INFRES – Innovative and effective technology and logistics for forest residual biomass supply in the EU (311881)

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Plan for promoting the demonstrated systems and technologies for further development – D6.4

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Preface

This publication is part of the INFRES project entitled *Innovative and effective technology and logistics for forest residual biomass supply in the EU*. This project is coordinated by the Natural Resources Institute Finland (Luke) and aims at high efficiency and precise delivery of woody feedstock to heat, power and biorefining industries. The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2012-2015) under grant agreement n°311881.

INFRES focuses on developing concrete machines for logging and processing of energy biomass together with transportation solutions and ICT systems to manage the entire supply chain. The aim is to improve the competitiveness of forest energy by reducing fossil energy consumption and material loss alongthe supply chains. New hybrid technology is demonstrated in machines and new improved cargo-space solutions are tested in chip trucks. Flexible fleet management systems are developed to run the harvesting, chipping and transport operations. In addition, the functionality and environmental effects of developed technologies are evaluated as part of the whole forest energy supply chain.

This report is the output of the task 6.4 *Plan for promoting the demonstrated systems and technologies for further deployment*. It is one of the final tasks of the INFRES project, and comprises several topics: from a machinery assessment, until the development of a plan to overcome innovation barriers, including an exploration of future scenarios and a brief risk analysis. The relevance of this document lies in the presentation of a summarized and quick view of the tested equipments, some measures to overcome the barriers, an estimation of future scenarios and machinery needs in the EU and the potential risks linked to the non-application of innovations in the forest biomass supply chains.

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Abstract	This report is the output of the task 6.4 to approach a *Plan for promoting the demonstrated systems and technologies for further deployment*. The goal of this task was divided into four specific objectives: 1. To assess the role of the demonstrated new or improved machinery for the sustainable and reliable supply of forest biomass to the facilities, with special focus on cost reduction and/or additional biomass supply that can be achieved by the demonstrated innovative technology; 2. To make proposals to promote the innovation and subsequent technology transfer and to present suggestions on how the inventions that have been developed in this project can overcome the obstacles encountered and reach commercialization; 3. To develop scenarios for the potential markets of lignocellulosic forestry residues for biorefineries and energy use; 4. To perform a risk assessment to estimate the side-effects of not putting interesting inventions into practice. In the first part, there is a summary of the assessment of the machinery demonstrated in the framework of the INFRES project. Some of the main advantages of the innovations are the cost reduction in comparison with conventional systems, in addition to improved productivity and increased supply. Besides this, a couple of innovations showed fuel savings compared to previous supply chains. Moreover, other improvements have been observed, but without a quantitative assessment. Finally, as a conclusion, certain innovations are successful only when they are used in the conditions they were designed for. In the second part, a plan for overcoming the previously identified barriers was elaborated, and the plan was then submitted for assessment by several experts. The application of the most important measures to overcome the barriers that manufacturers face when developing an innovation is mainly in the hands of the manufacturers themselves, and partly in the hands of policy makers who may contribute through the development of appropriate financing instruments or compensations for high-risk investments in SME's. In the case of measures proposed to overcome the barriers that manufacturers face during the implementation or use phase, the application of the measures is in the hands of a balanced mix of the main stakeholders, including forest companies and manufacturers. It means that both have to work, sometimes together, to overcome the detected barriers. In the third part, any of the future scenarios anticipates an increase in woody biomass demand. The growth of the biorefinery sector will change the landscape of the forest biomass requirements by 2030. Indeed, feedstocks such as forest residues and stumps can be easily used by this sector. Besides this, the increase and improvement of the machinery used in the forest biomass supply chains, together with the optimization of the whole chains, take some time. As a consequence, it is a challenge for Europe to reach high enough competitiveness and innovation levels so as to cover the demand needs in the best way, with its own resources, seeking a positive impact on all EU regions and on European machinery manufacturers. Finally, the fourth part concludes that if technological and logistical innovations are not implemented in forest biomass supply chains, then energy and environmental targets in the EU will not be reached. Sustainability and cost efficiency gains in the biomass supply chains will not be achieved either. The introduction of innovative solutions as those presented by INFRES will be made possible by implementing the measures that were identified in the third part for overcoming the barriers in the development, implementation and use phases of the innovations.
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1. Introduction

Europeanforests and other wooded land currentlycover around 155 and 21 million ha respectively, representing together over 42% of the European Union (EU) land area, this latter containing 5% of the world's forests (EC, 2013; EC, s.d.).EU forests show a great diversity of character across regions. While globally forest area continues to decrease, afforestation and natural succession have increased the EU's forest area by around 0.4% per year over recent decades. However, only 60-70% of the annual increment is being cut, therefore the growing stock of wood is rising. According to Member States' projections under Land Use, Land-Use Change and Forestry (LULUCF), harvest rates are expected to increase by around 30% by 2020 as compared to 2010.

Overall, 58% of harvested EU wood biomass (e.g.,in 2011: 345 Mm^3) is processed by EU forest-based industries representing about 7% of EU manufacturing gross domestic product (GDP). The remaining 42% areused for energy, accounting for about 5% of total EU energy consumption (EC, 2013). According to estimates based on the National Renewable Energy Action Plans, EU Member States plan to mobilise significant additional domestic biomass resources for heating and electricity generation, which is expected to increase from 76 Milion tonnes of oil equivalent (Mtoe) in 2006 to 113 Mtoe in 2020. If this is achieved, the amount of wood used for energy purposes in the EU would be equivalent to today's total wood harvest. Forestry will continue to be the predominant source of biomass supply, with an overall share of over 66% of total biomass as a renewable energy source by 2020 (EC, 2013).

Forforest harvesting, environmentally friendly and economically viable harvesting systems and forest operations are of crucial importance. The introduction of forest machines and techniques with innovative technology for the harvesting and extraction of forest biomass will improve harvesting productivity, reduce greenhouse gas emissions and enhance the sustainability of forest management. The profitability and competitiveness of the forest contractors and forest industry will rise as more biomass is harvested at a lower cost. This will also have positive impacts on regional development and employment.

INFRES aims at high efficiency and precise delivery of woody feedstock to heat, power and biorefining industries by producing technological and logistic innovations for developing new harvesting, transport and storage technology for forest fuel procurement, and by demonstratingnew solutions in full supply chains from harvesting to transport and storage in real operational environment. Furthermore, all innovations and resulting supply chains are assessed for environmental, economic and social sustainability.

Prinz *et al*. (2013) pointed out the 45 most promising innovations existing or upcoming in the market.These innovations address potential improvementson forest machinery, like an increase of the supplied amounts, an improvement of the working conditions (ergonomics and safety), an increase of the productivity leading to cost and fuel consumption reductions.

However, equipment innovations are not always implemented successfully, if considering "success" as an extended use (Athanassiadis *et al*., 2014). Several types of barriers may indeed arise and prevent improvements to be implemented.

The goal of this study was to propose a plan for promoting the demonstrated systems and technologies for further development. This goal has been divided intofour specific objectives:

a) To assess the role of the demonstrated new or improved machinery for the sustainable and reliable supply of forest biomass to the facilities, with special focus on cost reduction and/or additional biomass supply that can be achievedby the demonstrated innovative technology;

b) To makeproposals to promote the innovation and subsequent technology transfer and to present suggestions on how the inventions that have been developed in this project can overcome the obstacles encountered and reach commercialization;
c) To develop scenarios for the potential markets of lignocellulosic forestry residues for biorefineries and energy use;
d) To perform a risk assessment to estimate the side-effects of not puttinginteresting inventions into practice.

2. Machinery assessment[1]

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2.1. Methodology

The demonstration reports on the innovative machines tested within WP4 of INFRESwere reviewed and an assessment of the cost, productivity and fuel consumption of the innovative machines compared with currently used machinery was made.For each innovation, data on productivity, costs and fuel savings were retrieved and whenever needed, a literature review was performed to establish the current levels of productivity, costs and fuel consumption for comparison purpose. In addition,an estimation was made of the additional supply that can be achievedif the innovative machines are coming into use. The innovative machines were grouped into four categories according to thepart of the supply chain they belong to: harvesting and forwarding, chipping, grinding/screening and finally further transport.A detailed description of the equipment can be found in Appendix 1.

2.2. Review of demonstration reports

2.2.1. Harvesting and Forwarding

Small harwarder

According to the study of Spinelli *et al*.(2013),a small harwarder (combined harvester forwarder)specifically designed for thinning operations (Vimek Biocombi 610)might allow cost savings between 15% and 20% when compared with other conventional mechanized options. It can also bring additional savings since it can relocate independently over short distances.

Regarding productivity, the Biocombi 610 was more efficient in the felling and loading work, while the Pfanzelt was more efficient in the extraction work (extraction distance = 217 m), although there is only a 5% difference in overall productivity between the two machines.

The work with the Biocombi is more cost-effective thanks to a lower hourly cost (Table 1), but it has limited use in final fellings (limited operational flexibility) and requires a continuous thinning work to reach such a low hourly cost.

Table 1:Costs and measured fuel consumption of two harwarder systems (Spinelli *et al*., 2013)

Equipment	Hourly cost €/h	Harvesting cost* €/ green t	Fuel consumptionl/h
Biocombi 610	63.2	24-27	4.5
Pfanzelt	94.8	35-39	8

* Harvesting cost, including felling, extraction, chipping and delays

Using a large harwarder (Pfanzelt Felix 206) in farmland plantations would have costs similar to other conventional mechanized systems, since previous trials gave40-55 €/tonne for motor-manual felling and 28-30€/tonne for other mechanized supply chains.(Spinelli *et al*., 2013)

While farmland plantations offer good conditions to optimize the work of a small harwarder, a large one is more efficient the longer the extraction distanceand the larger the trees to be removed.

Regarding barriers or challenges, several conclusions are mentioned in the study:

- It is more efficient to fell and load (small harwarder) than to fell and afterwards change the head and load (large harwarder).

[1](DOW description) The role of the demonstrated new or improved machinery for the sustainable and reliable supply of forest biomass to the facilities will be assessed with special focus on the cost reduction and/or additional supply that can be achieved by the demonstrated innovative technology.

- When the stands to be thinned are scattered, independent relocation is an advantage. Some base machines for felling (e.g., excavators) need dedicated transportation for relocation.
- The small harwarder has limited operational flexibility regarding the size of the trees that can be felled. Due to this operational rigidity, in order to have a reasonable low hourly cost, it is necessary to operate duringenough yearly working hours (specialised work along the year).
- Farmland plantations are more suitable for small harwarders, due to the small trees handled and the limited manoeuvrability.

Accumulating felling heads (AFHs)

i. Naarva Grip EH28

One of the main threats toforests in the Mediterranean region are large forest fires. However, the advised prevention thinnings in young stands lack profitability, and are thusoften neglected. Therefore, any innovation aimed at increasing the profitability of these interventions is essential to enable the implementation of these approaches and to increase the supply of wood biomass chains.

Conventional whole tree harvesting systems with motor-manual felling and skidding were compared with mechanized felling with a small excavator with the accumulating felling head Naarva EH28 attached (López *et al*., 2014 and Tarradas, 2014). The change of the tasks by the Naarvahead did notbringany economic savings compared to motor-manual felling (29.3 €/tonnevs. 30.6 €/tonne) but some changes in the procedure showed that the head was very efficient when stacking whole trees. Therefore, adapting the conventional system by adding a stacking operation with the small excavator and the Naarva gripreduced the costs of operations by 20% until 23.3 €/tonne.

As conclusions of the study, the equipment can perform greatly(lower cost) when cleaning stripes along a forest road for forest fire prevention, since all residues have to be removed.

Many available base machines can be used to increase the mechanization of forest operations and can also serve other purposes outside forest operations (cost-effective solution). At the same time, the head allows the use of smaller and flexible machines for the Catalan forests. The reasonable initial investment cost of the head (c. 25,000 €)makes it easy to pay off(López *et al*., 2014).

Besides this, the movement of thetracked excavator by the strips removed the shrubs and allowed safely access to the site with pneumatic vehicles afterwards.

Regarding barriers or challenges, the main issue mentioned in the study is related to the capacity of the head, which was lower than expected (maximum cutting diameter: 28 cm; in practiceonly 25 cm though), and therefore an additional operator wasrequired to perform motor-manual felling of bigger trees.

ii. MAMA prototype

The study of Bergström and Di Fulvio(2014) compared two Accumulating Felling Heads (AFHs): the MAMA prototype againstthe C16, an older one, plus a following forwarding.The MAMA head showed a higher accumulation capacity (3.2 trees per crane cycle) than the C16 (2.3 tress/cycle), a shortertime for felling and processing (17%) and to reach the first tree. Thanks to the compaction performed, the MAMA head yielded an additional 22.6% solid volume per load and 46% bulk density per load.

The systems studied yielded similar total costs and fuel consumption for cutting and forwarding to road-side in an average stand. The MAMA system becomes more favourable as the size of the harvested trees and the extractiondistance increase.

In short, as the MAMA head is yet only a prototype, further improvements are expected to reduce the costs up to 12% under studied conditions. The time required for felling, accumulation, compression-processing and bunching is equal to that of the conventional systems.

The feed-roller enables effective bucking work and increases the bulk density of the harvested biomass by 47-70%, and the forwarder pay-loads by 17-24% due to the compression of the biomass (Bergström and Di Fulvio,2014).

Regarding barriers or challenges, the main issue mentioned was related to the compression-handling process, which reduces the harvesting yield by 10-23% (it is more pronounced as the size of the processed trees increases). Thus, harvester productivity with MAMA head is 12-14% lower than with the conventional one.Studies are needed to explore further the work of this prototype and some improvements will have to be implemented.

2.2.2. Chipping

Chipper truck

Thestudies of the Pezzolato HackerTruck PTH1200/820 on a MAN TGA 540 truck took place in Germany (Spinelli and Jessup, 2013) and Sweden (Eliasson *et al.*, 2013a). This chipper truck was designed to bring industrial chipping as close as possible to the forest, especially undercentral European forest conditions (steep terrain and limited loading space availability), and therefore,it can independentlyrelocate between work sites. As an innovative feature, it also included a flexible blower, allowing to blow the chips to theside, behind, andthe most innovative feature, to the front of the chipper. This is an advantage when the road is small and containers cannot stand at the side of the chipper.

In Germany, thechipper performance was compared with a conventional system (Table 2). The average productivity of the chipper truck system (including chip transfer to the landing) was 55 loose m^3/h (19.5 green tonnes/h). Therefore, compared with a conventional system, there is a cost reduction of 13% and a fuel reduction of 35%(Spinelli and Jessup, 2013).

Table 2: Productivity and fuel consumption of the chipper truck system and of a conventional one (Spinelli and Jessup, 2013)

		Productivity	Cost		Fuel consumpt.
	Process	Green tonnes/h	€/h	€/t	l/t
Conventional system (extracting uncomminuted residues to a landing before chipping)	Secondary extraction*	4	45	11	2.5
	Chipping	16	200	13	2
	Transportation	7	70	10	1.7
	Total			**34**	**6.2**
Innovative system (chipping at roadside and further transport to landing)	Secondary extraction	0	0	0	0
	Chipping	13	250	19	2.3
	Transportation	7	70	10	1.7
	Total			**29**	**4**

* Understood as a forest extraction after a previous one. For instance, there can be a primary extraction with skidder until the forest road, and a secondary extraction by forwarder until a storage yard for trucks.

The chipper produced good quality chips, suitable for demanding users (> 63 mm - 0.5%; fine particles slightly over 5%; 8-16 mm - 47%).

In conclusion, the chipper offered excellent mobility and high productivity. It is consideredan ideal solution for small, scattered tracts in mountain forests, and can offer financial and energy savings at supply chain level.

In Sweden,logging residues and roundwood were chipped. The effective chipping time when chipping logging residues was more than twice as high as when chipping roundwood, due to the time to handle residues with the loader being longer (Table 3).Fuel consumption was on average2.5 l diesel/odt (oven dry tonnes) chips produced(Eliasson *et al*., 2013a).

Table 3: Productivity and time consumption of the chipper truck according to the raw material processed (Eliasson *et al*., 2013a)

	Time consumption (min/odt)	Productivity (odt/h)
Roundwood	1.5	39.3
Logging residues	3.2	18.5

The percentage of fine particles in chips was especially high when chipping residues. Nonetheless, the fines share, in general, is not surprising given the 25 mm cut length of the knifes. The productivity observed is of the same magnitude as for similar sized chippers, but other chippers produce coarser chips. As a result, if the chipper had a longer cut length, chips' characteristics, chipper performance and fuel consumption likely would have been even closer to previously studied machines(Eliasson *et al*., 2013a).

Off-road capabilities ofthe Pezzolato chipper truckare better than ordinary 8x4 wheel drive chipper trucks in Sweden, but worse than chippers mounted on forwarders.

As general conclusions, productivity was high despite the relatively small chip size, which is known to detract from the productive potential, and the machine represents a solution for small and scattered tracts in mountain forests.

Regarding barriers or challenges, some questions were mentioned in the studies:

- The front blower performed well, but it was slower than the main one. It should thusbe used as a last resort, only when there are no other viable solutions.
- The performance of this machine could be improved by equipping it with a central tire inflation system to maximize its cross-country mobility, while minimizing forest road wear.
- The moisture content gauge and the machine computer gave instant readings but failed to give averages per container produced. An interesting option would be forit to also present average moisture content for the last minute or for a few minutes, or for a whole container.
- The chipper was designed for the production of small-size chips to be used in residential small-scale boilers, most common in Central and Southern Europe. But these chips are considered too small for the Scandinavian market, and therefore, it should be equipped with a separate large-chip drum.
- In northern Europe, as a lot of chipping is done duringwinter, the moisture gauge would not work since the material is frozen.

2.2.3. Grinding and screening, ground stumps

Following studies evaluated different options for sieving grinded stumps in order to improve the quality of the material.

Grinding and sieving

The performance of a Doppstadt DW 3060 low speed grinder and a Doppstadt SM 620 drum sieve was evaluated when it wascoarse-grinding stumps to get hog fuel for a heating plant(Eliasson *et al*., 2013b). Fine material was consideredas a reject as it was comprised mainlyof soil and humus.

When sieving, 31% of the dry weight was rejectedon average, which reduced the initial ash content from 22% to 7.6%. The productivity was 25.8 and 18.7 odt/effective hour grinding and 30.6 and 20.4 odt/effective hour sieving, forthe total and accepted processed material respectively.

This led to an increase inburnablecombustible material per tonne (69%), an increase in load capacity of the transport unit (46%), and so a reduction of the amount of material in need of transport (31%).

Regarding barriers or challenges, some issues were mentioned in the study:

- The produced hog fuel would not have been accepted at the majority of Swedish heating plants due to the size of the chips. However, this is not an issue as it fitted the specifications of the client that had ordered the fuel.
- For longer production runs it is necessary to have sieves installed in the grinder reducing the production of oversized pieces so that less material is returned to the grinder via the conveyor.

Integrated grinding and screening

The performance of a semitrailer-mounted Komptech Crambo 6000 low-speed double shaft shredder with a Komptech star screen was evaluated when processing stumps using two different sieve sizes (250 x 320 mm and 180 x 180 mm)(Laitila and Nuutinen, 2013). This equipment is a novel mobile grinder unit, which is capable of operating both at terminals and roadside landings.

The effect of the smaller size of the screen holes in primary screening causeda lower production rate, a higher fuel consumption, higher ash content, higher loose volume of the screening reject, and a higher expected productivity of a secondary grinding(Laitila and Nuutinen, 2013).

The screening increased the energy content of studied semitrailer loads by 2-6 % and the heating value of wood chips (MJ/kg, wet basis) by 3-6 %.

Besides this, the Komptech equipment operated well in constricted roadside landings.

The quality of the produced fuel chips was high due to the low ash content, and this highlights the significance of screening to guarantee sufficient quality when processing stump fuel.

Regarding barriers or challenges, when using any of the screen baskets, itappearsnecessary to perform secondary grinding either at the terminal or at the plant before combustion(Laitila and Nuutinen, 2013).

2.3. Discussion

According to the demonstrations' reports, some of the main advantagesof the innovations assessed is the cost reduction in comparison with conventional systems, in addition to improved productivity and increasedsupply. Besides this, a couple of innovations showed fuel savings compared to previous supply chains. Screening improved significantly the quality of hog fuel made from tree stumps, lowering the ash content and increasing the heating value.

Moreover, other improvements have been observed, but without a quantitative assessment: increase of the accessibility of wood chippers, mechanization of felling, independent relocation of the equipments (for moving from one place to another), better performancethan beforeof chippers with the same productivity and cost(smaller chip size for domestic boilers), and increase of the net transport load (improvement of forest biomass properties before transporting). However, it should be noted that innovations improving the productivity of the supply chain in some conditions may not work as effectively in other conditions. For example, harwarders have not proved to reduce harvesting costs in the Nordic countries. As a consequence, certaininnovations are successful only whenthey are used in the conditions they were designed for.One should alsomention that longer lasting follow up studies are needed to verify results in practice.

3. How to promote innovations

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Innovation occurs in the framework of a given development sector, and therefore it is necessary to approach the study of its barriers within this environment (Figure 1). Traditionally, forestry equipment manufacturers have been excluded from the analysis of innovation in forestry (Rametsteiner and Weiss, 2004; Hetemäki *et al.*, 2010). However, the production of machinery and forestry equipment is a driving force of innovation for forestry chains, which at the same timeare closely related to the machinery manufacturers sector. Indeed, forest machinery is a key componentof an efficient and sufficient biomass supply in the present and the future of the EU contributing to the increase of the competitiveness and sustainability of the biomass production industry, increasing productivity, optimizing processes or saving fuel (Asikainen *et al.*, 2011; Nylén and Holmström, 2011; Anttila and Asikainen, 2014).

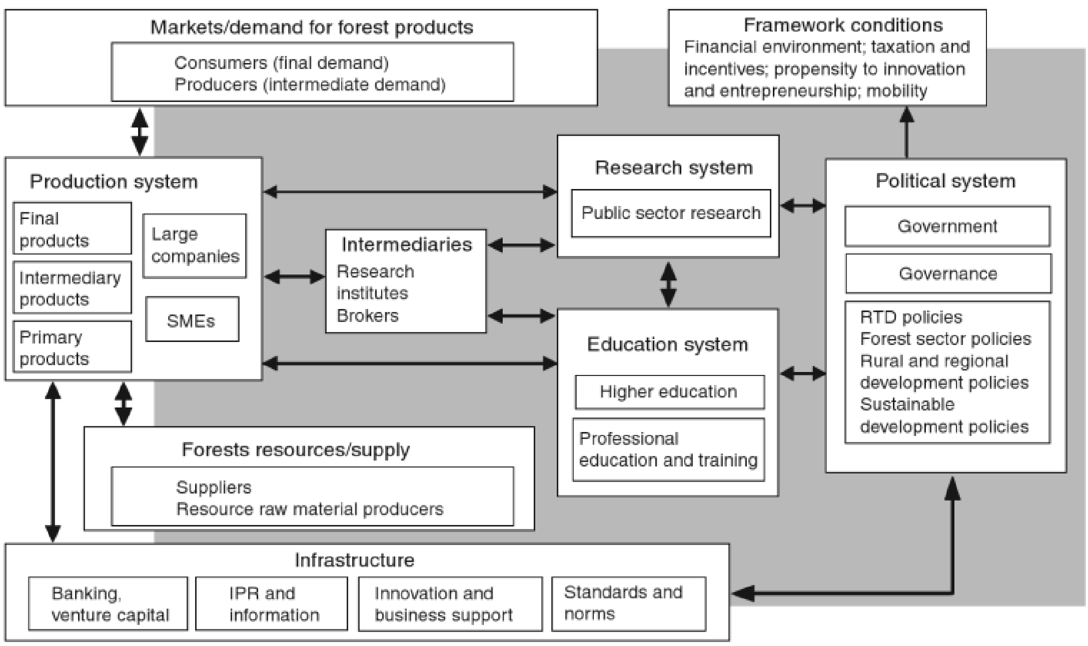

Figure 1: Forestry sectoral innovation system with forest machine manufacturers included in the “Forest resources/supply” and “Production system” boxes (Weiss, 2011)

The analysis of innovations and barriers that hamper their development can be approached from different perspectives and levels (Rametsteiner and Weiss, 2004; Weiss, 2011). Previous studies demonstrated relevant differences between regions in the EU regarding forest biomass supply chains (Bouriaud *et al*., 2011). Indeed, some studies ignore the South of Europe as a productive area, although it can contribute to a relevant supply of forest biomass in the EU (Verkerk *et al*., 2010).

On the one hand, innovations are not always implemented successfully, when considering “success” as theirextended use. Several types of barriers may arise and prevent an improvement from being implemented (Athanassiadis *et al*., 2014). In the framework of the INFRES project, technological and economic barriers impeding the introduction and application of innovations in the forest energy field were evaluated from different points of view. In Athanassiadis *et al*. (2014), machinery manufacturers were asked about the barriers for innovation that they face and several experts were surveyed about the reasons for success or failure of some innovations that have been in the market for several years. In Riala *et al*. (2015) a Delphi study on the development potential of inventions in forest biomass harvesting was presented. In that study, several experts were surveyed on the expected success of upcoming innovations, and possible barriers for their implementation.

Onthe other hand, another very important issue when innovating concernsthe end-users, i.e. the "adopters" of innovations and how they proceed (Brogt *et al*.; 2007; Cavallo *et al*., 2014). Cavallo *et al.* (2014) presentedthe three different profiles of users that can be "adopters" of innovations. This case was focused on Italy and agricultural tractors' users, but the framework in forestry can be similar. Theydistinguishedthree main types of users: 1) user unwilling to change their practices, 2) users who implemented innovations, and 3) users willing to change their practices but with lower resources than the previous type of users. These three profiles point out different needs: traditional equipment, innovations and low-cost innovations. Brogt *et al.* (2007) showed how different information channels had different relevance for forestry companies in different regions, emphasizing the role of informal channels as an important learning source for companies.

Therefore, in order to properly approach innovation and technology development with respect to the previously mentionend issues, it is first necessary to get a clear understanding of the characteristics of existing supply chains within a region, including among others equipment inventory, supply chains' systems or constraints. A few countries have already made some estimation (Asikainen *et al*., 2011; Kärhä, 2011; Lliró, 2013; Anttila and Asikainen, 2014). This diagnosis will also allow to foreseemore precisely the future needs in technology innovations in each area, and therefore to properly target innovation efforts.

The aim of this section was to presentwhat needs to be done to promote the innovation and subsequent technology transfer, as well as to makesuggestions on how the inventions that will be developed in this project can overcome the obstacles encountered and finally reachcommercialization.

3.1. Methodology

In order to addressthe aim of the chapter,the barriers detected in Athanassiadis *et al*. (2014), Riala *et al*. (2015) and during the field studies in Work Package 4 "Demonstrations and means of technology transfer" were put together and organized according to the phase of innovation during which they occurred.

- Barriers that appear during the development of the innovation (supply side, innovation manufacturers).
- Barriers that appear during the application and use of theinnovation.

A plan forovercoming identified barriers was elaborated by the authors, and severalmeasures were proposed and described for each identified barrier.The set of measures initially proposed and the barriers that they overcome are presented in Appendix 2.

The plan was then submitted for assessment by several experts from different regions and with different profiles. In order to obtaina widerrangeof opinions at the EU level, the questionnaire was sent to twenty expertsfrom Finland, Sweden, Germany, Spain, Netherlands, France and United Kingdom. The experts considered were representatives from forest machine manufacturers and forest companies, as well as researchers to a lesser extent. Indeed, the main actors of the innovation process are considered to be the manufacturers (supply side) and the forest companies (demand side, users), and researchers have already been surveyed many times along the INFRES project.

The experts checked and completed the measures and were also allowed to propose new ones.

A total of eleven answers have been gathered, whosebreakdown is shown in Table 4.

Table 4: Profile of the experts that answered the questionnaire

Region/Country	Machinery manufacturer	Forest company	Researcher	Overall Total
Finland and Sweden	3	0	1	4
Germany	1	1		2
Spain	1	4	0	5
Total	5	5	1	11

Parameters

The experts were asked to rank the initial set of measures according to three parameters:

- **Effectiveness**: To which extent does the measure contribute to overcome the barrier? (Scale: 0=does not contribute at all; 5 =contributes fully)
- **Relevance**: How relevant is the measure in fostering innovation and competitiveness in forest biomass production chains? (Scale: 0 = not relevant at all; 5 =very highly relevant)
- **Probability**: What is the probability forthe measure to be applied? (Scale: 0 = not probable; 5 =very highly probable)

In general, onone side,*Effectiveness* and *Relevance* are strongly and directly related to the interest of ameasure. Therefore, these two parameters have been considered the most important ones for the analysis. Onthe other side,*Probability* is related to the easiness or feasibility of a measure'simplementation.

Assessing parameters

As previously stated, theparameters were valued using the sameinterval scale ranging from 0 to 5, being 0 the minimum of the parameter and 5 the maximum. The middle point of the scale would be the 2.5 score, between the marks 2 and 3. Below this point and towards 0, the scores are more negative or pessimistic, and above this point and towards 5, marks are more positive or optimistic.

Data analysis

On the one hand, for each parameter, the arithmetic mean of the scores (as an average measure) and the standard deviation (as a measure of the dispersion from the mean) have been used. The average value of the parameter givesa central measure of responses, whereas the standard deviation (SD) reflects the agreement or disagreement in the answers.

The **sum of the scores forthree parameters** has been considered as a **comprehensive and operative indicator of the overallinterest of the measure**, since all parameters have the same reference scale from 0 to 5. Therefore, the measures considered to be the most important are those having higher scores forone of the parameters or the sum of all them.

On the other hand, a correlation analysis between each pair of parameters mean has been made in order to see if the valuation of the three parameters could be related. A simple correlation analysis was performed (Pearson Product-Moment Correlation Coefficient for each one of the two sets of values).

No additional statistical analyses have been carried outdue to the low number of responses. More advanced studies can be done by gathering more answers fromthe questionnaire.

3.2. Results and Discussion

The barriers and the measures proposed to overcome them are presented in Tables Iand II in the Appendix 2. Table I presents the barriers that appear during the innovation development phase while Table II deals with the barriers that appear during the use phase.

3.2.1. Barriers

The main barriers that the companies face when developing or introducing an innovation (Table I in Appendix 2) are listed below (cf. Athanassiadis *et al.*, 2014)

1. Cost and financing issues,e.g., when developing a completely new innovation. Mentioned examples are a lack of external funding for new ideas and high-risk projects or high development costs in combination with a rather small market, occasionally in combination with difficulties to charge a high enough price for a product. Patent costs were also mentioned as a financial barrier.
2. Lack of engineers or capacity: A few companies mentioned the difficulty to findsufficiently skilled engineers. This can be due to a competition with the mining or the car industry for example, and to ageneral lack of educated engineers. Smaller companies may not have enough personnel to both develop new products and maintain the production level of the current ones.
3. Lengthy, high-risk process: the time elapsed between conception and marketing is seen as a barrier.
4. Testing: the testing phase of the machinery is not easy. Forest companies seem not to be cooperative enough during this step.
5. Regulations: for instance, excessively stringent technical and security requirements foran equipment to be sold in the EU, and many standards to follow.
6. Lack of good quality components.
7. Knowledge leaks, information protection.

Regarding the barriers faced during the marketing or use phase (Table II in Appendix 2), they can be grouped into different categories:

8. High operation cost (€/m^3) and low productivity: the hourly cost is too highcompared to the productivity, the invested capital and the value of the processed material or produced product. The productivity is too low compared to the costs or expected output. Innovations designed for specificworking conditions such as a given terrain, forest type, tree species, and general infrastructure may perform poorly if machines are used somewhere else. For instance, that is the case for low mobility equipment used in regions or countries where roads are poorly maintained, or for large and productive equipment used in areas with small and scattered harvesting sites.
9. Lack of flexibility: if the machine is meant to process certain types of trees with given dimensions,or to operate in certain stands only, it may be inefficient if used elsewhere. The operation of the equipment does not allow dealing with most of the situations where the machine is tested. For instance, a small harwarder, primarily designed for thinning operations, can have problems cutting and forwardinglarger trees in an uneven-aged forest.
10. Competition with existing equipment: the innovation may be interesting as such, but it does not improve efficiency (e.g., productivity, cost) of the existing equipment/chain. For instance, we observed that a terrain chipper did not reduce the chipping costs although it was an interesting approach to combine forest transport and chipping.
11. High investment cost: the acquisition cost is too highfor the contractors.
12. Maintenance issues: lack of proper maintenance services because new innovations may not be able to rely on existing service networks.

13. Marketing: marketing is very challenging or inefficient because machines' manufacturers and users as well as the operation environment are very heterogeneous. For example, small companies cannot afford a large marketing department.
14. Existing logistic chains do not favour the innovation: established chains are not suitable for the innovation. For instance, logging residue bundles produced by a slash bundler do not fit all existing timber trucks.
15. Complicated logistics: implementing the innovation makes the process more complex.

3.2.2. Measures evaluation

A certain level ofcorrelationbetween the different parameters (*Effectiveness*, *Relevance* and *Probability*) is appreciated in the answers (Table 5). In general terms, the evaluation of the parameters by the experts follows the same trends. Therefore, next studies can be centred in only one parameter reflecting the relevance or interest of the measure.

Table 5: Correlation coefficient for each pair of parameters

Variables	r coef.	Correlation level
Effectiveness vs. Probability	0.62	Moderate-strong
Probability vs. Relevance	0.64	Moderate-strong
Effectiveness vs. Relevance	0.70	Moderate-strong

Nevertheless, the analysis in the text below has included all parameters, and the measures in the tables have been sorted according to either *Effectiveness* or *Relevance*, which are the most general parameters that reflectthe interest of the measure.

Moreover, in general, there is no agreement onthe likelihood for the proposed measures to beimplemented (*Probability*parameter) and in fact, none of the measures was given a high implementation probability score.

Barriers that manufacturers face when developing an innovation and measures to deal with them

In Table 6 the measures to overcome each barrier are listed according to their relevancy in overcoming the barrier.

In order to overcome cost and financing issues, the most important measures according to all parameters are "*Proper allocation of resources for product development and improvement of the business profitability*", "*Cooperation with other firms within horizontal structures in industrial districts*" and "*Ensuring favourable financing instruments*". The measure most agreed on among the experts (lower SD) is "*Decrease manufacturing costs"*, while the one most disagreedon (higher SD) is *"Cooperation with other firms within horizontal structures in industrial districts"*. The probability of implementation of those measures has been estimatedto be close to 2.5, i.e. the middle of the 0-5 scale. This suggests that the likelihood of implementation is not high, but at the same timenot impossible.

With regard to the *Lack of engineering skills or capacity* barrier, the top-rated measureis "*Cooperation with scientists and educational institutes and universities"*.

Concerningthe *Lengthy and high-risk process* barrier, the measures deemed most effective and relevant are *"Cooperation with customers (forest companies) to ensure product sales, feedback for further development, etc.","Subsidies or grants to compensate high-risk investments, particularly for small innovative companies"* and *"Find out how markets are developing and future trends"*.

Regarding *Testing*, *“Cooperation with customers (forest companies) in those regions where equipment is potentially sold”* is considered very relevant, with a medium level of effectiveness.

To approach the barriers of*Regulations issues, Lack of components and Knowledge leaks*, the respondents were mainly pessimistic towards the proposed measures: these have not been considered effective enough,nor relevantand probableenough.

Table 6: Barriers faced by manufacturers when developing an innovation and measures todeal with them

Measure	Relevance		Effectiveness		Probability		
	Mean	SD	Mean	SD	Mean	SD	SUM
01. Cost and financing issues							
1. Proper allocation of resources for product development and improvement of the business profitability	4.4	0.8	4.1	1.2	2.9	1.0	8.5
2. Cooperation with other firms within horizontal structures in industrial districts	3.6	1.2	3.7	1.4	3.2	1.5	7.3
4. Ensuring favourable financing instruments (e.g., affordable and secured loans)	3.5	1.1	3.8	1.1	3.1	0.9	7.3
6. Decrease manufacturing costs	3.4	0.8	3.2	1.0	2.7	0.8	6.2
5. Company focuses its production in some products from which they could receive increased profit	3.3	1.2	3.1	1.1	3.0	1.2	6.4
3. Develop realistic business plan and market prospecting for the innovation	3.0	1.2	3.1	1.3	2.4	0.8	6.1
7. Increase target markets by segmentation	2.9	1.3	2.8	1.2	2.0	0.8	5.7
02. Lack of engineers or capacity							
9. Cooperation with scientists and educational institutes and universities	3.7	1.2	3.4	1.2	2.6	1.0	7.1
11. Cooperation/fusion with other manufacturing companies (automobile, agricultural equipment, etc.)	2.3	1.3	2.6	1.5	1.6	1.1	4.9
10. Make company more attractive forskilled engineers, move to bigger cities, improve working conditions, etc.	2.2	1.9	2.1	1.8	1.8	1.5	4.3
03. Lengthy, high-risk process							
16. Cooperation with customers (forest companies) to ensure products’ sales, feedback for further development, etc.	4.0	0.8	4.2	0.8	3.1	1.1	8.2
17. Subsidies or grants to compensate high-risk investments, particularly for small innovative companies	3.9	1.5	3.6	1.2	2.5	0.7	7.5
14. Find out how markets are developing and future trends	3.8	1.0	3.7	1.1	3.1	1.2	7.5
13. Strategy evaluation. Risk/Benefit assessment to avoid extremely high risk	2.9	1.1	3.1	1.0	2.7	1.1	6
15. Count on risk capitalists	2.5	1.3	2.8	1.6	2.4	1.4	5.3
04. Testing							
20. Cooperation with customers (forest companies) in those regions where equipment is potentially sold	4.0	1.6	3.1	1.8	2.8	1.7	7.1
19. Cooperation with scientistsand educational institutes and universities	3.2	1.2	2.9	1.1	2.3	0.9	6.1
05. Regulations							
22. Involvement in lobbying organizations in order to facilitate the fulfilment of the standards	2.4	1.2	2.5	1.1	1.9	0.8	4.9
06. Lack of components							
24. Involve component suppliers in the development process of a new innovation	2.6	1.4	2.3	1.2	2.3	1.3	4.9
07. Knowledge leaks (protection)							
26. Search for patents to check that nobody else came up with that idea before	2.9	0.8	2.1	0.8	2.1	1.0	5
27. Keep the innovation secret as long as possible to avoid illegal copies	2.7	1.4	2.6	1.0	2.1	0.6	5.3
28. Strengthen confidentiality measures	2.6	0.7	2.3	1.0	2.0	0.9	4.9

Other proposed measures

Other measures proposed by one respondent are:

- Cost and financing issues: Reasonable simplification of regulatory requirements
- Lack of engineers or capacity: Reducing social charges for recruitment
- Lengthy, high-risk process: Stable legal tax framework

Barriers found during the implementationor use phase, and measures proposed for dealingwith them

In order to overcome the barrier *High operation costs and low productivity*, the most effective and relevant measures according to the experts are*"As a user, choose a machine that is properly adapted to the site*", *"Evaluate if, through small and low-cost changes, the machine can be made suitable for a specific environment"*, "*Train operators to work more efficiently on the specific machine"* and *"Ensure enough working hours for expensive machines"* (Table 7)*.* On the contrary, the measure *"Shared economy idea in forest companies"* did not get positive assessments.

Concerningthe *Lack of (enough) flexibility*, both measures *"As a manufacturer, ensure innovations are marketed for and used in the right working environments"* and *"Test if modifications or adjustments improve flexibility/adaptation"*appearedto be effective and relevant, although the probability of being implemented is rated asnot high.

Regarding *Competition with existing equipment*, the most effective measure appearedto be *"Demonstration actions to show and promote equipment"*, while the most relevant was *"A good service deal"*.

To approach *High investment costs*, the most effective and relevant measures appearedto be *"Long term contracts that ensure realistic prospects for profitable business"*, "*Collaboration with key stakeholders to ensure smooth supply chains"* and "*Solid funding agencies for loans"*. Again, *"Shared economy idea (cooperatives) in forest companies"* is deemed the less relevant and effective measure although it stills ranksabove the 2.5 middle point of the 0-5 scale.

Interestingly, measures against the *Maintenance issues* barrier appear to have high relevance and effectiveness according to the experts. The measures considered more effective and more relevant are *"Collaborating with existing dealers and service networks"*, *"Ensuring a reliable service network"*, *"The manufacturer providing expert help"* and *"Buying a machine with documented fewer maintenance needs"*. The odds to implement such measures seem reasonably good. Once again, *"Shared economy idea (cooperatives) in forest companies"* is deemed the less relevant and effective measure. Further studies could approach the reasons why the forestry cooperatives' idea is considered so in the framework of forest companies, and if this situation is desirable or if other shared economy ideas can be more appropriate for this sector.

Regarding marketing issues, the measure *"Contacting with contractors and forest companies"* is considered more relevant and probable, whereas the measure *"Country and user specific marketing and demonstrations"* was deemed more effective.

Regarding the barrier *Existing logistic chains that do not favour the innovation*,measures *"Demonstrating that the innovation is better than existing systems"*, *"Developing logistic management systems"* and "*Team up with other firms which have innovations in other points of the logistic chain"*were valued as the most relevant, effective and probable. The measure *"Find start-up-firms which are willing to use other logistic chains"* was not deemed to be an interesting measure.

Finally, for overcoming the *Complicated logistics* barrier, the measure *"simplifying processes"*is judged to be quite effective and relevant.

Table 7: Barriers found during the implementation or use phase, and measures proposed for dealing with them(listed according to relevancy)

Measure	Relevance		Effectiveness		Probability		
	Mean	SD	Mean	SD	Mean	SD	SUM
08. High operation cost (€/m^3) and low productivity							
35. As a user, choose a machine that is properly adapted to the site (size of the trees, topography, etc.)	4.0	1.1	4.2	0.7	3.4	1.4	8.2
34. Evaluate if, through small and low-cost changes (e.g., different tracks, addition of another axel or bogie to improve bearing capacity, tire size, air-pressure change in tires, knife-change), the machine can be made suitable for a specific environment	4.0	1.1	3.8	0.8	3.6	1.0	7.8
30. Train operators to work more efficiently on the specific machine	4.0	1.2	3.6	1.2	3.1	1.0	7.6
31. Ensure enough working hours for expensive machines by good planning and management	4.0	1.3	3.9	1.0	3.2	1.4	7.9
33. As a manufacturer, ensure machines are operated in suitable working conditions. New innovations should primarily be operated in conditions where their capacity can be used to its maximum	3.3	1.7	3.3	1.5	2.5	1.4	6.6
32. Shared economy idea (cooperatives) in forest companies	2.4	1.4	2.5	1.3	1.7	1.3	4.9
09. Lack of flexibility							
38. As a manufacturer, ensure innovations are marketed for and used in the right working environments	3.7	1.0	4.0	1.1	3.0	1.2	7.7
37. Test if modifications/ adjustments improve flexibility/adaptation (e.g., different felling heads suitable for bigger trees)	3.4	1.3	3.6	1.1	2.6	0.8	7
10. Competition with existing equipment							
42. Good service deal	4.3	0.9	3.9	1.1	3.6	1.3	8.2
41. Demonstration actions to show and promote equipment	4.0	0.9	4.1	0.7	3.7	0.9	8.1
40. Effective marketing focusing on unique selling point and advantages of new innovations	3.3	1.3	3.0	1.1	3.1	1.3	6.3
11. High investment cost							
45. Long term contracts that could ensure realistic prospects for profitable business	4.1	0.8	4.1	0.8	2.9	1.4	8.2
46. Collaboration with key stakeholders to ensure smooth supply chains, subsidies and investment grants for new and strategic openings	3.4	1.0	3.4	1.3	2.2	1.2	6.8
44. Solid funding agencies for loans	3.3	1.2	3.8	1.0	2.6	1.6	7.1
47. Shared economy idea (cooperatives) in forest companies	3.1	1.5	3.0	1.3	2.1	1.5	6.1
12. Maintenance issues							
50. Collaborate with existing dealers and service networks	4.4	0.8	4.2	0.8	3.8	1.2	8.6
49. Ensure a reliable service network	4.3	0.8	4.2	0.8	3.7	1.2	8.5
51. Expert help provided by the manufacturer	4.2	0.9	4.2	0.8	3.9	0.7	8.4
53. Buy a machine with documented fewer maintenance needs	3.8	1.1	3.6	1.2	3.1	1.2	7.4
52. Shared economy idea in forest companies	2.8	1.2	3.1	1.2	2.1	1.4	5.9
13. Marketing							
56. Contact with contractors and forest companies	4.1	0.7	3.6	0.8	3.8	0.8	7.7
55. Country and user specific marketing and demonstrations to the most probable users (A proper market study should be done before innovations are created to make sure there is enough potential for intended new products)	3.3	1.1	3.9	0.9	3.3	1.1	7.2
14. Existing logistic chains do not favour the innovation							
61. Demonstrate that the innovation is better than existing systems	3.8	1.1	3.8	1.1	3.3	1.2	7.6
64. Develop logistic management systems	3.6	1.5	3.8	1.1	3.0	1.3	7.4
58. Team up with other firms which have innovations in other points of the logistic chain which in sum favour a new logistic chain (enterprise networking within vertical structures)	3.0	0.9	3.0	1.2	2.8	1.1	6
59. Develop and adapt supply chains where new innovations fit (One should carefully consider beforehand how new innovations might fit the existing supply chains, or otherwise, optional supply chains –some innovations- should be introduced altogether)	2.6	1.3	2.6	1.3	1.9	1.2	5.2
60. Find start-up-firms which are willing to use other logistic chains, advertise other logistic chains	1.9	1.5	1.7	1.5	1.1	1.2	3.6
15. Complicated logistics							
63. Simplify processes	3.8	1.1	3.9	1.1	2.8	1.4	7.7

Regions

The measures the experts ranked highest(mean for *Effectiveness*> 4.2) in the North (Sweden and Finland), Spain and Germany are listed inTable 8. The measures that also have an average value for *Relevance* over 3.9 are considered the ones that could be the most important to work with, and give the highest effect when applied(Table 9).

In Finland and Sweden the most effective measure was considered to be*"Cooperation with customers to ensure product sales, feedback for further development",* reflecting the need to satisfy customers and take their opinion into consideration,when it comes to their opinion on future development of the machinery. The most relevant measure in this area is deemed to be "*Collaborate with existing dealers and service networks*". "*Ensure enough working hours for expensive machines by good planning and management*" is considered as one of the most relevant and effective measures.

In Spain, the most effective measure was considered to be the"*Proper allocation of resources for product development and improvement of the business profitability*", whereas the most relevant resulted to be a "*Good service deal*".

Finally, in Germany, the experts agreed on "*Demonstrate that the innovation is better than existing systems*" and "*Develop logistic management systems*"as the most effective and relevant measures.

Table 8: Measures ranked by *Effectiveness* depending on the region/country where the experts arefrom

	Measure	Effectiveness		Relevance		Probability	
		Mean	SD	Mean	SD	Mean	SD
North	16. Cooperation with customers to ensure products' sales, feedback for further development, etc.	4.8	0.4	4.0	1.0	2.5	1.1
North	31. Ensure enough working hours for expensive machines by good planning and management	4.7	0.5	4.3	0.9	3.0	1.6
North	55. Country and user specific marketing and demonstrations to the most probable users (A proper market study should be done before innovations are created to make sure there is enough potential for intended new products)	4.5	0.5	3.0	1.2	3.5	1.1
North	30. Train operators to work more efficiently on the specific machine	4.3	0.5	4.0	1.4	3.0	0.8
North	45. Long term contracts that could ensure realistic prospects for profitable business	4.3	0.9	3.7	0.9	2.3	0.5
North	4. Ensuring favourable financing instruments (e.g., affordable and secured loans)	4.3	0.9	3.7	1.2	3.3	1.2
North	50. Collaborate with existing dealers and service networks	4.3	0.4	4.5	0.9	3.8	1.3
North	51. Expert help provided by the manufacturer	4.3	0.8	4.3	0.8	3.8	0.4
North	17. Subsidies or grants to compensate high-risk investments, particularly for small innovative companies	4.3	0.8	4.0	1.2	2.8	0.4
Spain	1. Proper allocation of resources for product development and improvement of the business profitability	5.0	0.0	4.3	0.9	2.0	0.8
Spain	51. Expert help provided by the manufacturer	4.7	0.5	4.3	0.9	4.3	0.9
Spain	49. Ensure a reliable service network	4.7	0.5	4.0	0.8	4.3	0.9
Spain	38. As a manufacturer, ensure innovations are marketed for and used in the right working environments	4.5	0.5	4.0	1.0	4.5	0.5
Spain	45. Long term contracts that could ensure realistic prospects for profitable business	4.4	0.5	4.4	0.5	3.2	1.8
Spain	35. As a user, choose a machine that is properly adapted to the site (size of the trees, topography, etc.)	4.4	0.5	4.0	0.9	3.4	1.5
Spain	53. Buy a machine with documented fewer maintenance needs	4.4	0.8	4.4	0.5	3.8	1.3
Spain	42. Good service deal	4.3	0.9	4.7	0.5	4.7	0.5
Spain	50. Collaborate with existing dealers and service networks	4.3	0.9	4.3	0.9	4.3	0.9
Spain	63. Simplify processes	4.3	0.9	4.3	0.9	4.0	1.4
Spain	64. Develop logistic management systems	4.3	0.9	4.3	0.9	4.3	0.9
Germany	61. Demonstrate that the innovation is better than existing systems	4.5	0.5	5.0	0.0	4.5	0.5
Germany	41. Demonstration actions to show and promote equipment	4.5	0.5	4.5	0.5	4.0	0.0
Germany	64. Develop logistic management systems	4.5	0.5	5.0	0.0	3.5	0.5
Germany	3. Develop realistic business plan and market prospecting for the innovation	4.5	0.5	4.5	0.5	3.5	0.5
Germany	38. As a manufacturer, ensure innovations are marketed for and used in the right working environments	4.5	0.5	4.5	0.5	3.0	0.0

Table 9: Measures ranked by *Relevance* depending on the region/country where the experts are from

	Measure	Relevance		Effectiveness		Probability	
		Mean	SD	Mean	SD	Mean	SD
North	50. Collaborate with existing dealers and service networks	4.5	0.9	4.3	0.4	3.8	1.3
North	31. Ensure enough working hours for expensive machines by good planning and management	4.3	0.9	4.7	0.5	3.0	1.6
North	56. Contact with contractors and forest companies	4.3	0.4	3.8	0.8	4.0	0.7
North	51. Expert help provided by the manufacturer	4.3	0.8	4.3	0.8	3.8	0.4
North	20. Cooperation with customers (forest companies) in those regions where equipment is potentially sold	4.3	0.8	4.0	0.7	3.0	1.6
North	49. Ensure a reliable service network	4.3	0.8	4.0	0.7	3.3	1.5
North	1. Proper allocation of resources for product development and improvement of the business profitability	4.3	0.8	3.8	1.1	3.5	0.9
North	16. Cooperation with customers (forest companies) to ensure product sales, feedback for further development, etc.	4.0	1.0	4.8	0.4	2.5	1.1
North	17. Subsidies or grants to compensate high-risk investments, particularly for small innovative companies	4.0	1.2	4.3	0.8	2.8	0.4
Spain	42. Good service deal	4.7	0.5	4.3	0.9	4.7	0.5
Spain	17. Subsidies or grants to compensate high-risk investments, particularly for small innovative companies	4.5	0.5	4.0	0.0	3.0	0.0
Spain	45. Long term contracts that could ensure realistic prospects for profitable business	4.4	0.5	4.4	0.5	3.2	1.8
Spain	53. Buy a machine with documented fewer maintenance needs	4.4	0.5	4.4	0.8	3.8	1.3
Spain	1. Proper allocation of resources for product development and improvement of the business profitability	4.3	0.9	5.0	0.0	2.0	0.8
Spain	51. Expert help provided by the manufacturer	4.3	0.9	4.7	0.5	4.3	0.9
Spain	50. Collaborate with existing dealers and service networks	4.3	0.9	4.3	0.9	4.3	0.9
Spain	63. Simplify processes	4.3	0.9	4.3	0.9	4.0	1.4
Spain	64. Develop logistic management systems	4.3	0.9	4.3	0.9	4.3	0.9
Spain	31. Ensure enough working hours for expensive machines by good planning and management	4.2	0.7	4.2	0.4	3.8	1.0
Spain	61. Demonstrate that the innovation is better than existing systems	4.0	0.0	4.0	0.0	3.5	0.5
Spain	9. Cooperation with scientists and educational institutes and universities	4.0	0.0	3.0	1.4	2.0	1.4
Spain	49. Ensure a reliable service network	4.0	0.8	4.7	0.5	4.3	0.9
Germany	61. Demonstrate that the innovation is better than existing systems	5.0	0.0	4.5	0.5	4.5	0.5
Germany	35. As a user, choose a machine that is properly adapted to the site (size of the trees, topography, etc.)	5.0	0.0	4.0	1.0	4.5	0.5
Germany	64. Develop logistic management systems	5.0	0.0	4.5	0.5	3.5	0.5
Germany	49. Ensure a reliable service network	5.0	0.0	4.0	1.0	3.5	0.5
Germany	1. Proper allocation of resources for product development and improvement of the business profitability	5.0	0.0	3.5	1.5	3.0	0.0
Germany	19. Cooperation with scientists and educational institutes and universities	5.0	0.0	3.5	0.5	2.5	0.5
Germany	37. Test if modifications/ adjustments improve flexibility/adaptation (e.g., different felling heads suitable for bigger trees)	5.0	0.0	3.5	1.5	2.5	0.5
Germany	20. Cooperation with customers (forest companies) in those regions where equipment is potentially sold	5.0	0.0	1.5	1.5	2.0	0.0

Respondents profile

For the forest companies surveyed, the most effective measures were a "*Proper allocation of resources for product development and improvement of the business profitability*", "*Demonstration actions to show and promote equipment*" and to "*Ensure a reliable service network*" (Table 10). Onthe contrary, manufacturers donot consider either the allocation of resources or the demonstration activities as effective measures, although the former is the most relevant measure for them. As the most relevant actions for forest companies appear also "*Demonstration actions to show and promote equipment*", "*Good service deal*" and "*Demonstrate that the innovation is better than existing systems*" (Table 11). Therefore, the most important elementsfor users areto be allowed to watchthe equipment operatingdirectly and performing well, and to be able to count on a reliable and available service network they can fully trust.

For the manufacturers surveyed, the most effective measures are "*Expert help provided by the manufacturer*", "*Ensuring favourable financing instruments*" and "*Cooperation with customers (forest companies)*", whereas the most relevant ones are "*Proper allocation of resources for product development and improvement of the business profitability*", "*Ensure reliable service network*" and again "*Cooperation with customers*". Therefore, it seems that manufacturers are aware of the need forcooperation amongdifferent stakeholders, and of the necessity to offer a good service to the users (expert help, service network), besides the need forfavourable economic conditions (financing instruments, long term contracts).

Table 10: Measures ranked by *Effectiveness* depending on the expert profile

	Measure	Effectiveness		Relevance		Probability	
		Mean	SD	Mean	SD	Mean	SD
Forest company	1. Proper allocation of resources for product development and improvement of the business profitability	5.0	0.0	4.3	0.9	2.0	0.8
	41. Demonstration actions to show and promote equipment	4.7	0.5	4.7	0.5	4.0	0.8
	49. Ensure a reliable service network	4.7	0.5	4.0	0.8	3.7	0.9
	61. Demonstrate that the innovation is better than existing systems	4.5	0.5	4.5	0.5	4.0	1.0
	38. As a manufacturer, ensure innovations are marketed for and used in the right working environments	4.5	0.5	4.0	1.0	3.5	0.5
	35. As a user, choose a machine that is properly adapted to the site (size of the trees, topography, etc.)	4.4	0.5	4.0	0.9	3.4	1.5
	14. Find out how markets are developing and future trends	4.3	0.5	4.3	0.5	4.0	0.8
Manufacturers	51. Expert help provided by the manufacturer	4.6	0.5	4.4	0.8	4.0	0.6
	4. Ensuring favourable financing instruments (e.g., affordable and secured loans)	4.5	0.9	3.8	1.3	3.5	0.9
	16. Cooperation with customers (forest companies) to ensure products' sales, feedback for further development, etc.	4.4	0.8	4.2	0.7	3.2	1.3
	38. As a manufacturer, ensure innovations are marketed for and used in the right working environments	4.3	0.8	3.8	1.1	3.3	1.1
	49. Ensure a reliable service network	4.2	0.7	4.6	0.8	4.2	0.7
	50. Collaborate with existing dealers and service networks	4.2	0.7	4.4	0.8	4.4	0.8
	42. Good service deal	4.0	0.9	4.2	1.2	3.6	1.0
	55. Country and user specific marketing and demonstrations to the most probableusers (A proper market study should be done before innovations are created to make sure there is enough potential for intended new products)	4.0	0.9	3.2	1.0	3.2	1.2

Table 11: Measures ranked by *Relevance* depending on the expert profile

	Measure	Relevance		Effectiveness		Probability	
		Mean	SD	Mean	SD	Mean	SD
Forest company	41. Demonstration actions to show and promote equipment	4.7	0.5	4.7	0.5	4.0	0.8
	42. Good service deal	4.7	0.5	4.3	0.9	4.3	0.5
	61. Demonstrate that the innovation is better than existing systems	4.5	0.5	4.5	0.5	4.0	1.0
	17. Subsidies or grants to compensate high-risk investments, particularly for small innovative companies	4.5	0.5	3.5	0.5	2.5	0.5
	53. Buy a machine with documented fewer maintenance needs	4.4	0.5	3.8	1.2	3.3	1.1
	14. Find out how markets are developing and future trends	4.3	0.5	4.3	0.5	4.0	0.8
Manufacturers	1. Proper allocation of resources for product development and improvement of the business profitability	4.8	0.4	3.6	1.4	3.2	0.7
	49. Ensure a reliable service network	4.6	0.8	4.2	0.7	4.2	0.7
	20. Cooperation with customers (forest companies) in those regions where equipment is potentially sold	4.6	0.8	3.6	1.9	3.4	1.6
	45. Long term contracts that could ensure realistic prospects for profitable business	4.5	0.9	4.0	1.0	3.3	1.1
	51. Expert help provided by the manufacturer	4.4	0.8	4.6	0.5	4.0	0.6
	50. Collaborate with existing dealers and service networks	4.4	0.8	4.2	0.7	4.4	0.8
	31. Ensure enough working hours for expensive machines by good planning and management	4.3	0.8	3.8	1.1	3.8	0.8

3.3. Conclusions

Considering the results of the survey, we conclude that the measures with the highest impact would be the ones that have the highest scores for both *Effectiveness* and *Relevance*.

The measures proposed to overcome the barriers that manufacturers face when developing an innovationshould be prioritised as follows:

1. Proper allocation of resources for product development and improvement of the business profitability
2. Cooperation with other firms within horizontal structures in industrial districts
3. Ensuring favourable financing instruments (e.g., affordable and secured loans)
4. Cooperation with scientists and educational institutes and universities
5. Subsidies or grants to compensate high-risk investments, particularly for small innovative companies
6. Find out how markets are developing and future trends
7. Cooperation with customers (forest companies) to ensure products' sales, feedback for further development

The application of these measures ismainly in the hands of the manufacturers themselves, and partly in the hands of policy makers who may contribute through the development of appropriate financing instruments or compensations for high-risk investments in SME's.

The measures proposed to overcome the barriers that manufacturers face during the implementation or use phase should be prioritised as follows:

1. Choose a machine that is properly adapted to the site (size of the trees, topography, etc.) with a good service deal and network
2. Evaluate if, through small and low-cost changes(e.g., different tracks, addition of another axel or bogie to improve bearing capacity tire size, air-pressure change in tires, knife-change), the machine can be made suitable for a specific environment
3. Long term contracts that could ensure realistic prospects for profitable business
4. Collaborate with existing dealers and service networks
5. Secure expert help provided by the manufacturer
6. Demonstration actions to show and promote equipment

7. Ensure enough working hours for expensive machines by good planning and management
8. Contact with contractors and forest companies

In this case, the application of the measures is in the hands of a balanced mix of the main stakeholders, including forest companies and manufacturers. It means that both have to work, sometimes together, to overcome the detected barriers.

Besides the main stakeholdersexpected to implement the measures, others (e.g., policy makers, researchers) can take actions to promote or accelerate the implementation of those measures in order to reach the commitments of the EU regarding forest biomass and wood supply chains.

One major concern though is that experts are far from being convinced that the measures have a high probability of being implemented.

The discrepancies regarding high or low valuations may indicate the presence of different opinion groups. Therefore, a deeper analysis of the results according to the origin and profile of the experts may be needed in order to clarify which measures are considered the most suitable to overcome the barriers. This could lead to more homogeneous results. Obviously, the barriers and measures to overcome them can differ according to each one’s point of view and/or objectives.

As an exploratory study, the number of answers allows designing a preliminary outline of a plan to overcome the barriers found, and raisesa certain number of questions that must be answered in further studies.

4. Scenarios development

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In this chapter, scenarios of potential availability and expected consumption of wood for energy are explored and a calculation of the amount of machinery needed to harvest the available potential is performed.

4.1. Outlook for CHP plants and biorefineries and expected scenarios for potential markets of wood for energy

Outlook for CHP[2] plants and biorefineries[3]

Today's forest industry produces a large range of products from the forest feedstock, e.g., sawn wood and board products for construction of houses, furniture, etc., and paper products for printing, packaging and hygiene, to mention only important products' groups (Joelsson and Tuuttila, 2012). In many countries, sophisticated methods are used to maximize the value of each specific tree log. Examples of such methods are pricelists stored in forest harvesters' computers, to determine the optimal way in which to section (or cut into lengths) each log, and x-ray technologies in saw mills used to determine the optimal way to split the log into sawn products. Pulp mills and board manufacturers have made use of side-streams from the saw-mill value chain, such as small-diameter wood from thinning operations as well as by-products from the sawmills such as wood chips and saw dust. Waste streams are also to a large extent recovered for internal energy use (Joelsson and Tuuttila, 2012). There has been a rising interest in energy products from the forest industry, for example wood pellet production from saw dust, export of surplus heat and electricity from pulp mills and increased recovery of logging residues and other forest biomass with previously little use. The energy and biorefinery value chain is, however, less developed than the sawn wood, pulp and paper value chains.

CHP plants and biorefineries are going to be major receivers of wood biomass in the future. In a CHP plant, heat and electricity are produced simultaneously in one process and both are used. The share of electricity from combined heat and power in the total gross electricity production in the EU-27 was 11.4% in 2009. In the same year, the share of renewable fuel input to CHP plants in EU was 11%, with the preferred input fuels being natural gas and solid fuels (mainly coal) (EEA, 2012). Heat and electricity production from renewable energy sources has a great potential due to many reasons, e.g., policy decisions and biomass availability. According to CHP Sector Handbook (2012), bio-electricity is expected to represent 19.5 % of all renewable electricity in 2020 and it is expected to increase by 116 TWh between 2010 and 2020. Heat and electricity can be produced by direct combustion, pyrolysis or gasification of the biomass mainly in the form of chips and pellets.

However, the degree of integration between different types of products is often low. Most of the time, the focus lies on one or a few bulk products and the utilization of side streams is underdeveloped.

Forest industry as such could be said to already act as a biorefinery and forest raw materials could also serve as feedstock for a range of chemicals and new materials. This potential, however, is still underdeveloped (Joelsson and Tuuttila, 2012). With tightening market conditions, the industry is driven towards a more efficient use of the forest feedstock and increased added value. The issues of climate change and diminishingoil supplies haveinduced a search for forest-based energy and materials that can replace fossil-derived energy and

[2] Combined Heat and Power

[3] A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum (NREL, 2009).

materials. Altogether, these driving forces have led to a greater interest in the development of new products from the forest. Many of these new products are believed to benefit from integrated production in biorefineries, which can also improve energy efficiency by internal energy integration (Joelsson and Tuuttila, 2012).

A common approach consists in dividing biorefineries into two main groups based on biochemical and thermochemical processes. Cherubini *et al*. (2009) suggested a general scheme for the classification of biorefineries based on four features, i.e. platforms, products, feedstocks and processes (in order of importance), detailed below.

Platforms are intermediates which link feedstock and final products. There is an analogy in the petrochemical industry, which is based on a number of intermediate products derived from crude oil that are processed into final products.

Products from biorefineries are divided into energy products and material products. Energy products include solid and liquid fuels, energy gases and heat and power. Material products include, for example, plastics, fibres, chemicals, food and feed products.

*Feedstocks*areclassified as either dedicated crops or residues, where dedicated crops are grown specifically for use in a biorefinery. Theymay include, for example, oil and sugar crops and short rotation energy wood. Residues,e.g., logging residues, saw dust and food industry residues, are a type of feedstock that is produced as a by-product from another process.

Processes applied in a biorefinery may be of many different kinds and can be groupedinto thermochemical, biochemical, chemical and mechanical/physical processes (Table 12).

Table 12: Biorefinery platforms, products, feedstocks and processes (Cherubini *et al*., 2009)

Platforms	Products	Feedstocks	Processes (selected)
I) C5 sugars	I.) Energy products	I.) Dedicated crops	I.) Thermochemical
II) C6 sugars	I.1) Biodiesel	I.1) Oil crops	I.1) Combustion
III) Oils	I.2) Bioethanol	I.2) Sugar crops	I.2) Gasification
IV) Biogas	I.1) Biomethane	I.3) Starch crops	I.3) Hydrothermal upgrading
V) Syngas	I.1) Synthetic biofuels	I.4) Lignocellulosic crops	I.4) Pyrolysis
VI) Hydrogen	I.1) Electricity and heat	I.5) Grasses	I.5) Supercritical
VII) Organic juice	II.) Material products	I.6) Marine biomass	II.) Biochemical
VIII) Pyrolytic liquid	II.1) Food	II) Residues	II.1) Fermentation
IX) Lignin	II.2) Animal feed	II.1) Lignocellulosic residues	II.2) Anaerobic digestion
X) Electricity and heat	II.3) Fertiliser	II.2) Oil-based residues	II.3) Aerobic conversion
	II.4) Glycerin	II.3) Organic residues and others	II.4) Enzymatic processes
	II.5) Biomaterials		III) Chemical processes
	II.6) Chemicals and building blocks		III.1)Catalytic processes
	II.7) Polymers and resins		III.2) Pulping
	II.8) Biohydrogen		III.3) Esterification
			III.4) Hydrogenation
			III.5) Hydrolysis
			III.6) Methanisation
			III.7) Steam reforming
			III.8) Water electrolysis
			III.9) Water gas shift
			IV.) Mechanical/physical
			IV.1) Extraction
			IV.2) Fibre separation
			IV.3) Mechanical fractionation
			IV.4) Pressing/disruption
			IV.5) Pre-treatment
			IV.6) Separation

Scenarios for potential markets of wood for energy

The market for forest bioenergy and other wood products is expected to keep ongrowing in the future. Indeed, consumption of wood products and bioenergy is favoured by governmental targets and the policies and legislation implemented to achieve these targets. In a scenario analysis study of the European forest sector (EFSOS II), where one reference scenario and 4 policy scenarios were examined, it was sustained that consumption of wood energy will grow steadily and wood supply will expand to meet this demand (United Nations, 2011).

Consumption of forest products and pulp and paper were stable all through the scenario period (2010-2030) while wood demand for bioenergy was expected to increase significantly, representing nearly 50% of the total wood demand in the reference, carbon and biodiversity scenario (United Nations, 2011). In the “promoting wood energy scenario” (United Nations, 2011), which is going to be dealt with in more detail here, the proportion of wood energy demand exceeds 60% (45% in 2010) of the total wood demand by 2030. In the reference scenario, that figure reached 50%. A deeper analysis of the future customers and markets for forest biomass has been carried out byJessup and Walkiewicz (2013) and published as part of the INFRES project.

A comparison between the reference scenario and the “promoting wood energy scenario” is presented in Table 13. For the full set of scenario assumptions, the reader is referred to United Nations (2011). Nevertheless, it is worth mentioning here that even in the “promoting wood energy scenario” all measures that are put in place to mobilise woody biomass from Europe’s forests and elsewhere are also followingthe recommendations on sustainable wood mobilization.

Table 13: Comparison between the reference scenario and the promoting wood energy scenario in EFSOS II (United Nations, 2011). The table shows the expected consumption of wood for energy (million m^3) and wood for wood products

		Reference scenario		Promoting wood energy scenario	
	2010	**2020**	**2030**	**2020**	**2030**
Wood for products	540	570	590	550	560
Forest sector internal energy use	92	107	126	107	126
Biomass power plants	105	128	183	271	406
Households (pellets)	24	43	50	70	83
Households (other wood energy)	214	225	206	223	204
Liquid biofuels	0	1	21	1	40
Wood for energy, total	411	504	567	672	859
Total	975	1074	1176	1222	1419

Although theconsumption for the internal use of the forest energy sector is identical in both scenarios, a major increase is observed in the biomass use of biomass power plants as well as forfulfilling the market needs for liquid biofuels (biodiesel, bioethanol, HVO) (Table 13).

To achieve the goals of the “promoting wood energy scenario”, stemwood harvest as well as extraction of residues and stumps will have to increase. Most of the increment will happen in North, Central and Central-East Europe, the South contributing to around 15% (Table 14).The rest of the woody biomass that will be needed to cover the expected consumption of 1419 Mm^3 will be composed ofindustrial residues, post-consumer wood and landscape care wood. Moreover,an increase in biomass trade at world level is predicted (United Nations, 2011; Ikonen and Asikainen, 2013).

Table 14: Fellings, stemwood removals and extracted residues and stumps in 2030 for the promoting wood energy scenario in Europe (United Nations, 2011)

	North*		Central-West**		Central-East***		South-West****		South-East*****		Total	
	2010	2030	2010	2030	2010	2030	2010	2030	2010	2030	2010	2030
Fellings (Mm^3/yr)	220	253	218	253	159	191	42	47	43	60	683	805
Stemwood removals Mm^3/yr)	204	233	182	211	133	161	38	43	38	53	595	701
Extracted residues (Modt/yr)	10	24	8	21	5	15	2	5	1	6	26	71
Extracted stumps (Modt/yr)	5	21	0	14	0	10	0	2	0	5	5	51

*Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway, Sweden, **Austria, Belgium, France, Germany, Ireland, Luxembourg, the Netherlands, Switzerland, United Kingdom, ***Belarus, Czech Republic, Hungary, Poland, Republic of Moldova, Romania, Slovakia, Ukraine, ****Italy, Malta, Portugal, Spain, *****Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Montenegro, Serbia, Slovenia, The former Yugoslav Republic of Macedonia, Turkey.

Values in Table 14 agree quite well with the EFISCEN projections presented in Vaerverk*et al*. (2011) when strong focus was put on the use of wood for producing energy while a minimum of constraints was assumed forbiomass extraction. In that EFISCEN “high mobilization scenario” the annual potential from forest could be 895 m^3. In an alternative scenario where strong environmental concerns forbiomass extraction were assumed, the annual harvestable biomass potential was reduced to 623 Mm^3.

4.2. Machinery needs

According to the “promoting wood energy scenario”, European markets are expected to increase their wood consumption and wood suppliers are expected to boosttheir wood supply correspondingly. Therefore, the machinery fleet used in forest biomass supply chains will have to growby 2030 even if machines’ productivity increases. In countries where the use of biomass for energy generation has increased, harvesting has to be extendedto more distant locations and to more difficult conditions. As a result, we estimate that despite technological improvements, the annual capacities of the machines and trucks remainconstant; their technological performance increases, but more difficult operation conditions counterbalance this development. In this section, we calculate the amount of machinery that would be needed to extract the amount of biomass estimated by the “promoting wood energy scenario” in the different parts of Europe mentioned in United Nations (2011).

In order to calculatethe machinery needs, a typical European supply chain for timber harvesting was selected, consisting of a harvester, a forwarder, a chipperand a timber truck. Stumps are extracted with an excavator and small diameter trees for energy with a harvester equipped with an energy wood harvesting head (Table 15). All energy assortments are forwarded to the roadside and chipped/crushed there, and this approach isalso used for stumps for practical reasons, despite the fact that the largest share of stumps is crushed either in terminals or inplants (Díaz-Yáñez *et al*., 2013). It was assumed that 4% of stemwood removals would be directed to the production of energy chips, corresponding to 24 and 28 $Mm^3$of harvested stemwood being devoted to energy production in 2010 and 2030 respectively. The dry masses of residues and stumps were converted into cubic meters by using a conversion factor of 500 kg/m^3.

Table 15: Annual capacities of machines, m^3/yr(Asikainen *et al.*, 2011)

	Energy stemwood	**Energy residues**	**Energy stumps**
Harvester	10000		
Excavator			17 000
Forwarder	30000	30 000	30 000
Chipper	30000	30 000	30 000
Truck, North	18 000	18 000	18 000
Truck, other regions	10 000	10 000	10 000

The need for harvesting and transport fleet more than doubles if the wood energy scenario takes place(Figure 2). It must be kept in mind that only in the North country group the harvesting operations already approach today full mechanization, while in other regions, the growing use of modern machinery in biomass operations allows to move towards that same state. Forestry activity in South West and South East are more complex than in the North. For instance, biodiversity, social uses and agriculture often overlap. Therefore, the choice of given mechanization options isnot asobvious as in the North. For instance, the agricultural tractor used for wood extraction is a wellspread equipment in Catalonia as a result of its versatility, which allows both agricultural and forest operations.

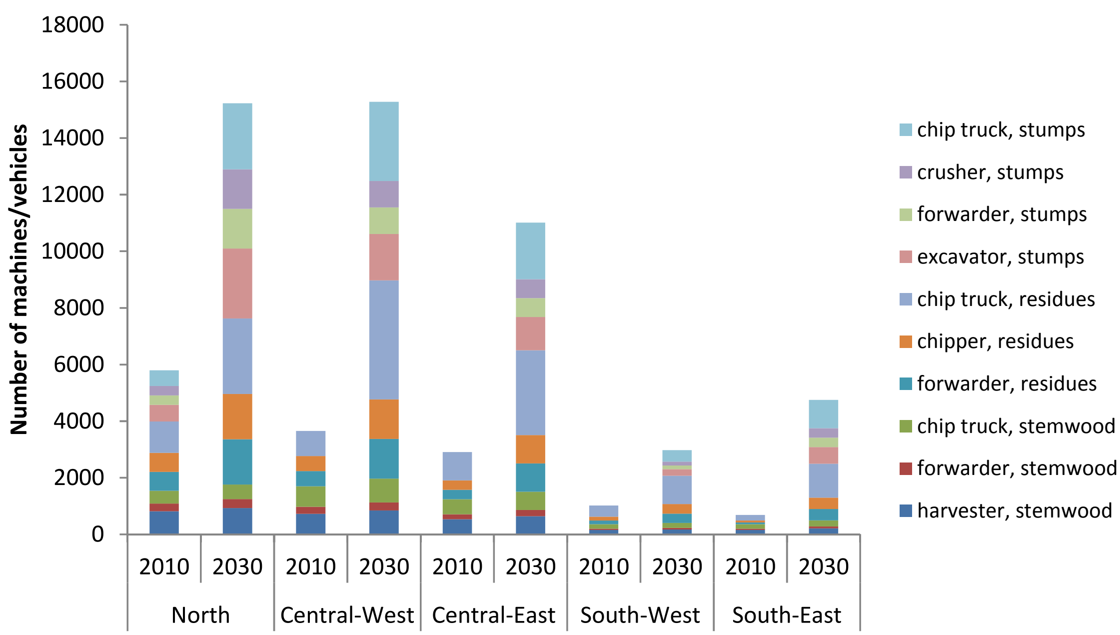

Figure 2: Annual need formachines and vehicles indifferent regions

However, by 2030, it is evident that the use of mechanized systems will bereaching its peak also in regions other than the North, although calculations show that large investments are needed to improve the harvesting and transport fleet by 2030. Tuomasjukka *et al*. (2015) have developed different supply scenarios according to promising innovations identified in the INFRES.

4.3. Other requirements: quality of the input feedstock

Any installation has different feedstock requirements according to its feeding system, conversion technology, and other constraints (Table 16).

In *heating systems (< 1 MW_{th})* the quality of wood fuel playsan important role. The general rule of thumb is that the smaller the system, the greater thewood fuel quality required. The highest quality chips for small installations can be made from delimbed stem wood from pre-commercial or commercial thinnings. Where lower quality chips can be fired, whole tree chips from undelimbed small tree stems can also be used.

In *bigger installations (>5 MW_{th})* the variety of forest fuel sources is greater. Logging residues, stump wood and also straw and other herbaceous biomass fuels are indeed suitable fuels for these installations. Depending on their availability, forest industry by-products such as bark, sawdust and cutter chips can also be used as fuel (Alakangas and Virkkunen, 2007).

In *district heating and large-scale combined heat and power production plants (CHP),* fuel deliveries must be reliable and on time. A clear fact is that the fuel supply can seldom be based on wood alone. To secure fuel availability, reduce costs and level out quality variations, large plants usually have multi fuel boilers that use bark, sawdust, peat, etc., with forest chips, or the wood pellets are co-fired with coal (Alakangas and Virkkunen, 2007).

Considering *fast pyrolysis,* the quality control chain should cover the whole fuel chain from feedstock processing to bio-oil combustion. There are numerous challenges related to feedstock handling, storage and feeding as well as bio-oil condensation, handling, pumping, and storage. It is important to specify the lowest quality feedstock which produces acceptable grade bio-oil. Also, bio-oil quality has to be monitoredfor detectingpossible cyclone failures or air leakages. Finally, the handling and pumping procedure forbio-oil transfer into fuel tank and laterfor its delivery to customers has to be standardised so as to limit oil ageing and degradation.

In general, all types of biomass can be pyrolyzed and pyrolysis plants should be able to handle minor changes in feedstock quality. However, some specifications for biomass quality have to be assessed in order to provide good-quality bio-oil for customers. High moisture content of feedstock may contribute to high water content of bio-oil which is prone to phase-separation. High ash content might cause problems during the process of grinding and sieving, as well as duringthe combustion. A long storage time of the biomass leads to a decrease in volatiles which in turnsreducesthe bio-oil yield, increases the water yield and might also yield inhomogeneous bio-oil product. Based on the experiences gained so far, it is suggested to include the following specifications for the feedstock quality: moisture content < 10 wt%, volatiles > 75 wt%, and ash < 2 wt%.

Requirements for biomass quality for *gasification* depend on the application. For instance, in *small scale biomass CHP applications based on thedowndraft gasification,* biomass quality must be inevitably high, and only dry (< 20 wt%) high quality wood chips or pellets with a low ash content (< 2wt%)can be used as fuel. However, in *large scale fluidized bed gasification* processes where the gas producedis directly burned at kilns, ovens or boilers, fuels have less stringent quality requirements, and these installations can actually make use of logging residues, stump wood and also herbaceous biomass. Moist fuels can be used in energy applications if high flame temperatures are not needed. In *kiln applications*, for example limekiln, fuel must be previously dried (< 20 wt%). In all *fluidized bed gasification* based processes, fuel must be ground to a similar particle size range as in fluidized bed combustion processes.

Biomass fuel requirements in a *gasification based synthesis gas* route to renewable transportation fuels and chemicals depends on the gasification technology. In *fluidized bed* *gasification,* biomass must be adequately dried (< 20 wt%) and ground (< 20 mm), and logging residues, stump wood and herbaceous biomass can be used as fuels. In the case of the *entrained flow gasification* technology, biomass must be dried and ground (< 200 µm) or some other biomass treatment (e.g., pyrolysis or torrefaction) must be used for biomass treatment.

Quality requirements for forest biomass fuels and suitable conversion technologies are listed inTable 16.

Table 16: Forest woody biomass supply chain options according to end-user sector (modified from Alakangas and Virkkunen, 2007)

End-user and average annual fuel consumption	**Woody biomass**	**Quality requirements**	**Technology for energy conversion**
Farms, large buildings (<1 MWth) Annual fuel consumption < 3 GWh)	Wood chips from whole trees or delimbed stemwood	Low moisture content, < 35 w% *	Stoker burners grate firing
District heating plants (< 5 MW_{th} or power plants (< 5 MW_e) Annual fuel consumption < 35 GWh (DH, CHP) or 85 GWh (power only)	Wood chips from logging residues or whole trees	Moisture content usually < 40 w%	Grate combustion Fluidized bed combustion Gasification
CHP and power plants (> 5 MW_e) Annual fuel consumption from 85 GWh to several TWh	Wood fuels from logging residues, stumps	Boiler and handling equipment based requirements	Usually cofiring with coal or peat Fluidized bed combustion Gasification
Pyrolysis plants Annual fuel consumption > 85 GWh	Wood fuels from sawdust, logging residues, stumps	Ground (typically < 5 mm) and dried (typically < 8 w% moisture) feed for pyrolysis	Pyrolysis
Gasification CHP applications based on downdraft gasification	High quality wood chips from whole trees or delimbed stem wood	Low moisture content, < 20 w%	Downdraft gasifier followed by gas engine and generator for electricity production (typically 10-100 kWe)
Gasification for synthesis gas applications	Wood fuels from logging residues, stumps	Fluidized bed technology: ground (typically < 20 mm) and dried (typically < 20 w %) Entrained flow technology: ground (typically < 200 µm) and dried (typically < 20 w%)	Fluidized bed or entrained flow gasifier. Production of transportation fuels as FT-diesel, methanol, SNG, hydrogen or chemicals
Biomass gasification for replacing coal, natural gas or fuel oil at boilers and kilns	Wood fuels from logging residues, stumps	Ground (typically < 20 mm); usually drying is needed (typically 20-25 w %)	Fluidized bed gasifier

* w %: moisture content, %

4.4. Conclusions

Any of the future scenarios anticipates an increase inwoody biomass demand. This implies the need to improve the competitiveness and optimization of the forest supply chains in Europe, in order to supply more forest biomass at the same or lower costs. Otherwise, this demand could fail to be covered, or could be supplied with external imports, threatening the sustainability of the system.

To improve the competitiveness of EU forest supply chains, it is necessary to study them in depth, especially in those countries where no data is available or no previous studies have been done. Asikainen *et al*. (2011) estimated the increase needed in the supply chains from a general point of view, whileErber *et al*. (2015) and Díaz-Yáñez *et al*. (2013) investigated in more detail the supply chain machinery. They all showedthat a variety of supply chains are presently usedthroughout the EU.

Therefore, in order to properly orient and accompany the machinery innovation during the next years, further studies are needed to clearly identify which supply chains are being used in all regions of the EU, and to determine which technical improvements can possibly make these chains more competitive. It is also possible forharvesting systems for energy wood to become more alikein the future acrossEurope; this has already taken place forroundwood harvesting. In addition, it is necessary to address all the barriers currently hindering the forest supply chains (Erber *et al*., 2015) and machinery innovation (Athanassiadis *et al*., 2014) and to anticipate those expected to appear in the future (Riala *et al*., 2015).

Obviously, the growth of the biorefinery sector is inevitableand this will change somehow the landscape of the forest biomass requirements by 2030. Indeed, feedstocks such as forest residues and stumps can be easily used bythis sector, and subsequently, the demand for adequate machinery for their production will rise.

Besides this, the increase and improvement of the machinery used in the forest biomass supply chains, together with the optimization of the whole chains, take some time. As a consequence, it is a challenge for Europe to reach high enough competitiveness and innovation levels so as to cover the demand needs in the best way, with its own resources, seeking a positive impact on allEU regions and on European machinery manufacturers.

Anyway, the increase inthe demand is already triggeringsome changes in the forest biomass supply chains. It is necessary to overcome existing innovation barriers to optimize the whole system and make it sustainable.

5. Risk assessment

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Some concrete targets for supply chain developments are set already in the INFRES DOW. For example, if fuel consumption can be reducedby 20%, one can wonder what implications will that have on biomass supply. Less fuel is going to be used and policy targets will be reached. If the cost of biomass supply can be driven down,then biomass can probably substitute other materials like wastes. If inventions are not penetrating markets, obviously the competitiveness of biomass cannot improve. This also hindersthe sales of machinery and vehicles and slown downmachine manufacturing (Ikonen and Asikainen, 2013).

5.1. Methodology for risk assessment

Risk assessment helps to determine which risks can be opportunities and which ones can be potential pitfalls. If the risk assessment is done correctly, it can give a clear view of variables to which a sector may be exposed, whether internal or external, reflective or forward looking. Risk assessment is tied with the risk appetite and tolerance, and gives support for determining risk responses. A consistent risk assessment process enables to better identify, appraise and exploit the right risks, while maintaining the required controls to guarantee effective operations (PricewaterhouseCoopers [PwC], 2008).

According to the Committee of Sponsoring Organizations (COSO), risk assessment is a systematic process for identifying and appraising events (i.e., possible risks and opportunities) that could influence the achievement of objectives, either in a positive or in a negative manner. These events can be defined in the external environment of the analyzed sector and within its internal environment. These events become risks when they intersect,or when they are expected to intersect any objectives. Hence, risk is defined as “the possibility that an event will occur and adversely affect the achievement of objectives.”

Capturing and analysing risks as a process

The critical step to determine the scope of the risk assessment can be consideredas understanding the objectives and the types of possible risks that may be faced. Objectives may be broad or narrower. Also, possible risks can spread over many categories or only a number of the categories if the discussion is more narrowly focused. Lastly, the scope may be enterprise- wide or limited to a business unit or a specific geographic area (PwC, 2008).

COSO (2004) states that after the definition of the scope of the risk assessment, the possible risks are rated in terms of impact (severity) and likelihood (probability), both on an inherent and a residual basis. With these results, a heat map or a risk profile can be provided, in which the results can be viewed in relation to entity’s willingness to take on such risks. This lets the entity determine its own appropriate response strategies and resources accordingly to its needs. Risk management discipline then establishes that risk assessments become a continuous process, in which objectives, risks, risk response measures and controls are repeatedly evaluated. Therefore, the risk assessment process is an important part of an effective risk management program.

On the one hand, qualitative assessments provide the most basic form of risk assessment, according to PwC (2008). Theycategorize the potential risks based on either nominal or ordinal scales, and they areuseful to obtain external validation to prevent potential management biases. On the other hand, more accurate quantitative techniques can be used for assessing risk whenmore data is available. These data allow a finer analysis of the potential risk exposures, inform on the evolution of relevant indicators that can be controlled regularly, and permit more rapid and efficient responses to risk situations.

The capability to identify, assess and manage risk is often demonstrative of a sector or a company ability to respond and adapt to change. Therefore, risk assessment is helpful to identify potential adverse events, to be more proactive and forward looking, and to set up related risk responses. This way, unexpected situationsand costs or losses related with business disruptions are minimized. So, the main purpose of the risk assessment process becomes preventing or minimizing negative surprises and discovering new opportunities (Proviti, 2006).

Key principles for effective and efficient risk assessments

PwC (2008) states that in order to obtain relevant results from risk assessments, the following key principles should be investigated.

1. The risk assessment should begin and end with specific objectives, and the risks should then be identified and measured in relation to those. Therefore, it is important to define objectives that are specific and measurable at different levels of the sector or the organization for a successful risk assessment. Assessing the risks relative to the objectives eases the allocation of resources to manage these risks and achieve the established objectives.
2. Risk rating scales are defined in relation to objectives in scope. In the risk assessment process, risks are typically measured in terms of severity and probability. Therefore, risk rating scales can be defined either in quantitative or in qualitative terms. Quantitative rating scales lead to a more precise and more measurable risk assessment process. However, qualitative rating scales must be used when the data is not suitable to quantification. Ordinal, internal and/or ratio scales are commonly used when risks are measured. Ordinal scales define a rank of importance (e.g., low, medium, high), interval scales have numerically equal distance (e.g., 1 equals lowest and 3 equals highest, but the highest is not three times greater than the lowest), and ratio scales have a "true zero" and this feature allows for greater measurability (e.g., a ranking of 10 is 5 times greater than ranking of 2). Table 17 below gives an example of measuring risk in terms of impact and likelihood of occurrence.

Table 17: Assessing risks considering their impact and likelihood of occurrence (PwC, 2008)

	Impact		Likelihood	
	Definition	Description	Definition	Description
1	Negligible	The risk will not hinder the achievement of the objective, causing minimal damage.	Unlikely	The risk is seen as unlikely to occur during the time frame planned by the objective.
2	Moderate	The risk will cause some parts of the objective to be delayed or not to be achieved, causing potential damage.	Likely	The risk is seen as likely to occur during the time frame planned by the objective.
3	Critical	The risk will impedethe objective to be achieved, causing damage.	Certain	The risk is expected to occur during the time frame planned by the objective.

3. A portfolio view of risks has to be arranged to support decision making. Asthe risks are assessed individually regardingthe objectives they affect, it is also important to bring risks together in a portfolio view that shows interrelations between them, and to highlight correlations between risks or concentrations of risks. The portfolio view helps to

understand the effect of a single event and to determine when and how to deploy systematic responses to risks.

Risk assessment in theINFRES context

In this report, the risk assessment process began with the identification of the objectives that are pointed out in the INFRES Description of Work document. These are the following:

Develop and demonstrate technological and logistical solutions that decrease the fossil energy input in the biomass supply by 20% and reduce the raw material losses by 15%. The cost of supply can be reduced by 10-20% and precision of supply improves the economic outcome of CHP production by 10%. The CO_2 emissions of feedstock supply will diminish by 10%. With the novel technologies and efficient transfer of best practices between the countries in the consortium and other countries with similar natural conditions the volume of forest energy supply in EU27 by 2015 will be 30% higher than today.

A number of potential risks associated with not bringing the demonstrated technological and logistical solutions to practical application were identified, along with their consequences and are presented in Figure 3.

As an example and based on the values presented in Table 13 on the amount of extracted residues and stumps in 2030 for the P*romoting wood energy* scenario in Europe (United Nations, 2011), it is estimated that the total amount of fuel that would be needed to harvest and transport 71 Modt of logging residues and 51 Modt of stumps could reach 570 Mlof diesel (assuming 4.8 l/odt in stump harvesting, 2.9 l/odt and 2.4 l/odt in forwarding of logging residue and stumps, respectively). If INFRES objectives were to be realised, this would mean that fuel consumption would be cut by 115 Ml of diesel. In INFRES deliverable 5.3 “Report documenting sustainability impacts of scenarios for different fuel sources and procurement technologies” (Tuomasjukka *et al*. 2015), each objective of the INFRES project is assessed according to the performance of the innovations that were demonstrated in the project as well as the potential the innovations have at theEuropean scale.

If the technological and logistical solutions demonstrated during the INFRES project are not implemented or their implementation is delayed considerably, then energy and environmental targets in the EU will not be reached. Sustainability and cost efficiency gains in the biomass supply chains will not be achieved either.

The introduction of the solutions presented by INFRES will be made possible by implementing the measures that were identified in section 3 for overcoming the barriers inthe development, implementation and use phases of the innovations.

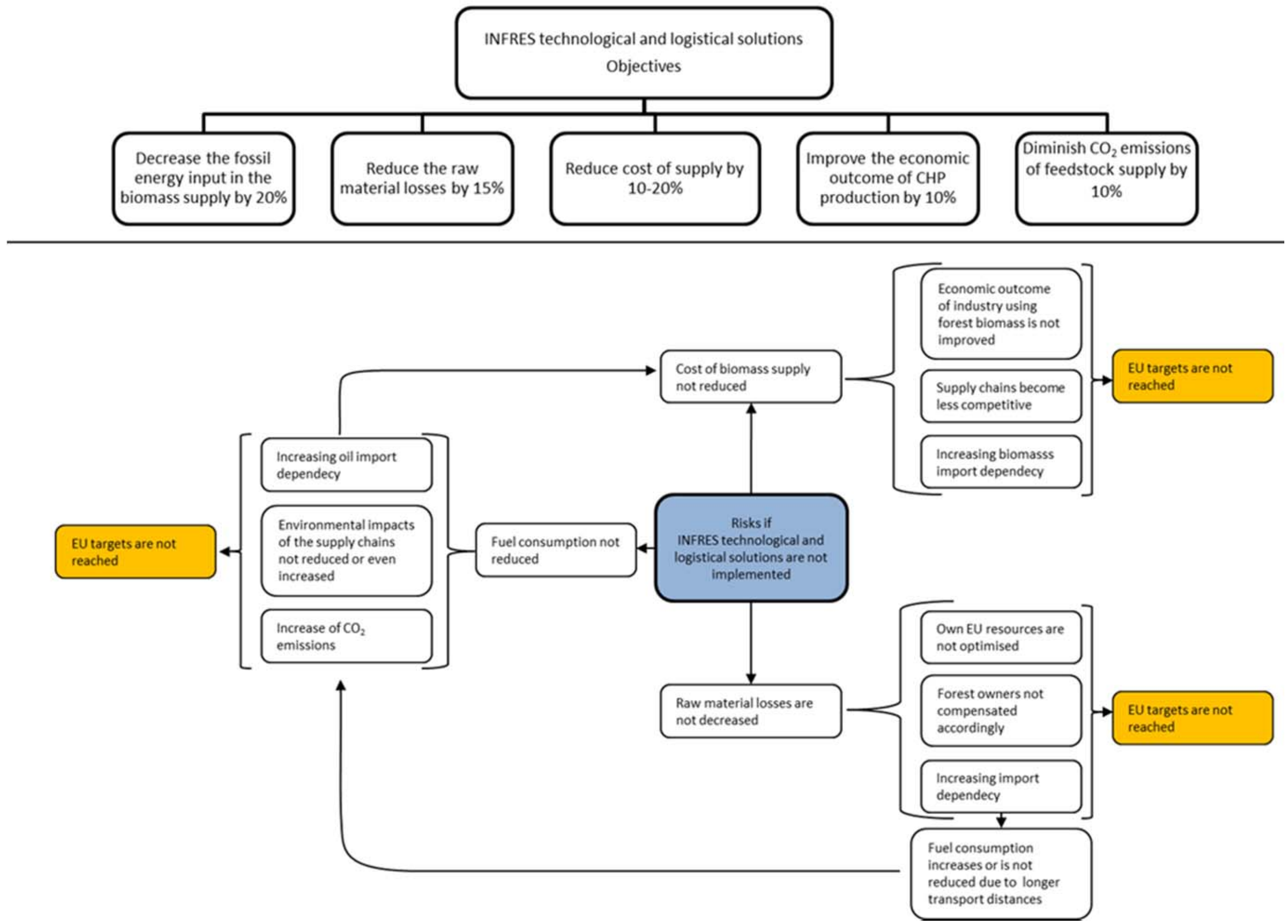

Figure 3: First approach to assessing the potential risks of not putting into practice technological and logistical solutions

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Appendixes

1. Detailed characteristics of the machinery used in the INFRES demonstrations

<table>
<tr><th colspan="3">Demo/Study</th></tr>
<tr><th>N.</th><th>Step</th><th>Element</th></tr>
<tr><td>5</td><td rowspan="3">Harvesting and forwarding</td><td>Harwarder thinning plantations (Spinelli et al., 2013):
- <u>Small harwarder: Vimek Biocombi 610.</u> 6 wheels, 44 kW engine, 4.9 t weight, 5 t load capacity, crane reach of 5.2 m, equipped with an Hypro grapple-saw fitted with accumulating arms, loading bunk with compacting stakes for load-compression
  - Harwarder specifically designed for thinning operations
- <u>Large harwarder: Pfanzelt Felix 206.</u> 4 wheels, 130 kW engine. Extendable load bunk. Complete unit weight 14 t, 10 t load capacity . Crane reach of 8.5 m, quick connection device for time efficient changing of two heads:Logmax 5000 harvester and a timber grapple for roundwood
  - More flexible harwarder for use in different forest operations</td></tr>
<tr><td>6</td><td>Multi-tree felling head(Lópezet al., 2014):
- <u>Felling-bunching head Naarva Grip EH28.</u> Base machine: excavator Caterpillar 308D CR
- Forwarder: 6 wheeled John Deere 1010D Eco III</td></tr>
<tr><td>7</td><td>Prototype of felling head for thinnings(Bergström and Di Fulvio, 2014):
- <u>C16 head</u>: Designed to fell and bunch trees, it can also buck trees. 700 kg, maximum cutting capacity of 270 mm. Equipped with four-jawed grabbing arms and four-jawed accumulating arms. Piled the whole tree sections
- <u>MAMA head</u>: New prototype based in C16, adding feed-rollers, designed to fell, compress-process, and buck small diameter trees from dense early thinnings. 950 kg, with a circular saw-disc, with a maximum cutting capacity of 300 mm. Three feed-rollers (one with a cylindrical shape on the head-plate and two with conical shapes at staggered heights on either side of the head) and a pair of accumulating arms on the top of the head. Piled the roughly delimbed tree sections.
- Harvester Ecolog 560 D, 18.6 t, where both heads where attached.
- Forwarder Ponsse Buffalo: 20 t</td></tr>
<tr><td>2
3</td><td>Chipping</td><td>Chipper truck (Eliasson et al., 2013a;Spinelli and Jessup, 2013):
- <u>Pezzolato Hacker-Truck PTH1200/820</u> on a MAN TGA540 truck
  o Mounted and powered by the truck engine, max output 397 kW
  o Closed drum, 820 mm diameter, 1200 mm width. This drum was specifically designed for processing logging residues (tops and branches).
  o Wood splitter integrated
  o Reduced vehicle width
  o Traction on all 6 wheels
  o Capacity to discharge to front, side and rear
  o Chip moisture content meter
  o On board GPS tracking and CAN-BUS data collection
  o Mesh screen: 170 x 60 mm or 60 x 60 mm
  o Chip cut length: 25 mm</td></tr>
<tr><td>1</td><td rowspan="2">Grinding and screening, ground stumps</td><td>Grinding and sieving (Eliasson et al., 2013b):
- <u>Doppstadt DW 3060 low speed grinder</u>: Grinder "feeder": truck mounted grapple loader
- <u>Doppstadt SM 620 drum sieve:</u> drum with 20 mm mesh size
  o Sieve "feeder": articulated wheel loader</td></tr>
<tr><td>4</td><td>Integrated grinding and screening(Laitila and Nuutinen, 2013):
- <u>Komptech Crambo 6000 low-speed grinder</u>, double-shaft, tandem-axle semitrailer mounted, driven independently and it was powered by a 429 kW CAT C18 six-cylinder diesel engine, 22 t.
  o Towing vehicle: Volvo FM 12; Heavy duty Kesla 2012T cab timber loader; Loader with a five-spike grapple; 40 t including grinder
- <u>Komptech star Screen:</u> integrated (to separate off the fine fractions); 2 screen baskets: 250 x 320 mm; 180 x 180 mm (both require secondary grinding)
Chip container semitrailer loads, 90 m^3</td></tr>
</table>

2. Questionnaire of measures

Table I: Barriers from the supply side (innovations' manufacturers) and measures proposedfor dealing with them. M: Manufacturers of forest machinery/innovations; PM: Policy makers; FC: Forest companies

Barrier	Measure	Who	Value measures according to:		
			Effectiveness (0-5, N/A)	Probability (0-5, N/A)	Relevance (0-5, N/A)
Cost and financing issues	Proper allocation of resources for product development and improvement of the business profitability	M			
	Cooperation with other firms within horizontal structures in industrial districts	M			
	Develop realistic business plan and market prospecting for the innovation	M			
	Ensuring favourable financing instruments (e.g., affordable and secured loans)	PM			
	Company focuses its production in some products from which they could receive increased profit	M			
	Decrease manufacturing costs	M			
	Increase target markets by segmentation	M			
	Other measures: ... (propose)...				
Lack of engineers or capacity	Cooperation with scientists and educational institutes and universities	M			
	Make company more attractive to skilled engineers, move to bigger cities, improve working conditions, etc.	M			
	Cooperation/fusion with other manufacturing companies (automobile, agricultural equipment, etc.)	M			
	Other measures: ... (propose)...				
Lengthy, high-risk process	Strategy evaluation. Risk/Benefit assessment to avoid extremely high risk	M			
	Find out how markets are developing and future trends	M			
	Count on risk capitalists	M			
	Cooperation with customers (forest companies) to ensure product sales, feedback for further development, etc.	M			
	Subsidies or grants to compensate high-risk investments, particularly for small innovative companies	PM			
	Other measures: ... (propose)...				
Testing	Cooperation with scientists and educational institutes and universities	M			
	Cooperation with customers (forest companies) in those regions where equipment is potentially sold	M			
	Other measures: ... (propose)...				
Regulations	Involvement in lobbying organizations in order to facilitate the fulfilment of the standards	M			
	Other measures: ... (propose)...				
Lack of components	Involve component suppliers in the development process of a new innovation	M			
	Other measures: ... (propose)...				
Knowledge leaks (protection)	Search for patents to check that nobody else came up with that idea before	M			
	Keep the innovation secret as long as possible to avoid illegal copies	M			
	Strengthen confidentiality measures	M			
	Other measures: ... (propose)...				

Table II: Barriers that appear during the innovation use phase and measures proposed for dealing with them

Barrier	Measure	Who	Value measures according to:		
			Effectiveness(0-5, N/A)	Probability(0-5, N/A)	Relevance(0-5, N/A)
High operation cost (€/m^3) and low productivity	Train operators to work more efficiently on the specific machine	FC			
	Ensure enough working hours for expensive machines by good planning and management	FC			
	Shared economy idea (cooperatives) in forest companies	FC			
	As a manufacturer, ensure machines are operated in suitable working conditions. New innovations should primarily be operated in conditions where their capacity can be used to the full	M			
	Evaluate if, through small and low-cost changes (e.g., different tracks, addition of another axel or bogie to improve bearing capacity, tire size, air-pressure change in tires, knife-change), the machine can be made suitable for a specific environment	M/FC			
	As a user, choose a machine that is properly adapted to the site (size of trees, topography etc.)	FC			
	Other measures: ... (propose)...				
Lack of flexibility	Test if modifications/ adjustments improve flexibility/adaptation (e.g., different felling head suitable for bigger trees)	M/FC			
	As a manufacturer, ensure innovations are marketed for and used in the right working environments	M			
	Other measures: ... (propose)...				
Competition with existing equipment	Effective marketing focusing on Unique Selling Point and advantages of new innovations	M			
	Demonstration actions to show and promote equipment	M			
	Good service deal	M			
	Other measures: ... (propose)...				
High investment cost	Solid funding agencies for loans	FC			
	Long term contracts that could ensure realistic prospects for profitable business	FC			
	Collaboration with key stakeholders to ensure smooth supply chains, subsidies and investment grants for new and strategic openings	M			
	Shared economy idea (cooperatives) in forest companies	FC			
	Other measures: ... (propose)...				
Maintenance issues	Ensure a reliable service network	M			
	Collaborate with existing dealers and service networks	M			
	Expert help provided by the manufacturer	M			
	Shared economy idea in forest companies	FC			
	Buy a machine with documented fewermaintenance needs	FC			
	Other measures: ... (propose)...				

Table II: Barriers that appear during the innovation use phase and measures proposed for dealing with them (cont.)

Marketing	Country and user specific marketing and demonstrations to the most probable users (A proper market study should be done before innovations are created to make sure there is enough potential for intended new products)	M			
	Contact with contractors and forest companies	M			
	Other measures: ... (propose)...				
Existing logistic chains do not favour the innovation	Team up with other firms which have innovations in other points of the logistic chain which in sum favour a new logistic chain (enterprise networking within vertical structures)	M			
	Develop and adapt supply chains where new innovations fit (One should carefully considerd beforehand how new innovations might fit the existing supply chains or otherwise optional supply chains –some innovations- should be introduced altogether)	M			
	Find start-up-firms which are willing to use other logistic chains, advertise other logistic chains	M			
	Demonstrate that the innovation is better than existing systems	M			
	Other measures: ... (propose)...				
Complicated logistics	Simplify processes	M			
	Develop logistic management systems	M			
	Other measures: ... (propose)...				

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