps as possible, processing whole trees into fine and regular material implies longer time and processing costs. Therefore, whenever the material produced is not transferred directly to a final consumer, but to an intermediate biomass hub or logistic centre, an option is to save time and costs in the operations at field side, meaning that the objective is to perform the comminution as rapid as possible.
4. Feeding the crusher/shredder/chipper: the form of fruit and olive trees, with branches expanded

in form of vase or fan, and with a short stem (in comparison to forest trees) makes difficult the feeding and the conveying at the inlet of the machinery. Feeding is usually the bottleneck for the performance. An ineffective feeding lead to very low performances, and thus to large costs per unit of biomass processed.

5. Outlet system: ideally the best solution at field side is to discharge on a container or on a truck. Even though the processing is slow, the cost associated to waiting time of the transport should be considered. Discharging on soil implies two drawbacks: the material should be loaded afterwards (need of a shovel or tele-handler) as well as the further contamination with soil.

In the next section, more details are given for each one of the different collection methods.

3.4.1 Whole tree uprooting, shredding and further processing

The typical operation when a plantation is terminated is 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 7.a) or treated "in situ" (Figure 7.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.

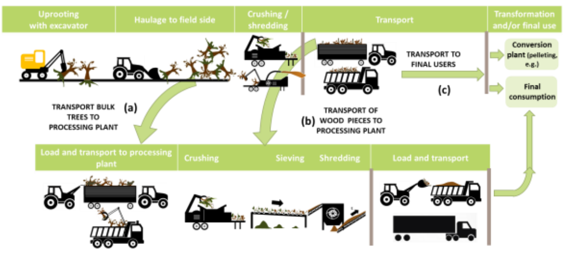

Figure 7: Alternative paths for implementing the supply chain of plantation removal wood when the whole tree is up-rooted and processed.

Except for the case that the material processed is directly sent to a final consumer with capacity to directly use or process it (Figure 7.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.

3.4.2 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 8). 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.

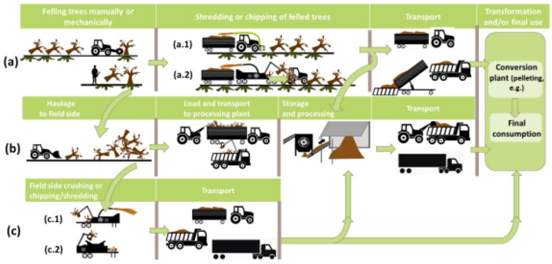

Figure 8: Alternative paths for implementing the supply chain of plantation removal wood when the trees are felled to obtain the aerial part of the tree.

In Figure 8 three principal alternatives can be discerned:

(a) Once the trees are felled, they can be treated directly without haulage. The main advantage is the better quality of the wood, as it has not been hauled along the field. Option (a.1) consist on a shredder/chipper of high power coupled to the power take-off of a large tractor. The system may need in some cases an alignment of trees, which involves some additional costs in the preparation. Case (a.2) consists in a kind of processing train, where a tractor pulls the forestry chipper and a large trailer. The implement moves alongside the trees felled, and feed the shredder or chipper with an arm. The main trouble is to find a shredder able to convey the whole tree. The arm needs to push the tree at the inlet, and thus the feeding and final performance (measured in t/h) will be low. Both systems obtain a material that can be sent directly to final consumers; an alternative is to send it to an intermediate storage and processing plant for further treatment.

(b) Another option is the direct transportation of whole aerial part of the trees to the processing plant. This practice is possible in short distances. Whole trees are usually partly broken and lose their original shape when hauled with shovel or bulldozers, and thus, they fit and fill better the trailers or containers utilized. The processing center carries out directly shredding or chipping. Alternatively, it performs a rushing operation. Sieving is not necessary unless the haulage has caused the wood to get polluted with soil and stones. Therefore, the means of haulage is a key issue.

(c) A third option is performing a chipping or shredding (c.1) or crushing (c.2) at field side. Chipping should be considered only when the haulage has been carefully performed, and stones or soil are absent. The material could be sent to final consumers, or alternatively, b sent to an intermediate center for storage and further processing.

3.4.3 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 operation with forestry chippers or large shredders or crushers, the investment is high. The main difference is that in the 2-stage process, the value chain actors to be involved in the area may already possess with the necessary machinery, and 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). In the case of a single pass, it may be rare to find a local actor that owns the required high power tractor and front shredders; therefore, the investment usually is totally on purpose to obtain the plantation removal wood. This is a main bottleneck for the deployment of this system.

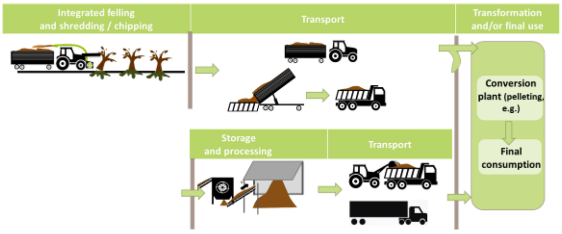

Figure 9: Alternative paths for implementing the supply chain of plantation removal wood when an integrated felling and shredding / chipping is performed.

3.4.4 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. The reason is that 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. In such case, the farmer is completely released from the management operations of the plantation removal residues. The costs are then increased for the company providing the service, and thus a fee or money transfer is asked to the farmer (who should still save money with respect the as-usual costs). In other words, a service company could organize a service of plantation removal, leaving the field clean of residues to the farmer, but at a lower cost for him, given the fact that part of the biomass can be utilized to cover partly the plantation removal costs. The operations performed in such a value case are similar to the operations performed when the whole tree is uprooted, as described in section 3.4.1 and presented in Figure 10.

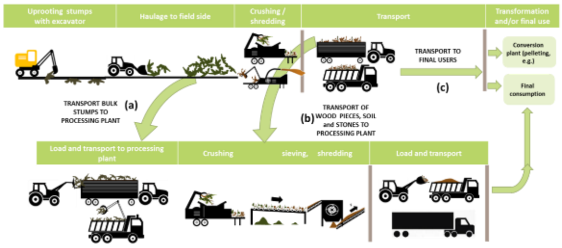

Figure 10: Alternative paths for obtaining stumps and roots and provide them to a final consumer.

3.5 Transforming APPR biomass to energy

The last step for producing energy from APPR biomass is the final transformation of the fuel to useful heat and/or electricity. The chemical energy contained in the APPR biomass is usually obtained through thermo-chemical conversion in systems like furnaces, boilers, gasifiers, etc. The traditional use of APPR biomass was constrained usually to self-consumption in small heating devices. Although still relevant, new modern applications and niche markets have emerged in certain locations: heating of municipal buildings, farm heating or industrial processes. Moreover, the APPR biomass may also be co-fired in large thermoelectric plants to replace part of the biomass or fossil fuels currently used, as can be seen with more detail in the value chains reported by the uP_running project [11,12]. Usually, a combustion process using grate-fired systems or fluidized bed technologies is employed in such cases.

Such combustion installations typically have the following distinct components: biomass supply; biomass storage; feeding system; energy conversion system (burner and heat exchanger); ash collection; gas cleaning; chimney; control panel and safety system. Compared to biomass installations based on forest wood pellets or chips, systems ready to use APPR biomass are different in the following three aspects: the feeding system, the burner technology and the ash collection system. More details are given later in section 4.4.4.

As a summary of the conversion systems utilized in initiatives described by EuroPruning and uP_running projects, the different technologies that have been applied up to now are summarized hereinafter:

- Small-scale biomass boilers, with fixed and stainless steel grate: one example is the 45 kW Guntamatic POWERCORN that operates with vineyards prunings pellets and chips in "Domaine Xavier Muller" (Alsace, France).
- Medium-scale boilers, with fixed grate and robust feeding system: several boilers from Heizomat operate with municipal pruning residues in Calpe, vineyards prunings in Vilafranca del Penedés (Spain) or other prunings residues in Germany.
- Medium-scale boilers, with moving grates and fully automatized operation: one example is 130 kWth HERZ Firematic, operating with a mix of standard chips and vineyard prunings chips at Cavas Vilarnau. The overall installation is placed in a container, next to the winery. In Ukraine the company ITC Shaboo

produces steam out of vineyard pruning in a 1.16 MWth boiler of the Ukranian manufacturer Kriger.

- Large boilers with reciprocating or inclined grates and flexible operation: different examples arise, as those ones of L.Solé 4 MWth steam boiler installed at Bodegas Torres (Spain), which operates with a mix of standard chips and vineyards prunings; the ORC (Organic Rankine Cycle) installed at Fiusis power plant (Italy) that fires olive trees prunings in a Uniconfort boiler and produces electricity with a 1 MWe turbine from Turboden; and the Standardkessel boilers operating in Sacyr Energía power plants with olive pomace and olive prunings (Spain).
- Finally, other many boiler manufacturers like OKO-THERM, LASIAN, Hargassner or Fröhling (at small-to-medium scale) and BINDER, Compte-R, SUGIMAT or LIN-KA (at medium-to-large scale) also claim that they can produce boilers capable of burning burn APPR biomass.

To a minor or major extent, the biomass combustion technologies initially designed and developed to work with conventional biomass fuels (i.e., forest wood pellets or chips) have been modified in order to operate with high ash content and heterogeneous biofuels. Nonetheless, these modifications and/or retrofit have not compromised the techno-economic feasibility of these installations, as demonstrated by the existence of the aforementioned initiatives.

3.6 Sustainability aspects of pruning utilization

The utilization of APPR biomass for energy involves a series of advantages in respect the use of fossil fuels that are evident: reduction of pressure on fossil fuel reserves, reduction of energy dependence, and positive impact in reducing GHG emissions among others.

However, the actual use of APPR biomass for energy may be subject of distrust because of some environmental issues like: generation of air emissions and local pollution, displacing the use as organic input for soils, or insufficient capacity to abate CO_2 emissions. Even though these concerns rely on some funded argumentations, their generalization is usually incorrect. Next sections try to provide clarity on the actual sustainability of APPR biomass for energy.

3.6.1 Air quality and pollutants from APPR biomass

Biomass use can be a source of air pollution when rudimentary and obsolete combustion systems are utilized. For example, the traditional use of APPR biomass as a firewood can be a source of pollution, especially in cases where the moisture content of the firewood is high. Moreover, obsolete boilers or heating systems in farms, agro-industries or other non-regulated and non-monitored sectors can be a source of air pollution. However, modern combustion systems are developed to perform an appropriate combustion of biomass. Furthermore, APPR biomass can be burnt in devices already prepared for it. In large scale systems the air emissions are monitored and the units are equipped with flue gas cleaning systems.

It is also argued that due to the pesticides and other phytosanitary products, APPR wood is contaminated with dangerous elements, and thus it should not be combusted. Findings from the Biomasud Plus project, in which an extensive sampling of olive tree and vineyard prunings was performed, verify that the only minor element that can be found in higher quantities in APPR biomass compared to "standard" forest wood is copper, which is coming from fungicides used in permanent crops. However, it can be argued that the increased presence of copper does not have a significant impact on the air emissions for the following reasons:

- Copper is a non-volatile element, so it is not expected to contribute to increased particulate matter (PM) emissions (in particular PM1 or PM2.5).
- Copper generally facilitates the formation of dioxins when chlorine is present. However, in modern biomass boilers, the temperature that flue gases reach is sufficient for destruction of any dioxins formed.
- Finally, the ash content of APPR biomass is generally higher than that of forest wood. Therefore, the percentage of copper in the grate ash would not be as high as the percentage of copper in the fuel suggests.

The copper content of APPR biomass can be reduced if the material is washed out via rains when left on the field.

3.6.2 Use as soil organic amendment

The utilization of pruning wood as organic amendment to improve the properties of the soil is an extended practice in several areas in Europe, principally in non-Mediterranean countries (Germany, France, Slovenia, Slovakia, Poland or Ukraine) as example [2]. A change from a pruning-to-soil to a pruning-to-energy practice may seem unsustainable from a soil quality preservation perspective. In order to bring some light to this issue, next facts should be considered:

- APPR wood is imbalanced in its composition of C/N: soils are a living ecosystem. Adding organic matter involves an activation of the soil. The organic matter is assimilated by the soil living organisms and transformed into new products; part of the metabolized carbon is released in the atmosphere while another part is stabilized and contributes to the humus and improves soil structure and fertility. However, given the C/N imbalance, integrating APPR wood can cause a temporary blockage of the available nitrogen of the soil, which is utilized by microorganisms in order to assimilate the added organic matter.
- APPR wood transformed causes CO_2 and N_2O emissions to the atmosphere: the APPR wood integrated into the soil decomposes and causes emissions (see more details in section for LCA). From the total dry matter about 15 % may become humus (according to typical humification coefficients).
- Adding APPR biomass as soil cover, without integration (mulching) does not but a residual effect on the SOM (Soil Organic Matter) of the topsoil. It may prevent from soil erosion and transpiration.
- APPR biomass utilized as soil amendment is only possible if there is no risk of disease and pest propagation. If the area under

consideration is being threatened by the olive tree borer, Xylella fastidiosa (affecting olive but also almond) or vineyard fungal diseases (e.g. mildiu, botrytis, oidium) then removal of APPR from the field is a one-way street for the farmers.

- The utilization of APPR biomass as soil amendment is not by itself the solution to rise the SOM pool of soils, or to improve its quality. Other agronomic practices are complementary, and even more relevant: application of manure or compost, keeping a green cover mowed several times per year, or reduction of tillage.

Notwithstanding the previous arguments APPR biomass can play a role in preserving and improving the characteristics of the agricultural soils. Some indications that can be followed have been provided by EuroPruning project [13,14] as expressed in Table III.

Table III: Recommendations from EuroPruning where pruning wood should be left at plantation soil according to the results obtained in its research on soils in Spain, France and Germany.

Prunings should not be removed if:	• No vegetation cover > 80 % between trees (interrows) can be established and (a) soil structure is weak and tends to compaction / silting / surface runoff or (b) the orchards are prone to erosion and there are no alternative erosion protection measures or (c) top soil tends to water logging / anoxic conditions or
	• No vegetation cover with > 15 t ha-1 year-1 fresh biomass (3 t ha-1 year-1 dry mass) can be established and soil carbon content is low.
Specific measures	• Case (a) or (b): Prunings should be chipped and used as cover mulch. • Case (c): Prunings should be chipped and worked into the soil.

Special mention should be paid to Mediterranean countries where in areas of low annual rainfalls the spontaneous grass cover is absent or partial, and where agricultural soils tend to be object of tillage (to avoid competitiveness for water between grass and crop). This fact causes soils to be traditionally more exposed to erosion, and to a decrease in its organic matter. Therefore, these areas should be object of special care. EuroPruning, [15] in collaboration with the S2Biom project [16] and its assessment on soil sustainability at European scale, established that Mediterranean soils in permanent crop plantations presented poor organic carbon contents. In such cases, a grass coverage can be a very effective method to preserve and grow the SOM in soils.

3.6.3 The GHG emissions

The use of APPR biomass for energy brings a question in comparison to its use as organic amendment: is it really an environmentally friendly practice considering the actual effect on GHG emissions from a life cycle perspective? It is usually argued that the use of APPR wood as soil amendement recycles nutrients with the organic matter; thus, the use of synthetic fertilizers can be reduced. For this perspective it can be argued that, whenever the biomass is utilized for energy, the opportunity to reduce the use of fertilizers is missed.

Life Cycle Assessment (LCA) is a methodology developed for comparing the environmental impacts of several products or services, counting all their lifetime: from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. In the case of pruning wood, an assessment was performed by EuroPruning project [15], by comparing the LCA of pruning-to-energy with the pruning-to-soil.

The results of EuroPruning (see Figure 11) revealed that in terms of climate change impacts, the pruning-to-energy path performed better. The reason is that the pruning-to-soil path also involves a series of emissions (as measured by EuroPruning parcels in 3 countries). In the case of pruning-to-energy path it is needed to compensate the soil effects that would have obtained through the alternative pruning-to-soil. As observed the impact is low, since the contribution to nutrients to the soil is very low, and thus, the replacement rate of synthetic fertilizers is also low. In contrast, pruning-to-energy leads to reduced consumption of fossil fuels, and thus a direct and large reduction of GHG takes place. In the case of olive tree prunings, the use for energy is 6 times more effective in terms of GHG emission reduction compared to their use as soil amendment. In other words, from the viewpoint of global emissions, the use of pruning for energy is very effective.

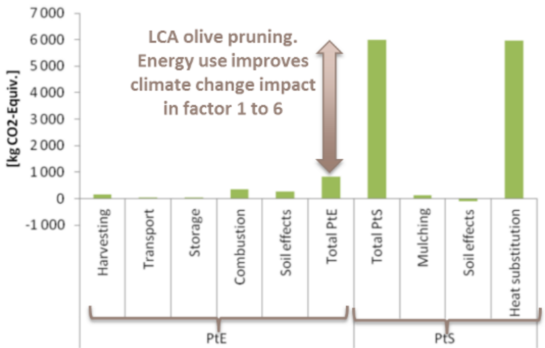

Figure 11: Results climate change impacts obtained by EuroPruning for olive prunings through LCA methodology (adapted from [15]).

4 RECOMMENDATIONS FOR SETTING UP NEW APPR BIOMASS VALUE CHAINS

4.1 Organization of the value chain actors: foster collaborative relationships and mutual benefits

A basic key is to recognize that the management of APPR residues involve costs, and that in some cases implies a problem for the farmer. When this fact is acknowledged by the producer of the residue, then this actor is more prone to collaborate and cover part of the costs or efforts to facilitate its extraction. A second premise is that both the supplier and the other agents of the value chain have to understand and perceive that the overall chain profitability is quite adjusted. Contrary to conventional products sell-buy mechanisms (e.g. for acquiring shoes, computers or food), APPR value chains usually require collaboration agreements between the actors, especially for the organization of pruning and plantation removal operations, from one hand, and their harvesting operations, on the other hand.

There are multiple ways to organize an APPR value chain, but in all of them there is the win-win aspect between the supplier of APPR wood (e.g. the farmer or cooperative) and the intermediary company or the consumer and this mutual benefit relationship does not always imply a simple economic transaction.

That is why replicability is more complex. Creating the demand for APPR biomass does not ensure its effective mobilization. It is necessary to coordinate all the agents involved in those steps between the collection and the consumption. In contrast to conventional biomass, where demand mobilizes silviculture treatments, unblocking agricultural residues requires intense local work and bilateral meetings.

4.2 The intangible value, a typical ingredient for the success

The narrow profit margin for APPR value chains is usually regarded as a risk by entrepreneurs, a weak driving force for starting a new value chain. Why to bet for APPR biomass if other biomass resources, with comparable or even better quality, are locally available at a better or reasonable price?

Beyond basic economic aspects the intangible value of APPR biomass may be the key for activating the implementation of a new chain. Not everything is money, and some actors may find a real appealing value in saving time, avoiding annoying operations for the residue management, reducing fires risk, branding they are "green" and contributing to the wealth of the local community, among others.

The intangible values are very varied, but a lesson learned through uP_running is that in all the cases analyzed the intangible gains were an essential driving force for some actors, and lead to a successful and steady use of APPR biomass. It has also been observed that some initiatives based on economics, stuck and turned to an alternative biomass resources when the market conditions changed. In such cases the intangible benefits were conjectural. Intangible benefits include the following: avoidance of pest risk, avoidance of fire risk, the reduction of CO_2 emissions, creating the image of a sustainable business, diversification of a company, and reduced reliance on fossil fuels.

4.3 What is the market value of the APPR biomass: it's all about quality

Understanding the final consumer needs in terms of fuel quality is fundamental when designing APPR biomass sourcing schemes. In the "ideal" case, future consumers invest in combustion facilities that are able to handle this kind of biomass. However, when it is intended to put APPR biomass as an alternative fuel in an existing biomass market, the value the APPR biomass can reach depends on the market prices of the biomass resources utilized currently by the targeted segment (e.g. forestry woodchips, straw, almond shells, etc.). Each area is particular, and whereas the APPR biomass properties are in some cases a drawback, its price can be adjusted to become competitive. Finding buyers of APPR biomass can be complex, since most of the existing biomass facilities are prepared for the specific fuel they consume, and then they may fail in the attempt to burn APPR wood (see section 4.4.4), generating the erroneous belief that this type of biomass cannot be used to energy.

The challenge is to find a good fit between the characteristics of the APPR biomass generated and the quality demanded by the final consumer. In other terms, the logistic path through which APPR biomass is harvested, treated and transported must be performed taking into account the requisites of the energy system that will convert APPR biomass to energy. Two particular parameters are the most complex: the maximum particle size and the maximum ash content that the boiler or gasifier is able to handle. The moisture content of the harvested APPR biomass may also pose limitations; however, there are more possibilities to find low or no cost alternatives to reduce the water content of the fuel, e.g. by leaving piles of pruning wood on the field to dry before harvesting.

It is important to underline that there exist many logistic paths and ways to harvest and treat APPR biomass and that none of them is "the best one". Each path has its own pros and cons, specific costs and a different quality level of the final product (as presented in sections 3.3 and 3.4). The right treatment is the one that allows optimizing operation costs and generating a product that is accepted by the end-user or the intermediaries. In that sense, for some initiatives it may be more appropriate perform costlier field operations and avoid problems later in the value chain (biomass fermentation, additional screening, erosion or fires in mills due to stones, etc.); in other cases, it may be better to work quickly and at low cost in the field and then treat the biomass in an intermediate platform.

In the case the APPR biomass will be put on conventional biomass market, the APPR biomass produced has to fulfill some quality criteria that allow its combustion in conventional boilers. This is particularly relevant for the size distribution, as described before. The problem is that current pruning harvesting systems are principally shredders, which were initially designed for other purposes, generally to leave pruning on the plantation soil either in form of pieces, or in form of very thin shredded wood. In the last years, these machines have been adapted by manufacturers to propel these small pieces to a self-loaded bin, a big bag or to a towed agricultural trailer, instead letting them on soil. The work performed, which can be satisfactory in terms of hourly yield per hectare, nevertheless obtains a type of biomass incompatible with most current combustion facilities, even in large boiler plants of more than 10 MW (as attested by three EuroPruning demonstrations in Spain and two in France). Similar is the case with plantation removal shredders. They are prepared for larger pieces of wood, and thus the material produced out of vines, olive or fruit trees tends to have a very heterogeneous particle size. Treating this biomass entails additional costs of 5 to 10 €/t, which can be a death track for the chain's profitability.

This is why, when the objective is to put APPR biomass directly on the market, an alternative can be the use machines capable of producing more homogeneous biomass in a single operation. The possibility can be performed with shredders combining hammers with a second cutting system and a sieve (some models are already available in the market). Chipping is another alternative. The clean cut produced by the chipper shape blades improve the shape of the biomass particle. The homogeneity may improve substantially, even though also it depends on the sieving system at the outlet of the chipping systems, and the inter-spaces between the knifes and the sieve. Static chippers are available in the form of small units (coupled to a tractor PTO or powered by their own engine), where the branches have to be fed manually, or large forestry chippers prepared for comminuting thick stems from forestry logging. Mobile chippers integrated with the gathering of prunings are rare, and only few commercial models are available. Two Italian companies have recently developed them: Nazzareno (Marev Alba) and ONG-SNC (PC50); both models were implemented as a result of national or European R&D programs, illustrating their degree of innovation compared to conventional shredders.

4.4 Facts and recommendations in the implementation of new APPR biomass value chains

4.4.1 Organizing the APPR biomass supply

The organization of the value chain is crucial. It involves not only the practical means and operations (see next sections) but also the agreement between actors. Transparency in business model, expected difficulties, and communication ensures that all involved actors are on the same page.

A critical aspect is the involvement of farmers in the value chain organization: farmers must have a clear understanding of the benefits that they can gain from the management operations required in an APPR-to-energy scheme: cost reduction, work simplification, reduced working time. Additionally, it is best to adopt practices that have limited interference with execution of standard agronomic practices. Fruit production remains the main priority of farmers over residue management.

Designing the value chain so as to allow different harvesting methods to be employed increases the flexibility of sourcing. It is also important that the value chain actor implementing the collection step has sufficient technical means available to cope with peaks in the demand for harvesting services. The use of advanced systems for the planning of the logistics operations also facilitates the optimization of the logistics.

Finally, unnecessary operations should be avoided. It is generally a good idea to consider if machinery that is already available in the area can be utilized for the purposes of the value chain. In any case, pilot scale testing of the machines to be used in the value chain is suggested before investment decisions are made.

4.4.2 Collecting and treating at field: select the appropriate machine, not the “best” one

The different ways to collect agricultural pruning and plantation removal have been described in sections 3.3 and 3.4, respectively. In this section, some practical recommendations based on lessons learnt from uP_running and also based on results from previous projects [18] and experiences are provided.

- Use proved technology for harvesting the APPR wood in order to reduce uncertainties.
- The selection of machines should be made based on the local conditions. It is wise to perform initial tests before any investments. Results should take into account variability and measures to increase performance (e.g. reduction of idle times). Basing business plans on thumb rule estimations or general data (such as that provided by salesmen) should be avoided.
- Downstream operations should be considered when investigating the different investment options.
- Preventive maintenance and appropriate handling can reduce the medium and long term costs and avoid failures and interruptions during the APPR collection campaign.
- Farmers should be involved in the discussions about the method for the removal of APPR biomass. It is also important to agree upon maximum acceptable losses of material; too high amounts of losses may require the farmers to perform additional cleaning operations that will reduce the benefit they acquire from an APPR collection scheme.
- The operation mode should be selected having in mind the quality required. Economic and technical alternatives should be evaluated. For example, there may be a balance between an improved but costlier field operation vs. a simpler and lower cost extraction method followed by a secondary pre-treatment step out of the field.
- Avoid harvesting methods or timing that have a negative impact on APPR biomass quality. Haulage should be performed with systems able to reduce soil incorporation (fork, grabber instead of shovel). Work should be done on compacted soil or on soils with grass cover. Working during or immediately after rains should be avoided.

4.4.3 APPR biomass transport and storage: take care to maintain the product quality

During transport and storage of APPR biomass, there is a serious risk of biomass degradation or biomass contamination due to improper loading/unloading, inadequate particle size during storage, etc. This may entail a strong impact on the quality of the biomass product and, consequently, a substantial effect on the feasibility of the value chain. In some cases, the biomass degradation and/or contamination may “kill” the economic profitability of the initiative. For this reason, particular care should be given to the operations performed during the transport and the storage of the APPR biomass. In the following paragraphs, some recommendations and lessons learnt about transport and storage are summarized based on experience gained through uP_running and other previous projects like EuroPruning [18,19,20].

Particularly, the lessons learnt have shown that a value chain based on APPR biomass cannot succeed unless all actors are well involved and understand their role and responsibility. In the side of farmers, they should understand they may have to perform some operations differently from their usual methods, in case these tend result in contamination of the biomass (e.g. the method to rake, windrow, or prepare the biomass). Downstream, if the logistics are not well organized or if the actors do not execute their work properly, APPR biomass quality can easily decay. Then its potential market value, or the satisfaction of the final user, can be seriously compromised.

Other considerations regarding the APPR biomass quality include the following:

- The physical form of APPR to be delivered to the end-user should be carefully chosen. Bulk biomass is the most appropriate option since it reduces the handling costs for larger scale operations. The use of big bags is only suggested for self-consumption cases. Bales should be considered if long-term storage of the material is required and / or if the final consumer possess a bale boiler.
- Discharging of harvested biomass directly on containers, trailers or paved soils should be promoted to reduce handling time, losses and contamination.
- Specific considerations should be taken regarding storage. Leaving the material to dry naturally at the field side / field soil before its collection should be encouraged. In most cases, harvested material will be in the form of hog fuel, which is more susceptible to degradation when it is arranged in piles. Previous moisture reduction or frequent aeration of the pile should be considered. Ideally, the material should be stored under cover, in barns without walls. If it is stored in the open air, larger piles are preferable in wetter climates since the outer layer of the pile protects the material on the inside.
- Contaminations during transport should also be avoided; actors involved should ensure that the means used for transport (e.g. trailers, trucks) have been properly cleaned if previously used to transport other materials.
- Mixing APPR with other biomass fractions is a strategy that can improve the quality of the final product. Apart from economic considerations, care should be taken to ensure that mixing is not performed with contaminated fractions such as demolition wood, chemically treated wood, etc.

4.4.4 APPR biomass use to energy: conversion systems fitted to APPR characteristics

The use of APPR biomass can be carried out in existing facilities not initially designed for APPR biomass; alternatively, it can be utilized in facilities initially designed and prepared with this fuel in mind. Penetrating in a conventional biomass market is usually not easy, as the APPR biomass characteristics are different from other biomass already in use. Mixing the APPR biomass with other biomass types is an alternative. Another alternative is to offer a substantial reduction in the biomass supply that balances the costs of any retrofitting investment that a final consumer may have to adopt. Additionally, the boiler manufacturer or maintenance service should agree to keep the product and service warrantee.

When a new consumer adopts APPR biomass it is strongly suggested to adopt mature and proved technologies able to use the APPR biomass in form of 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 APPR supply. It is important to understand the different type of properties that determine the behavior of the biomass, e.g. particle size, moisture content, elemental composition, ash fusion temperature and others. As shown in the previous sections, the biomass from APPR residues are characterized by a wider particle size distribution, even with the presence of some long pieces, and by a higher ash content. In order to adapt to these properties, therefore the combustion systems adapted to APPR biomass usually 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.

Firstly, it is crucial that the feeding system can work continuously with heterogeneous chips or shreds without clogging. For this, both augers and rotary valves are more robust than conventional systems and specifically designed to break the longest pieces. Secondly, the combustion chamber must have an automatic adjustment of primary and secondary air and a combustion system able to burn the largest particles (in case of grates, sufficient area and time of residence). Finally, the ash removal system of the furnace must allow the evacuation of the relatively high amount of these combustion residues, which may also present some sintered material or stones. The ash bin, usually located next to the boiler, must have a sufficiently large volume to ensure the autonomy of the system.

5 CONCLUSIONS

The present paper has presented the status of value chains based on APPR biomass at European level and has described the main operations that are needed for extracting APPR wood and using it for energy production. Moreover, specific recommendations for implementing new APPR biomass value chains have been provided, with special focus on the operations of the supply chain, the organizational aspects, the dialogue and needs of the different value chains actors, and the importance to keep in mind quality issues during each step of the chain.

In addition, the existing barriers that block the expansion of APPR-to-energy chains have been briefly presented; they are principally non-technical, e.g. related to social aspects, economic framework, existing regulations and energy, environment and agriculture policies.

Beyond this article, uP_running continues carrying out a series of actions in order to tackle some of the non-technical barriers and unlock the APPR biomass potential in Europe. More information on the project activities is available through the uP_running website, http://www.up-running.eu/.

6 LIST OF ACRONYMS

APPR	Agricultural Pruning and Plantation Removal
ar	As Received
db	Dry Basis
GHG	Greenhouse Gases
LCA	Life Cycle Assessment
LHV	Low Heating Value

ORC Organic Rankine Cycle
PM Particulate Matter
SOM Soil Organic Matter

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9 LOGO SPACE