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Future of forest energy in Europe in 2030

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Abstract

The need to increase the use of forest energy is connected to the EU goals for use of renewable energy. If the targets are to be reached, forest energy should play a role. The share of forest energy out of all renewable energy will vary between countries.

This study focuses on the future of forest energy. The method chosen was a two-round dissensus-based Delphi. The respondents consisted of members of the COST action FP 0902 and in the second round also of members of the RoK-FOR programme. Most of the respondents were experts in the field of forestry, from more than 20 countries.

The first section of the survey addressed the issue of trends and operational environment. The respondents assessed the likelihood and desirability of several trends happening by 2030. They also, for example, estimated the increase in use of forest energy and the constraints to its use. There seemed to be a strong belief in technological development and beneficial policy interventions, but the respondents also recognised the problematic competitive situation in relation to other sources of energy.

In terms of technological development, the experts saw that the main challenge to address is transport and logistics. This included a wide range of different issues, such as the handling of bulky, low-value product in an efficient way. The experts saw greatest development potential in improving energy density before transport, and multi-tree handling. Driver-assisting systems would be particularly useful in helping with the planning of felling, e.g. in the case of placing of tracks.

Labour shortages are also a pertinent issue. The respondents gave many suggestions on ways to attract new workers to forestry, for example by increasing the salary to the level of manufacturing industry, and by promoting forestry as an environmentally friendly and technologically advanced employer.

Overall, this report describes some alternative future prospects, which could be achieved by decisive action. Hopefully this report provides insights for bioenergy sector and policy-makers and offers pathways to increasing the use of forest energy in Europe to the target level.

Keywords
forest energy, futures research, technological development, trends, labour

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Table of contents

1. Introduction

In order to reduce greenhouse gas emissions, the Council of Europe has accepted the proposal of the European Commission that EU countries should produce 20 percent of their energy by using renewable sources, including bioenergy, by 2020. Each member state has their own target, for example, Finland should produce 38 percent and Sweden 49 percent of their energy from renewable sources by 2020. (Commission of the European Communities 2008) The mix of renewable energy sources can vary by country.

Forest energy is one potential source of renewable energy, and could be particularly significant in countries such as Sweden, Estonia, Lithuania, Poland, and Finland, where wood currently forms a large part of the total renewable energy use (Mantau et al. 2010). The use of forest energy also offers possibilities for productive use of by-products of other forestry operations. Recent studies indicate that by 2020 EU's forests could annually supply approximately 200-400 million m^3 woody biomass for energy (Asikainen et al. 2008, Verkerk et al. 2011).

Forest energy is a topic that has been studied quite extensively and also the future prospects of forest energy have been analysed. In order to reach the targets set for the use of forest energy, the technological and logistical constraints and development needs have to be identified. This study analysed the future possibilities and challenges of forest energy by using the Delphi method with a group of forest and energy sector experts. The target year of this study is 2030, which was also used in Mantau et al. (2010). The time up to 2030 is long enough for significant changes to occur, but close enough for experts to have insights into what might happen.

This working paper first outlines the results of some key prior studies on the future of forest energy. The next section consists of methodology and data, with a particular focus on the core aspects of Delphi method. The study was split into three themes: trends related to forest energy, technological development of forest energy harvesting machinery, and associated labour issues. The working paper finishes with discussion and conclusions about what these findings mean for the forest energy industry and related research.

2. Background

2.1. A brief overview of studies and policy documents on forest energy

Use of forest biomass for energy production is one solution to increase the share of renewable energy in the EU's energy mix. Forest energy and the possibilities to promote its use have been studied from a variety of perspectives. Stupak et al. (2007) made an extensive literature review of European research, policy documents, certification guidelines and other documents pertaining to sustainable forest bioenergy production. They, for example, set out various European guidelines for sustainable silviculture, and PEFC standards for different countries. The focus is more on forestry than on forest bioenergy, but the article does provide a good starting point for exploring the issue of forest energy.

On European level, there have been several outlook studies on the use of forest energy such as European forest sector outlook study (2005) by United Nations. There the developments of the entire forest sector were covered. The statistics based projections showed a decline in forest energy use in Europe. However, the study evaluated that the renewable energy policies and associated support measures could increase the demand of forest biomass in the energy sector. More recently Mantau et al. (2010) published an extensive report, with a stronger focus on the point of view of forest energy. It covers the entire forest industry, but devotes more attention to forest energy than for example United Nations (2005). Mantau et al. (2010) estimated the wood resource balance up to 2030 on the basis of three alternative mobilisation scenarios. They argue that the market shares of energy uses of wood will increase by 2030, and that meeting the demand scenarios would require increases in the mobilisation of wood. They state that the most important driver for energy use of wood would be the EU Directive on the promotion of the use of energy from renewable sources.

At present, wood accounted on average for a little more than 50 percent of the gross inland energy consumption from renewable sources in the EU. This share is particularly high in Estonia, Lithuania, Poland, and Finland. Mantau et al. (2010) estimate that demand will increase, especially for biomass power plants, but that the increase might be slower if, for example, energy efficiency measures are implemented successfully. In any case, there is a need for plenty of new workers in the forestry sector, even in the low mobilisation scenario, in order to meet the demand for wood.

There have also been similar studies in Finland. For example, Kärhä et al. (2010) analysed the availability and use of solid wood fuels in 2020 for the Ministry of employment and the economy. The focus of the study was on forest converted chips. They first defined the theoretical sourcing potential in different scenarios, and modified this on the basis of technical use potential. They also took into account ecological and economic aspects. The price of emission rights had, in these projections, a strong impact on the competitiveness of wood-based fuels, and on the supply and use of these fuels. According to them, increasing the use of wood-based fuels would require a price of around 25 €/ t CO2 for emission rights. Thus, their opinion on increasing the use of wood-based fuels seems somewhat pessimistic.

2.2. Previous studies on the future of forest energy

The future of forestry and forest energy has also been studied extensively. Interesting examples on the industry level include Meristö et al. (2000) and Hietanen (2010). Meristö et al. (2000) reports alternative scenarios created for the forest industry. Their scenarios utilised background scenarios from other studies, which created an underlying structure for future possibilities. Interestingly, they did not fix the timeline to particular years, but rather used fixed points (e.g. events), which would guide the path of a specific scenario to the future.

Hietanen (2010) reports the results of a ‘Future of forestry in Finland’ process. This was a wide-ranging project, which extended to industries only slightly connected with forestry, (‘photosynthesis industry’, according to their term) such as waste management and logistics. The focus of the project was on exploring alternative future possibilities, and on creating innovative ideas for the forest industry of the future. They strongly highlight the fact that achieving any of these alternative futures will require work. Both Hietanen (2010) and Meristö et al. (2000) provide interesting insights into previous efforts of Finnish forest industry to map and create future possibilities.

Laitila et al. (2010) is a more focused study, which analyses the challenges, and development needs of sourcing and logistics of forest chips[1]. The target year is 2020, and the study covers for example the use of forest chips by different actors and the harvesting potential for energy purposes. The background to the study lies with the policy goals to increase the use of forest chips in Finland from 6 TWh to 25 TWh by 2020. In terms of methodology, they used various projections, as well as a survey to determine development needs. The use of forest chips was projected to increase particularly in large combined heat and power plants and possibly even through combined use with coal or in biorefineries. One area, which stood out in terms of development needs, is thinning stands, particularly in terms of harvesting costs. The development needs influenced the structure of our survey to an extent. Laitila et al. (2010) state

[1] Forest chips are chips made of primary forest biomass such as logging residues, stumps and small diameter trees from early thinnings.

that the goal of 25 TWh primary energy for forest chips by 2020 can be reached, but this requires consideration of forest chips as a fuel alternative in all large-scale generating plant projects. The harvesting potential is much greater than 25 TWh. However, there would be a need for much greater transport fleet and number of workers (based on calculations in Kärhä et al. 2009) in order to supply the required amount of forest energy.

Delphi approach has also been applied in the forest industry. Pätäri (2010) focused on pulp and paper industry and converting forest biomass into bioenergy in Finland, while Nuutinen et al. (2009) studied Finnish sawmills. Both of these used a variant of dissensus-based Delphi. In Pätäri (2010), this consisted of three rounds and was done online, and was supplemented with four themed expert interviews. In Nuutinen et al. (2009) the first stage of Delphi was completed by in-depth interviews of experts, the data were then processed into scenarios, which were discussed and modified at a workshop.

Pätäri (2010) offers information on e.g. perceptions of bioenergy, and areas of bioenergy production with the greatest potential. An interesting argument arising in this study is that financial and environmental benefits might not always be achieved at the same time. However, the commercialisation of bioproducts is perceived feasible. Nuutinen et al. (2009) focused on creating scenarios to stimulate conversation and ideas for the development of the Finnish sawmilling industry. One of the scenarios included a focus on the production of forest energy, and in this scenario the sawmills would be self-sufficient in terms of energy. They also state that product development in sawmilling tends to take 10-20 years, and thus the future is strongly influenced by the current product selection. Nevertheless, it is important to remember that the scenarios are not predictions or mutually exclusive, but rather tools for understanding future possibilities.

2.3. Previous studies at the Finnish Forest Research Institute and links with COST action FP 0902

This research project was closely connected with the COST action FP 0902, ‘Development and harmonization of new operational research and assessment procedures for sustainable forest biomass supply’. This action includes international cooperation on a variety of issues related to forest energy. While other parts of the COST action did not explicitly address the issue of future developments, future prospects were deemed a relevant concern that should be addressed. Thus, this project will contribute to development of forest energy in Europe through a foresight approach. The participants of the COST action FP 0902 also formed an excellent expert panel for the Delphi study.

Two prior studies completed at the Finnish Forest Research Institute acted as starting points to this study. Asikainen et al. (2005) presents a vision and roadmap for forest technology up to 2020. It is based on expert interviews and answers questions such as what kind of development is seen as the most potential or the most necessary and what would be the most pressing needs for product development. One of the interesting views was that the importance of forest technology sector in Finland would increase in comparison to e.g. the ICT sector. Thus, forest technology was seen as a sector with significant development potential. Asikainen et al. (2009) updated this roadmap and focused more on harvesting and forestry machines. It assessed the current situation in different markets, potential in different markets, and development needs of forestry machines. In this study as well it was stated that the Finnish forest machinery sector is one of the strongest in the world, and it will probably stand at the forefront of technological development. Among other things, this study aimed to chart the most potential development areas.

The Finnish Forest Research Institute has also studied the future of man-machine interfaces used in forestry machines (Väätäinen et al. 2012, Ylimäki et al. 2012). Väätäinen et al. (2012) provides an overview of driver-assisting systems currently in use, their advantages and disadvantages, their development potential, and current use in other industries, as well as in forestry. Ylimäki et al. (2012) was a quantitative survey study for operators of forestry machines, harvesting entrepreneurs, and lectures and students of schools offering education in operating forestry machines. In this study, we adapted the parts of their questionnaire, which address the issue of driver-assisting systems. Interestingly, the requirements for driver-assisting systems in Ylimäki et al. (2012) were much more practical than those resulting from this study, and there were also differences in perceived needs for driver-assisting systems. These will be discussed in more detail in section 7.

3. Methodology and data

3.1. Futures studies – theory and methods

This study is based on the theoretical tradition of futures studies and used methods specific to futures studies. In order to give a general understanding of futures studies, this section starts with an overview of theory and methods of futures studies. For those interested in reading more about futures studies, good starting points are Kamppinen et al. (2003a) and Bell (2003, 2004).

Futures studies is a relatively new discipline, and modern futures studies is thought to have started around the time of the Second World War. One possible origin is in the work of Kondratiev in the early 20th century. He analysed large masses of economic data and discovered the existence of long waves in the economy. He discovered that the economy tends to move in cycles of approximately 50 years, which is obviously interesting when looking at possible future developments. The origins of futures studies are also connected with operations research, which led to the foundation of the RAND Corporation in the US. The RAND Corporation for example developed the Delphi method, and other research organisations emerged from contact with RAND. (Söderlund and Kuusi 2003).

In brief, the development of theory in futures studies can be described as two major shifts. The first is the move from prediction to the concept of possible worlds, and the second the shift from large-scale societal planning to studies focusing on specific actors. (Söderlund and Kuusi 2003) The shift to the concept of possible worlds is particularly significant in that it removes the illusion that the future exists independently of the present. The basic premise of the concept of possible worlds is that several paths lead from the present to the future, and they can result in different possible worlds. The possible worlds can result from the actions of a particular entity, or occur in spite of these. (Kamppinen et al. 2003b)

Other concepts closely connected with possible worlds are scenarios and forecasts of different orders. Scenarios are one of the most widely recognised concepts of futures studies, and can be defined as ‘hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points’ (Kahn and Wiener, quoted in Söderlund and Kuusi 2003). Scenarios are often used to highlight those actions, which can lead to a particular possible world. The concept of forecasts of different order was introduced by de Jouvenel. First-order forecasts describe the future, as it would occur if no one or nothing intervened in it. Second-order forecasts would occur if an actor chose to direct actions towards it. A third-order forecast describes a future, which is plausible if certain actors behave in a way that is expected of them. (Söderlund and Kuusi 2003). This concept also emphasizes the importance of actions by key actors in fulfilling a certain future.

The key aspects of the theory of futures studies also include uncertainty and values. Uncertainty and risk are inherent features of futures studies, as it is impossible to have absolutely certain information about the future. The different aspects of risks and probability have been discussed for example by Kamppinen and Malaska (2003). Uncertainty is also connected with trends, megatrends, and weak signals. The first two of these tend to represent things that will probably take place in the future, while the impact and likelihood of occurrence are more uncertain for weak signals (Kamppinen et al. 2003b).

Values also tend to play an important role in futures studies, particularly because the future is made, it does not just emerge (Kamppinen et al. 2003b). Futures studies often uses a normative approach and seeks ways to reach preferable futures, although often these are preferable for a particular community, not the researcher. Seeking ways of reaching the 'best' possible future is a key part of futures studies, but it is important to recognise the absence of value-neutrality.

Futures studies includes a wide-range of methods. Futures studies is characterised by multidisciplinarity, which has also contributed to the wealth of methods. Some methods, such as Delphi surveys, have been developed particularly for futures studies, while others, such as trend extrapolation, use for example mathematical methods first pioneered in other disciplines. Other methods include for example collection and analysis of weak signals (see e.g. Hiltunen 2010), futures workshops, and soft systems methodology developed by Checkland (description in Rubin 2003). Scenario building, Delphi studies, and trend extrapolation tend to be the most commonly used methods, but others, such as collecting weak signals, have gained in popularity.

In sum, futures studies provides a good background for this study. As the theoretical foundations of futures studies show, the future is uncertain and there are numerous possible worlds, and the outcome depends on the course of action taken. Thus, the results of this study only provide indications of possibly relevant factors and possible outcomes, not a prediction about what will actually happen in the future.

3.2. Methodology – Delphi method as a tool for exploring the future

The method used in this study, the Delphi, is one of the most commonly used methods of futures studies. The Delphi method was developed in the 1950s in the RAND Corporation in the US. To start with, it was designed to get a shared opinion of a group of experts. It is particularly useful when the topic of study is complex and laypeople would have very little to say about the issue, which is the case with forest bioenergy.

The key aspects of Delphi are generally recognised to be anonymity, iteration, and feedback. Anonymity signifies that it is impossible to trace a single statement or opinion back to a specific expert. However, for motivational purposes it can be useful to let the participants know, at least in general terms, who the other experts are. This assures them that the other participants are also knowledgeable about the issue at hand. The meaning of iteration in Delphi is that there is more than one round of the survey. Thus, the respondents are able to review and modify their opinions in the light of those of others. Feedback is closely connected with iteration, in that the respondents receive feedback on answers of others and can see how they compare with others. (Kuusi 2003). Combined, these should enable the creation of a group opinion, without the negative features of group interaction, such as the dominant role of some group participants.

While the Delphi method was originally used to seek consensus, an alternative approach, labelled Policy Delphi, was introduced reasonably soon by Turoff (1975). In this approach, the process is based on dissensus rather than consensus. The aim is to seek all possibly relevant factors, and gain qualitative information on why these would be important in the future. Kuusi (1999) also emphasises the search for valid and relevant arguments as one of the goals of Delphi. However, his approach, Argument Delphi, is more strongly structured around a process of argumentation and debate, and in the several rounds some experts defend standpoints on particular issues, while others offer counterarguments.

Many recent Delphi studies have used some version of dissensus-based Delphi, which is also used in this study. These have in common the focus on finding the relevant and interesting arguments pertaining to the future, and thus consensus is not a priority. Examples of these types of studies include Pätäri (2010) and Nuutinen et al. (2009) discussed in section 2.2., and Steinert (2009). Steinert (2009) analysed the non-adoption of mobile data services with a qualitative online survey. In the first round, they collected relevant factors from experts, and in the second asked them to process them further. Interestingly, they found out that enabling communication between experts during the survey would be useful, and also in this study it might have offered new insights. The approaches used by Pätäri (2010) and Nuutinen et al. (2009) were similar.

In this study, we used a two-round dissensus-based Delphi. The surveys can be found in appendixes 1 and 2. The data were collected online through the Webropol service. Each participant was sent a personalised link to the survey by email, and those who did not respond were reminded about the survey by email twice in both rounds. Due to the length of the survey, the respondents were given the option to save their answers and return to complete the survey at another time.

The survey design, in terms of topics to cover, utilised previous studies completed at the Finnish Forest Research Institute and elsewhere. They included Asikainen et al. (2005), Asikainen et al. (2009), and the survey used by Ylimäki et al. (2012). On the basis of these resources and other prior research, we decided to focus on trends, technological development, and labour issues. The content and form of the surveys was discussed by the researchers and others at the Finnish Forest Research Institute. The usability of the survey and the clarity of the questions were also reviewed before sending it to participants.

In the Delphi method, the selection of the expert panel is very important. It should consist of experts who have good knowledge of the issue at hand, and who are able to give valid arguments in support of their statements. As Kuusi (2003) states, in Delphi the quality of the experts, rather than their quantity, is of paramount importance. In this study, the expert pool consisted of those people listed on the COST FP 0902, ‘Development and harmonization of new operational research and assessment procedures for sustainable forest biomass supply’ mailing list. They range from students to very experienced experts on forest energy issues. In the second round, the pool of experts was supplemented with the RoK-FOR (Regions of Knowledge for Forestry) programme mailing list. This resulted in a larger, but equally competent, pool of experts.

The online tool gave respondents anonymity. However, they were told in the invitation that the other participants were also involved in the COST action FP 0902 and in the second round in the RoK-FOR programme. Iteration and feedback aspects were solved by incorporating some of the results from the first round in the second round survey, and by indicating which of the statements arose from the first round. Thus, the experts were able to give their opinion on insights raised by other experts. The surveys were also designed so that the second round provided more in-depth information on issues that were only touched on in the first round. Those issues, which were covered well enough in the first round, were left out of the second round in order to keep the length of the survey at a more manageable level. Due to this, in the first round there was more emphasis on trends, and in the second round the focus shifted more towards technological development and labour issues.

The data collected were analysed with both quantitative and qualitative tools. If the questions were structured and allowed quantitative analysis, basic statistical tools such as frequencies and cross-tabulation were used. For open-ended questions, the analysis was mainly qualitative. Generally, the variables were grouped together thematically and the most common themes were listed. However, sometimes the interesting answers were unique, and in these cases the replies are used as they are to highlight particular issues. This is one of the benefits of using a dissensus-based Delphi, because in a consensus-based Delphi these would probably merge with other statements.

3.3. Data

As stated above, the data were collected in two rounds. Table 1 shows details of data collection for both rounds. The number of invitations sent is greater in round two. Both of the surveys were rather long, and because of this, the response rate can be taken as sufficient. The quality of the data was very good, for example, the answers to open-ended questions tended to be detailed and relevant. Interestingly, many respondents specified if they did not feel qualified to answer a particular question, which might signify that those who answered them had sufficient knowledge. The high quality of answers means that the somewhat low response rate is not too problematic. In terms of the Delphi method, it is good that 27 of the respondents participated in both rounds of the survey. One of the main advantages of Delphi is that it allows the participants to modify their answers and to think about the contributions of others, and thus it is useful to have the input of people in both rounds.

Table 1 Data - invitations sent and responses received

	Round 1	Round 2
Time of data collection	June-July 2011	October-November 2011
Invitations sent		
- COST mailing list	172	172
- RoK-FOR mailing list	0	47
- Total	172	219
Responses		
- Only one round	20	17
- Both rounds	27	27
- Total	47	44
Response rate (%)	28	20

In both rounds, the majority of the respondents were researchers. In the first round the share of researchers was 66 percent, and in the second 70.5 percent. In the second round, more respondents chose the alternative ‘expert’, while in the first round there were more PhD students among the respondents. A clear majority of respondents in both rounds worked in the field of forestry (85 percent first round, 84 percent second round). Only a couple of respondents worked in the fields of energy or environment. Most respondents were in the age group 31-50, and thus can be expected to have years of experience in their field of expertise. The distribution of countries in which the participants currently live is shown in figure 1. The respondents in first round lived in 26 different countries and in the second round in 22. The greatest numbers came from Finland, Sweden, and Italy. These distributions show that the experts were well chosen and represent most of Europe. They are very likely to have extensive information on forest energy and insights into its possible future.

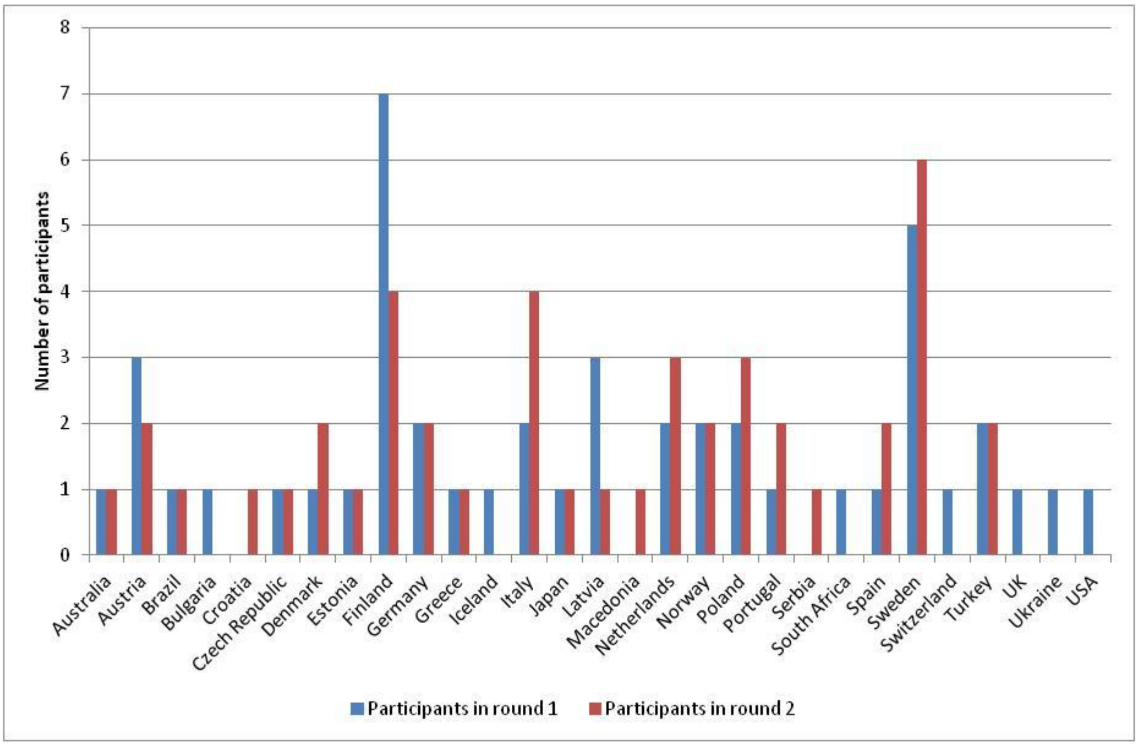

Figure 1 Countries in which the participants currently work, number of participants.

4. Trends and operational environment

4.1. Likelihood and desirability of trends

The first section of the Delphi survey covered trends affecting the use of forest energy in Europe up to 2030. In both rounds, the respondents were first asked to assess the likelihood and desirability of certain on-going trends occurring by 2030, and were also requested to list other trends, which might affect the future of forest energy. In the second round, some of these trends introduced by the respondents replaced trends listed by researchers in first round.

The trends assessed in the first round are listed in table 2. It also shows the mode and mean values for the likelihood and desirability of these trends and standard deviations for the means.

Table 2 Likelihood and desirability of trends, round one. (5= very likely/ desirable,..., 1= very unlikely/ undesirable) Includes standard deviation.

Trend	Likelihood			Desirability		
	Mode	Mean	Stand. dev	Mode	Mean	Stand. dev
Energy and climate policy will support the use of renewable energy, including forest biomass.	**5**	4.34	1.01	**5**	4.34	0.96
Energy use per person will continue to increase.	4	3.72	1.12	**1**	1.91	1.30
Increasing criticism of land use changes and of increased use of land for energy biomass production reduce the use of bioenergy.	**2**	2.85	1.18	**2**	2.40	1.26
Forests will be used for carbon capture and storage.	3	3.66	1.13	3	3.53	1.33
Efficient subsidies will be in place to support the use of forest biomass for energy production.	4	3.09	1.25	**5**	3.62	1.38
There will be a marked shift from traditional wood processing industry to energy industry in terms of wood consumption.	4	3.28	1.28	3	2.87	1.08
The use of recycled products and of recycled fibre will continue to increase in forestry industry.	4	4.11	0.98	4	4.23	0.87
Harvesting of wood will be increasingly mechanised.	**5**	4.32	1.13	**5**	4.11	1.03
Energy value of paper will affect on the price of paper more.	3	3.38	1.07	3	3.02	0.97
Forest sector entrepreneurs will be in charge of harvesting and forestry work also in the future.	4	4.04	1.06	4	3.62	1.03
The harvesting companies will operate internationally.	4	3.36	1.28	3	3.15	1.06
The importance of planted forests for energy production will increase.	4	3.68	1.16	4	3.81	0.97

As can be seen from table 2, most of the trends were deemed at least somewhat likely to take place. Those thought to be the most likely were ‘Energy and climate policy will support the use of renewable energy, including forest biomass’, and ‘Harvesting of wood will be increasingly mechanised’, which both received the mode rating of being very likely to take place. The only exception is the trend ‘Increasing criticism of land use changes and of increased use of land for energy biomass production reduce the use of bioenergy’, which had the mode of somewhat unlikely.

The picture is a little more diverse when assessing the desirability of the trends. As table 2 shows, three trends ‘Energy and climate policy will support the use of renewable energy, including forest biomass’, ‘Efficient subsidies will be in place to support the use of forest biomass for energy production’, and ‘Harvesting of wood will be increasingly mechanised’ received the mode of very desirable. By contrast, ‘Energy use per person will continue to increase’ was rated very undesirable, and ‘Increasing criticism of land use changes and of increased use of land for energy biomass production reduce the use of bioenergy' somewhat undesirable.

Table 3 shows the trends assessed in the second round. Those marked in bold were also included in the first round. The other trends were introduced by the respondents during the first round.

Table 3 Likelihood and desirability of trends, round two. (5= very likely/ desirable,..., 1= very unlikely/ undesirable) Includes standard deviation.

Trend	Likelihood			Desirability		
	Mode	Mean	Stand. dev	Mode	Mean	Stand. dev
Energy use per person will continue to increase	4	4.02	0.93	**2**	2.52	1.42
Energy and climate policy will support the use of renewable energy, including forest biomass.	**5**	4.36	0.78	**5**	4.36	0.89
Other renewable energy forms (e.g. solar, wind, and hydropower) will be more prominent than bioenergy.	4	3.59	0.92	3	3.73	0.85
Technology converting biomass to energy will be considerably more efficient than today.	**5**	4.30	0.90	**5**	4.64	0.69
Productivity per hectare in silviculture and agriculture will increase significantly because of advances in tree breeding, more intensive forestry management and genetic modification.	4	3.39	0.95	4	3.95	0.81
Nature protection programmes and/or forest certification limit felling of wood for energy use.	4	3.84	0.78	**2**	2.91	1.22
Ecological concerns, for example about fertility depletion, will limit the use of bioenergy.	4	3.66	0.96	4	3.16	1.06
Management of biodiversity and ecosystem services will be integrated with forest energy production.	4	3.82	0.97	4	4.20	0.80
Harvesting of wood will be increasingly mechanized.	**5**	4.26	0.90	4	4.09	0.78
There will be increasing tensions between energy industry and wood and paper industry caused by limited availability of wood.	4	3.98	0.87	**2**	2.36	1.14
Timber construction will become more prominent, and thus there will be less wood available for energy use.	3	2.98	0.87	3	3.09	0.97
Increasing criticism of changes in land use and of increased use of land for energy biomass production reduce the use of bioenergy.	3	2.98	0.95	**2**	2.32	0.96
Land use will shift from bioenergy crops to growing food.	**2**	2.73	0.95	3	2.95	1.03

The use of recycled products and of recycled fibre will continue to increase in forestry industry.	4	4.00	0.86	4	4.11	0.87

In the second round, the results for the likelihood of taking place were very similar to those in the first round. As table 3 shows, most trends were thought to be at least somewhat likely to take place. The most likely trends included the same ones as in the first round, and in addition the trend ‘Technology converting biomass to energy will be considerably more efficient than today’ was deemed very likely to take place. On the negative end of the spectrum, only ‘Land use will shift from bioenergy crops to growing food’ was thought to be somewhat unlikely.

The results for desirability were again quite similar in the second round. The results are shown in table 3, and it shows that several trends were rated very desirable. There were also several trends where the mode of desirability was ‘somewhat undesirable’. It is interesting that overall the trends received many more ratings as very undesirable than as very unlikely. This could be because we deliberately chose trends which are happening at least to some extent, while their outcomes might not be positive for the forest energy industry.

In sum, it appears that the respondents have quite strong beliefs in technological development. They think that by 2030 harvesting will be increasingly mechanised, and that there will be more efficient technology for converting biomass to energy. However, they also seem to find it quite probable that energy use per person will continue to increase. This could be addressed by political means, but if left unchecked this undesirable outcome might occur.

4.2. Other trends

The respondents were also asked if there were other trends, which might influence the use of forest energy in the future. In the first round 14 and in the second 13 respondents answered this question. Nine of the trends described in round one were included in the structured question on likelihood and desirability in round two.

The trends introduced in the first round fall under six broad headings. Most trends fall under the theme ‘conservation and biodiversity’, for example the trend ‘Unpredictable impact of certification organisations (FSC etc)’ (Sweden, 50[2]). The other themes are ‘competing forms of energy’, ‘other uses of wood’, ‘global warming’, ‘(bio)technology development’, and ‘other land uses’. Thus, the trends introduced by the respondents complemented the trends chosen by researchers by creating a wider range of possible future outcomes. As a result, the trend selection used in the second round was wider than in the first round.

Interestingly, also in the second round many respondents added other trends, which indicates that even the wider selection did not exhaust all the alternative trends for the use of forest energy. The trends in this section can be grouped into categories ‘technology’, ‘changes in energy production’, ‘factors limiting the use of forest-based bioenergy’, ‘competition between branches of forestry’, ‘recycling and environmental issues’, ‘integration’, and ‘combined effects of different trends’. The trends described in round two are thus quite similar to those introduced by the respondents in round one.

Some particularly interesting trends outlined in round two were ‘More focus on re-use and proper recycling of nutrients (from combustion ash, sludge etc), reducing the nutrients lost in food and energy feedstock production and increasing efficient use of nutrients. E.g. mineral phosphorous reserves are limited and pollution of the environment should be decreased.’ (Denmark, 45), and ‘European law’ (Poland, 47). The issue of re-using and recycling nutrients

[2] All quotes from respondents are marked with the country of residence and age.

would present an interesting way towards even more environmentally sound bioeconomy, while the constraints European law might introduce to use of bioenergy can be considerable.

Overall, it appears there are a great variety of trends at play in the field of forest energy. It is still unclear which of them will come true, but the expert estimates of their likelihood provide some indication of future possibilities. However, it is important to remember that the future is affected by our actions, and thus the right decisions can make the most desirable trends come true.

4.3. Limits to use of forest energy and addressing these

In round one, the experts were asked to assess the relevance of seven factors and actors which might limit the use of forest bioenergy in their country in 2030. They could also add other limits to its use to the list. In round two, they were asked to think of ways to counteract the four most important of these limits and two limits added by experts in the first round.

When the importance of limits to use of forest bioenergy was assessed, the issue that stands out the most is the price competitiveness of forest energy. It is followed by weak competitiveness against other energy sources, and attitudes of forest owners, and then by the availability of forest energy for users and the availability of technology. The importance of competitiveness in comparison to other sources of forest energy would suggest that there is a need for both policy action and for technological development in the forest energy industry. There are some regional differences in terms of the perceived limits to the use of forest bioenergy. While price competitiveness generally received the highest rankings, in Western Europe weak competitiveness against other energy sources was deemed the most important limiting factor, while in Eastern Europe attitudes of forest owners were the most important.

The experts who stated that the attitudes of the public or environmental issues and organisations were limiting factors also rated these as the most important limits. Other new issues raised were restrictions to forest use, environmental and other legislation, government policy, low electricity price, oil industry, and subvention by forest law for the forest villagers. Thus, it would seem that environmental issues and attitudes related to environment are important, particularly in Sweden, which was the place of residence for most of the respondents who raised these issues.

In round two, the experts gave a wide range of solutions for addressing these limits. In the case of price competitiveness, the most important limit in the first round, the most often introduced ideas were connected to fiscal policy. This included changes in taxes on fossil fuels, stopping subsidies on fossil fuels, continuing to subsidise the production of forest energy, and incorporating the externalities of energy production in energy price. Other solutions included developing supply of forest energy or technology for it. Some respondents also thought that there would be no need for action because the market would take care of this.

It is interesting that many experts did not perceive weak competitiveness against other energy sources as a problem either now or in the future. This is in contrast with the results of the first round, and might be caused by differences in the pool of respondents. The ways to address this issue consisted of dealing with the skewed market rules and subsidies, working on technology development, and using the best renewable option in each situation. There are strong similarities with these and the means of addressing the problem of price competitiveness.

The attitudes of forest owners towards forest energy were also not perceived problematic in many cases. The main ways to change the attitudes to being more positive towards forest energy were ensuring the right price was paid, and providing information and education about forest energy to forest owners. An interesting, somewhat different suggestion was to address this by ‘More friendly forest service companies, development of long-running forest management services (Latvia, 38)'. This might be an effective tool to create closer cooperation between forestry companies and forest owners.

The availability of forest energy was not a very big problem, according to many experts. The means to improve availability included increasing productivity, investing in technologies to improve price competitiveness, and improving the distribution channels and availability of information.

In the first round, some experts thought that restrictions on the use of forest energy on environmental grounds could be an important factor limiting the use of forest energy. In the second round, the consensus of the experts was that sustainability is an important value which needs to be achieved, and as a result, restrictions on use of forest energy are sometimes necessary. The suggestions on how to stop the restrictions from being too strong were research, guidelines, certification, legislation, management, and use of non-cultivated agricultural land for energy production. Environmental values are one advantage forest bioenergy can have over fossil fuels, and thus finding the right balance between using forest biomass and ensuring sustainability of operations is an important issue.

In general, the experts in this round perceived the attitudes of general public towards forest energy to be positive or neutral, not problematic. The suggestions to turn these attitudes even more positive revolved around providing more information to the public, promoting sustainability, and using positive PR. More unique solutions were 'Reliable supply, reliable and relevant regulations and restrictions (Norway, 32)', and 'More public appearance, equal distribution of forest management related goods (local communities should benefit) (Latvia, 38)'. The last suggestion in particular is interesting; in the sense that local communities, which are significantly affected by forest energy operations, should probably gain some benefits.

4.4. Use, sources, production, and customers of forest energy in 2030

In the first round, the respondents were also asked to estimate the situation in their country in 2030 in terms of use of forest bioenergy, and its sources, production, and customers. The data from the first round were sufficiently detailed to allow us to leave these questions out from the second round.

There was fairly uniform consensus among the experts that the use of forest biomass for energy will increase in Europe by 2030, when compared with the current situation. 95.7 percent of the respondents were of this opinion. There was more diversity in terms of the estimated percentage changes. The estimated percentage increases range from 200 percent to nothing. The mean estimate is 49 percent, while the mode is 20 percent. The disparity is caused by a couple of very high estimates which skew the mean upwards. One respondent estimated the growth in Finland to be significantly faster than in rest of Europe, and another stated that it would be better to look at the entire energy portfolio, and to focus more on other renewable sources of energy, for example solar power.

The survey also charted what the respondents thought would happen to harvesting of industrial roundwood and energy wood in their countries by 2030. They estimated that the harvesting of energy wood will increase more than is the case for industrial roundwood. The estimates for harvesting of industrial roundwood range from a decrease of five percent to an increase of 500 percent. The mean is 23.6 percent, while the mode is 0. For harvesting of energy wood, the range is from 0 to 1000 percent, with a mean of 89.4 and a mode of 10 percent.

When the respondents were asked to estimate the shares of different types of bioenergy out of all bioenergy in their country in 2030, forests emerged as the most important source. The mean estimate for forests as a source of bioenergy was 49.2 percent, and it was even thought to contribute all bioenergy by one respondent. The next greatest estimates were received by agricultural residue and garbage. Some interesting outstanding figures include the estimated 17.8 percent share for garbage in Western Europe, and 16.9 percent for agricultural residue in Southern Europe.

Forests where conventional forestry is practised were deemed the most important source of forest energy in 2030. They received a total of 31 first-place rankings. They were followed by other types of farmed forests (e.g. plantations), and forests grown for the purpose of forest energy. Protected forests were thought to be the least likely source of forest energy, which is obviously reassuring from the point of view of ensuring sustainability of forest energy operations.

When asked whether the plants producing bioenergy in 2030 would only use biomass or be hybrid plants, the opinion was reasonably equally divided. A small majority (55 percent) reckoned the plants would only be using biomass, while 40 percent thought they would be hybrid plants. Plants using exclusively biomass were deemed more likely in Nordic and Baltic countries, and in Western and Southern Europe. By contrast, in Eastern Europe and the rest of the world hybrid plants seemed more likely.

The most important customer group for forest energy in 2030 was thought to be heat and power production, which received 27 first rankings and 13 second rankings. The second most important customer group is traditional forest industry, with 9 first and 13 second ratings. These were followed by households and biorefineries. One respondent also thought that state forestry enterprises might be a relatively important customer group.

The experts seemed to think that energy wood would mainly be a by-product of forestry. 60 percent of respondents were of this opinion and 36 thought it would be sourced separately.
Seasonal variation in sourcing of forest biomass was considered probable. 47 percent of respondents thought this was the likelier situation, and 36 percent thought it would be sourced all year round.

In terms of ownership of forestry machines, the most important group in 2030 seems to be forestry entrepreneurs, with 34 first rankings. They are followed by machine operators and large forest industry and energy companies. The category with the smallest ratings is for companies, which hire the machines to other companies or drivers. One respondent thought the most important owner of machines would be the state; in particular the General Directorate of Forestry, and another that banks would have a relatively important ownership stake in forestry machines.

5. Technological development

The section on technological development of forest energy focused on harvesting and transporting forest biomass, not on the development of plants using forest energy. The respondents were asked about requirements for technological development, challenges that should be addressed, and the usefulness of particular technological solutions, including driver-assisting systems. The last part was based on the surveys used by Ylimäki et al. (2012), and the goal was to chart the most potential areas for development of driver-assisting systems. The same topics were covered in round two, but the questions were more detailed.

5.1. Challenges in harvesting forest energy

According to the expert panel, there is a need for technological development for machines harvesting wood for energy purposes. When asked about this in the first round, 34 percent of respondents thought many new solutions would be necessary and 57 percent that some new solutions were required.

In the first round, the experts were asked what were the key challenges of harvesting energy wood in their country in 2030. On the basis of the responses, it seemed that many people thought about the current situation, and not the future, because some of the issues listed are things that are problematic already at present. 37 of the experts (79 percent) answered this question and many mentioned more than one issue, so the range of challenges is quite wide and they have been grouped into categories.

The most commonly mentioned challenge to harvesting was transportation and logistics. It was mentioned 14 times, and covered transport all the way from forest to the energy-producing facility. It was followed by, in order of number of appearances, storage, planning, costs, infrastructure and terrain issues, harvesting small diameter trees, more efficient harvesting and new technologies, and stumps. Challenges which were mentioned only a couple of times were various and consist of, for example, logging residues, harvesting scattered resources, measurement and quality, preventing future damage, and GPS data.

It seems safe to state that some of the challenges pertaining to harvesting of energy wood are common all around Europe. A good example of this is transportation and storage. Other problems, for example those related to infrastructure and terrain issues, are more particular to some regions, in this instance those with rugged terrain or poor road network. These challenges give some ideas of what problems could be solved by developing better methods and technology.

In round two, 19 of these challenges were picked out and the expert panel was requested to assess the importance they will have in the expert's country in 2030. The most important of these challenges were thought to be 'cost and quality efficient handling of bulky, low-value product', 'development of integrated harvesting methods', 'transportation technology and intermodality infrastructure', and 'development of silvicultural technologies to create synergy between energy wood production and growth of forests'. Some of these seem to be connected, for example better transportation technology would enable cost efficient handling of bulky product, and thus it is reasonable they both receive high ratings. Interestingly, there are no great differences between regions according to importance of challenges, with the exception of 'harvesting systems for steep terrains', which was a considerably more important challenge according to the southern European respondents than according to respondents from other regions.

In the second round, the experts were next asked to suggest ways of addressing these challenges by 2030 and 20 of them chose to do so. The most commonly stated solutions revolved around the interface and cooperation between forest industry, companies, and society. Improvements to logistics have also been grouped into this category. These solutions were very interesting, and thus a full list of them is presented here:

- Development of efficient and friendly forest management service companies taking care for private forests. (Latvia, 38)
- We need more bio-energy plants and a good co-operation of many owners of small forests for efficient logistics; we need some change in traditional forestry in the Netherlands. (Netherlands, 51)
- Developing market support tools to ease the access of smaller farms and producers. Those market tools may include all the services along the chain from harvesting to energy usage. Those tools may be integrated to sustainable forest management capability to protect long-term resources. Market support tools contribute to stabilize prices protecting both the investor and the smaller resource owner. (Portugal, 46)
- Subvention for forest villagers and energy producers, in the name of forest biomass usage. (Turkey, 38)

- More efficient supply chains. (Denmark, 45)
- Local economical development (Spain, 33)
- Improved logistics and quality standards (Finland, 36)

These highlight the important role cooperation between different actors could have in promoting forest energy. This would also save resources by making the efforts to increase use of forest energy more systematic.

The second most common pool of solutions consisted of technological development. This included development of harvesting and transport systems, but also of small-scale and boiler technologies. Other ways of addressing these challenges included research (e.g. into productivity and harvest models), decision support tools, silvicultural technologies, and improving infrastructure. Thus, the range of ways to address challenges to harvesting forest energy is great, but the most potential would appear to be in improving cooperation and supply chain efficiency, and in developing technology for the purposes of forest energy.

5.2. Driver-assisting systems

Driver-assisting systems could be one way of improving the harvesting of forest energy. In the first round, the respondents were asked to rate various aspects of harvesting process in terms of where driver-assisting systems would be the most useful. The results of the question are presented in figure 2. The most important areas for driver-assisting systems appeared to be planning the felling operation, during felling (e.g. avoiding unnecessary movements of the feeder), and planning the forest transport. Alertness level monitoring, by contrast, received surprisingly low ratings. This is interesting because it is one area where there would be potential to improve both the quality of harvesting, and the safety of the drivers.

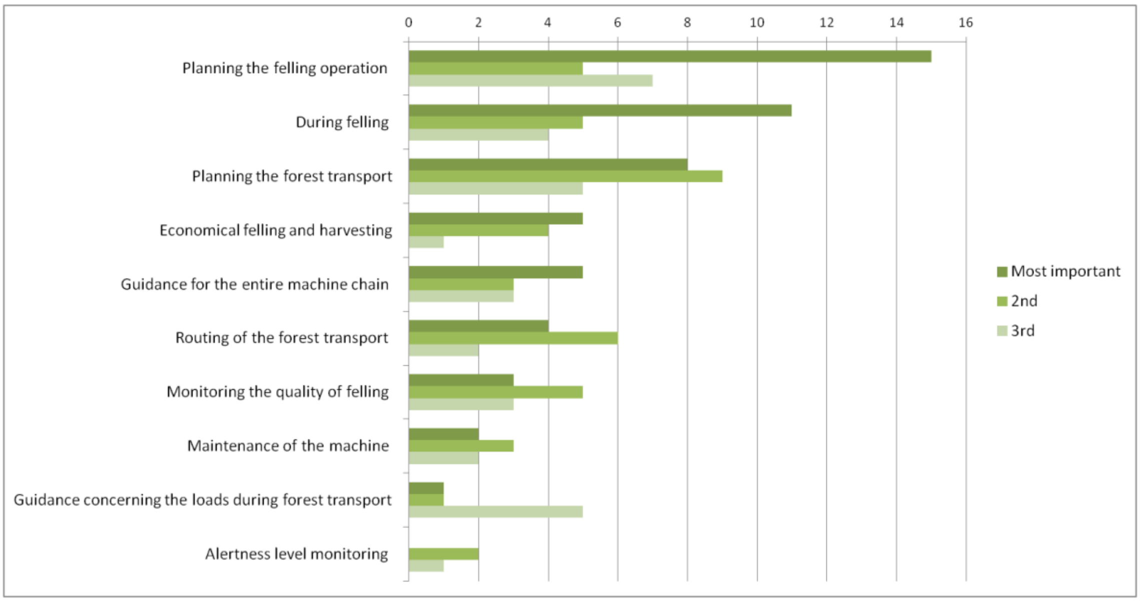

Figure 2 Usefulness of driver-assisting systems - top rankings, number of times given.

In the second round, we wanted to get information that is more detailed on the top five categories (see figure 2). The details were based on the survey used by Ylimäki et al. (2012) with forestry entrepreneurs, drivers, and lecturers and students of schools offering courses in harvesting. Using the same survey provides opportunities for comparisons. The examples given in Ylimäki et al. (2012) for the top five categories (figure 2) were listed in the second round survey, and the respondents were asked to give ranking for their importance.

The aspects that received the highest rankings were efficient methods of working (17 ratings as number 1), fuel efficiency, placing of tracks, terrain, and location and viability of tracks. The ones with the least relevance seemed to be optimal size of stacks, and bulk handling, although it is important to bear in mind that these were parts of the stages of harvesting that were deemed the most important for driver-assisting systems. Thus, it would appear that driver-assisting systems have the greatest relevance in terms of efficiency, tracks, and terrain, and development efforts might provide the greatest results in these cases.

5.3. Technological solutions – development potential

The next section focused on technological solutions to harvesting wood for energy use. In round one, the experts were first requested to assess the potential offered by three solutions. Out of these, multipurpose harvesting heads for roundwood and energy wood received the highest ratings, followed by multi-tree handling and partial debarking of stems for drying.

The experts were then asked if there were other technological solutions that could help with harvesting energy wood in the future. Twelve respondents provided an answer, and most of these were included in the round two questionnaire. In general, it appears that there is some demand for more automated forestry machines, or even fully automated harvesting systems. Many of the suggested solutions fall under this classification, even if some focus more on stands with particular characteristics (e.g. non-even age stands). Others look for solutions to more particular needs, e.g. mountain terrain, forest residues, or broadleaved trees. One interesting idea is to improve energy density before transport, and if this could be achieved, it could result in more efficient forest energy supply chain.

In round two, the experts assessed the development potential and research and development (R&D) needs of 13 technological solutions. The greatest development potential was seen in the cases of improving energy density before transport, and multi-tree handling. These were quite closely followed by multipurpose harvesting heads for round wood and energy wood, and roadside crushing solutions. The least development potential was perceived by the respondents in the case of self-moving chippers for naturally afforested areas and non-even age coppices. The others, for instance the development of a fully automatic harvesting system, fall in the middle of the range.

Interestingly, when asked about how much R&D efforts these technological solutions would require, the results were pretty much the opposite from those concerning development potential. At the top are a fully automatic harvesting system, self-moving chippers for naturally afforested areas and non-even age coppices, and a multipurpose machine for harvesting and processing the whole tree into units ready for forest transport. Most of the solutions were thought to require some R&D efforts, with the exception of partial debarking of stems for drying, which was deemed to require only little R&D efforts.

Thus, it seems that the solutions that are closest to being realised have more development potential and require only some R&D efforts. Those that were thought to have the most need for R&D efforts did not rate very highly on development potential, and as a result it might be unnecessary to devote very much attention to them. It would be interesting find out how much R&D efforts should be assigned to development of these solutions, but it could be assumed that that those with the most development potential would come on top of that list.

6. Labour issues

The last section of the Delphi addressed the issue of labour. Labour shortages are often discussed in the context of forestry, and thus we deemed it important to ask about their importance and future estimates for them.

6.1. Labour availability

The issue of labour availability was addressed in both rounds, with slightly different questions. In both rounds, the experts were asked about the current labour shortages in their country. In round one, most respondents (62 percent) thought there were some labour shortages in the forestry sector in their country, 11 percent thought there were bad labour shortages, and 23 percent that there were no labour shortages. The responses were similar in round two, with an even larger majority (70.5 percent) thinking there were some labour shortages. In round two, the respondents were also asked to estimate the labour shortages in their country in 2030. The situation seemed to be worse. 52.3 percent thought there would be some labour shortages, 25 percent that there would be bad shortages, and 9.1 percent that there would be very severe labour shortages. In addition, only one respondent downgraded their estimate from their view of the current situation, and all others either retained their estimate at the same level or indicated that the situation would worsen.

In round one, the experts were asked to specify which parts of the forestry sector were influenced the most by labour shortages. The greatest shortages appeared to be in the case of harvesting machine operators, as 61.7 percent of respondents thought there would be shortages. The situation appears to be the worst in the Nordic countries, where all respondents thought there were shortages of harvesting machine operators. The other categories were chosen significantly less often, but the ones that follow in importance were energy truck operators, and wood procurement managers. The responses that specified other parts suffering from labour shortages were polarised between manual operations (e.g. planting and thinning), and very skilled workers.

Seasonal fluctuations of labour demand in forestry were also assessed in round one. Most countries seem to face some seasonal fluctuations, as 77 percent of respondents were of this opinion. Fortunately, it appears it would be possible to mitigate the impact of these fluctuations by complementing employment in forestry with work in other sectors, or through other means, as combined these statements account for 70 percent of respondents. Other means of mitigating the impact of seasonal fluctuations include mechanization, less seasonal restrictions on certain operations, education of operators to do different tasks, flat supply amount, working abroad in low season, and casual labour from Eastern Europe in threshold period. These issues were scrutinized in greater detail in round two as one way of attracting new employees to forestry.

6.2. Attracting new employees

In both rounds, the experts were asked if forestry in their country faced a lack of new workers. In round one, 68 percent thought there was a small lack of new workers, and an additional 11 percent thought forestry would need plenty of new workers. The situation was similar in round two, with 56.8 percent thinking there was a small lack of new workers. In round two, the experts also estimated the future situation for attracting new workers. In 2030, the situation could be worse than it currently is. 43.2 percent thought there would be a small lack of new workers, and 20.5 percent that forestry would need plenty of new workers. Only two respondents thought the situation would be better in 2030, others moved their estimate towards greater lack of new workers.

In the first round, the experts chose ways, which could improve attractiveness of forestry as an employer from a list of six alternatives. The main way to improve attractiveness appears to be better pay. It was closely followed by image marketing to increase the attractiveness of forestry as an employer, and by improving the working environment. Interestingly, the least popular option was giving the workers more control over their work, e.g. the timing of breaks.
The respondents mentioned also other ways of attracting new employees, and three of these were incorporated in the second round of the survey. In the second round, the respondents were

asked to rate the importance of different means, which gave us their relative rankings. Better pay stands out even more clearly in this case. It got 30 ratings as the most important way to improve attractiveness, which is a lot more than the other alternatives. The second most important way was better working environment, and it was followed by increased mechanisation of forestry, less manual and motor manual operations, and decreasing time when working alone. Thus, it appears clear that increasing the level of pay would help to attract new employees to forestry sector.

It was also important to find out who should bear the responsibility for taking action to enhance the attractiveness of forestry. In round one, the greatest responsibility was allocated to large forestry companies, followed by the state, educational institutes and smaller forest sector enterprises. In round two, the experts allocated responsibility separately for each of the nine courses of action. Again, the responsibility mainly fell on forestry enterprises, both small and larger ones. For almost all actions, large forestry enterprises were selected most often, followed by smaller forestry enterprises. The two exceptions were the development of better machinery (main responsibility for research institutes), and improving vocational and life-long training (main responsibility for educational institutes). Educational institutes were also at shared first place with large forestry companies for improving image marketing. Educational institutes were in general chosen the least often as the responsible ones. Research institutes were in third place, while the state was fourth. It is interesting to note that rankings of the actors differ quite considerably from round one. This could be because it is easy to assign abstract responsibility to the state, but more difficult to hold the state responsible for particular smaller actions. It is also interesting that research institutes were thought to be responsible for development of better machinery, when it could be assumed that this would be the role of companies manufacturing machines.

In round two, the experts were asked a series of open-ended questions about labour issues in order to gain more detailed information about proposed solutions to problems. Improving the availability of qualified labour was the first of such questions, and the suggested means covered better salary, reputation, education, image, and working conditions in forestry. Availability of qualified labour was not a problem in all cases, for instance some Greek and Portuguese respondents stated that this was not a problem.

In the first round, better pay stood out as the best way to attract new workers to forestry, and thus it is useful to find out what level of pay increase was deemed sufficient. In general, the respondents compared the salary to industrial wages, for example in manufacturing or mining, or stated that is should be around the country average, instead of being at the bottom of the scale. When the experts gave percentage increases, the most common one was 20 percent increase, but the range was from 0 to 100 percent. Some experts stated that the required increases differed by type of employment (traditionally manual forest operations vs. mechanised work), and according to skill level. Overall, it would seem that attracting enough new employees would require higher wages that would be comparable to those in industrial jobs, which could be achieved by an increase of approximately 20 percent from the current level.

In terms of image marketing to increase the attractiveness of forestry, two key aspects emerged. One was to emphasise greenness and sustainability of forestry, and the other to focus on the advanced technologies used in the industry. Either of these approaches would offer a good way to create a more attractive image. There were some more unique suggestions, which could also serve as a basis of image marketing. These included the reduction of gray business in forestry, emphasising the role forestry plays in local and regional development, tranquillity, and working in rural areas. These could also offer a basis for an effective marketing campaign.

Improving the working environment of forestry sector elicited a large number of actions that would improve attractiveness. Concrete examples included decreasing time when working alone, working in one shift, ensuring more personal interactions, reducing seasonality of employment, isolating operators from external weather conditions, secure conditions, involving workers in planning, and increasing their personal responsibility. Some respondents also stated that mechanisation, for example user-friendly development of machines, would help improve the working environment.

Interestingly, machine development to attract new workers was in many cases not an important issue. The development needs for machines tended to focus on ergonomy, safety, and comfort. Other suggestions included multipurpose machines, such as 'harwarders', machinery for mountain terrain, and, with more detail 'feedback on working habits, repair maintenance friendly, increasing automatization of standard tasks, increase working safety by detecting workers daily condition/mood (microsleep…)' (Austria, 35). Thus, development of machinery might help in attracting new workers, but it is unlikely to be the main attraction.

Ways to mitigate seasonal fluctuation of employment included seasonal harvesting, whereby different areas would be harvested at different times, performing other tasks such as training when harvesting is impossible, and increasing supply. One interesting suggestion was to integrate forestry more closely with other rural activities, which could provide employment during forestry low season. Thus, the key to addressing seasonal fluctuation would seem to lie with integrating other activities with forestry. However, it should be noted that seasonal fluctuation was, according to some respondents from Sweden and Poland, not a problem, so it might not be an equally severe issue all over Europe.

Workers being given more control over the work performed was not always a problem. If it was perceived problematic, it could be addressed by education and training, delegating more, for example when doing route-planning, creating self-management structures, and enabling flexible working times. Many of these are already in place in other workplaces, so it should not be too difficult to adapt them in forestry.

The actions that could decrease the time forestry workers spend alone could be, according to the expert panel, increasing the size of work objects, and increasing the supply amounts, which could enable combining activities or working in teams. Coordination and better planning were also mentioned as possible solutions. Other solutions included training at frequent intervals, and 'multimedia, joint breaks, "meeting" facilities (container) at the logging site' (Finland, 36). Thus, it seems that there are ways to decrease time working alone, and it could be achieved for example by better coordination and larger work packages, which would also improve the overall efficiency of harvesting of forest energy.

The rate of mechanisation in forestry could mainly be improved by technological developments. These included mechanisation in hardwoods, machinery for silviculture, and development of steep terrain capabilities and of efficiency in small stems. Other means would be cheaper machines and subsidies, research to develop technology, and scaling up the operations in order to reach sufficiently large size to benefit from the machines. Unsurprisingly, the key to increasing mechanisation lies in solving issues that are still problematic with current machines.

6.3. Education in forestry

The topic of education offered in the field of forestry was directly addressed only in round one. When asked about the current educational system and whether it teaches drivers enough skills to operate harvesting machines for energy wood in 2030, the majority of the respondents thought the educational system could be improved. These opinions ranged from the system needing some improvements (28 percent), to large improvements (28 percent), and further to the system needing a complete overhaul (11 percent). In contrast, 17 percent thought the system is satisfactory and 11 percent that the system is fully sufficient. The respondents from Nordic countries were particularly satisfied with the educational system, as the majority of them were satisfied with the current system.

The main areas for development of educational systems by 2030 were perceived to be teaching about the organisation of work and the efficient use of machinery, use of technology in teaching, and simulators and computer games for teaching. Paying particular attention to recruitment of women was thought to be the least important improvement.

The respondents thought that the current level of knowledge of energy wood procurement managers was at least somewhat limited, when thinking about increased use of forest energy in 2030. 49 percent thought the level of knowledge was somewhat limited, while 15 percent thought it was extremely limited. In contrast, 21 percent found it sufficient and 6 percent completely sufficient.

The greatest requirements for knowledge improvement for procurement managers were thought to be in logistics and quality management. These were followed by information systems and energy technology. Other knowledge gaps identified included ecology of forest growth and growing hybrids for energy crops like aspen and willow.

In round two, the experts were asked what actions could improve vocational and life-long training so that it would help attract new workers to forestry. The suggestions included the provision of more practical and shorter courses, incentives (e.g. greater pay) for training, incorporating training as part of work, and highlighting the dangers of untrained workers. Overall, providing better prospects for workers might be helpful. In sum, it appears that integrating work and shorter courses together, and ensuring the workers benefit from training, would be the most effective way for training to improve the attractiveness of forestry.

7. Discussion – comparisons with previous research

There have been previous forestry studies that have used Delphi as a research method. This study followed these examples with a dissensus-based online Delphi, which was targeted to an international group of participants. The results are encouraging. The rate of participation is reasonably good for a long and complex survey, and the quality of data is good. Thus, these results give interesting indications of what the use of forest energy might be like in Europe in 2030. It should be kept in mind that these results are just some of the possible futures, and their actualisation depends on the actions of a great number of people, including researchers who work in the field of forest energy.

The respondents had strong trust in technological development and in policy support for forest energy. This is evident from the ratings of likelihood and desirability in the section on trends. These beliefs probably influenced the opinions of the participants also in other sections of the survey, for example when they were asked to assess the development potential of various technological solutions. There is some external evidence for policy support, for example in the form of EU targets for renewable energy, but what happens with technological development remains to be seen. However, it seems probable that other renewable energy sources will also benefit from development of technology, and the respondents did find it somewhat likely that other sources of renewable energy would be more prominent than forest energy in the future. The proportions of various sources will probably vary between countries, but even for a country such as Finland the goal is to have approximately half of renewable energy from non-bio sources (Laitila et al. 2010). Thus, even with technological development, forest energy must operate in a more competitive environment.

Interestingly, the respondents seemed quite environmentally friendly, when looking at the desirability ratings given to various trends taking place by 2030. They, for example, thought increases in energy use per person would be undesirable. However, they seemed to understand environmental issues in quite a comprehensive way, because they identified the possibility that environmental affairs might develop in a direction that influences the use of forest energy in a negative way. This could happen, for instance, because of actions by forest certification organisations such as FSC or strict RES directives for solid biomass. The impact of environmental actors also connects with other issues addressed in the survey. For example, one quite positive finding was that the experts thought that the main source of forest energy in Europe in 2030 would be managed forests. It is reassuring to note that the experts did not find dystopian futures, where protected forests would be utilised, equally probable. They also indicated that environmental concerns about the harvesting process need to be addressed. It appears likely that if environmental challenges are sufficiently taken into account, forest energy will remain a green alternative to fossil fuels.

Another interesting issue are the experts' opinions on the increases in the use of forest energy and in the sourcing of energy wood by 2030. The mean estimate for increase in the use of forest energy is 49 percent, while the mode was 20 percent. The year of estimation is different from many previous studies, but these estimates are still rather low. For example, the Finnish goals for use of bio-based fuels would require an increase of forest chips by of 66 percent by 2020, and this would obviously be even higher by 2030 (Laitila et al. 2010). The increase in demand for wood energy by 2020 is projected to be the same by Mantau et al. (2010). Their projection relied on the conditions that the EU27 targets for energy efficiency and renewable energy use are reached, and that the share of wood out of all renewable energy decreases from 50 percent in 2008 to 40 percent in 2020.

The experts also gave relatively conservative estimates of how much harvesting of energy wood would increase. The mean estimate was an increase of 89.4 percent, while the mode was an increase of merely 10 percent. This increase would be far from sufficient in even reaching the increases in use stipulated by the experts, and even more so those set in policy targets. Mantau et al. (2010) also state that harvesting enough energy wood would require plenty of new workers and machinery, even in a low mobilisation scenario, which would be very far from meeting even the lowest demand. Thus, there are still many challenges to address.

As the discrepancy above suggests, there are several limits to the use of forest energy. In the first round, the experts recognised the price competitiveness of forest energy and weak competitiveness against other energy sources as the most important limits to use of forest energy. This contrasts with e.g. Laitila et al. (2010), which includes neither one of these as an important direct development need. On the other hand, technology development contributes to improved efficiency and through that to price competitiveness. Thus, our findings are in line with Laitila et al. (2010). Interestingly, the competitiveness limits are not recognised in Mantau et al. (2010) either, which tends to focus on supply and demand issues, also in terms of policy recommendations. Thus, it would be useful to analyse these issues in future research.

The suggestions given by the experts in the second round could offer interesting starting points for finding means to overcome the competitiveness limits. The solutions to both competitiveness issues were mainly concerned with fiscal policy and addressing skewed market rules. Achieving these outcomes would require concerted efforts by policy actors in order to achieve outcomes beneficial to forest energy. However, it might be useful to target the competitiveness actions against fossil energy sources, because the same fiscal measures might benefit also other renewable energy sources.

There are also technological challenges to harvesting of energy wood. In the first round, the most commonly mentioned challenge was transportation and logistics. In the second round, the experts assessed the importance of various challenges in their country in 2030. Here again transportation and efficient harvesting of a bulky product were thought to be the most important ones. These challenges have not really been addressed in previous studies such as Asikainen et al. (2005, 2009). One possible reason is that these would require solutions that go beyond the harvesting process. For instance, logistics also relies on good infrastructure, which might be difficult to achieve on some terrains. The solutions offered by the expert panel are quite wide-ranging. Most of the solutions offered could be grouped into categories 'interface and cooperation between forest industry, companies, and society' and 'technological development'. The first of these would probably require policy cooperation on a higher level, and thus might be achieved if energy policy is redesigned to provide better possibilities for forest energy.

The expert panel assessed the development potential of various technological solutions, some introduced by the respondents in the first round. Those thought to have the greatest potential were improving energy density before transport, multi-tree handling, multipurpose harvesting heads for round wood and energy wood, and roadside crushing solutions. There are some similarities with suggestions from previous studies. For example, Asikainen et al. (2005) thought multi-tree handling could enable more efficient loading and thought this was a potential development area. It should be noted that many of the ideas presented in Asikainen et al. (2005, 2009) focused more on development of automatization and e.g. sensory technology. In this study these kinds of suggestions, such as a fully automatic harvesting system, were thought to require plenty of R&D efforts, but to have relatively low development potential. Thus, according to our results, full automatization of harvesting might lie further in the future than 2030.

One step towards full automatization could be driver-assisting systems. In the first round, the experts thought driver-assisting systems would be most useful in planning the felling operation, during felling, and planning the forest transport. In the second round, the experts assessed the usefulness of certain aspects of driver-assisting systems. Those thought to be the most useful were efficient methods of working, fuel efficiency, placing of tracks, terrain, and location and viability of tracks. There are some similarities with the results of Ylimäki et al. (2012). In both studies, the placing of the tracks was thought to be important. However, the differences are greater than the similarities. In Ylimäki et al. (2012) the respondents expressed need for guidance about the location of special stands, borders of stands marked for cutting, and tracks. This was followed by efficient methods of working, but fuel efficiency did not feature, while the experts were not concerned with the location of special stands or of borders of stands. These differences probably stem from the different professional roles, although the country of operation might also influence the results. The respondents of Ylimäki et al. (2012) are probably more familiar with the harvesting operation, and thus they might have a clearer view of what the most useful applications for driver-assisting systems might be. Interestingly, guidance on timing of breaks and monitoring the alertness level of the driver was not thought to be very useful either in this study or in Ylimäki et al. (2012). This is somewhat surprising, because this was assumed to be an area where automatization would bring benefits. However, it might be that other needs for driver-assisting systems are more pressing.

Mantau et al. (2010) projected the need for labour for three different scenarios in 2030. The projections are based on Finnish labour productivity, and they state that because the Finnish labour productivity is quite high, the real numbers would probably be even higher. The increase in workers required for harvesting stemwood ranges from 43 percent in the low mobilisation scenario to 61 percent in the high mobilisation scenario. In comparison, the estimates of the expert pool seem quite optimistic, since the majority of them thought there would be only some labour shortages in 2030.

The difficulties in recruiting new workers have been identified also by Asikainen et al. (2005), and it seems that there is a need to increase the attractiveness of forestry sector as an employer. The respondents allocated most of the responsibility for this on large forestry companies. If they start to experience the effect of labour shortages in their own operations, they might be motivated to take action. The range of actions suggested to attract new workers is very broad, and includes for instance better pay, and marketing forestry as an environmentally friendly and technologically advanced industry. The suggestions listed in section 6.2. could be useful, but there is a need for action.

In terms of education, life-long training was one of the core issues in this study. Ideas such as suitability testing for applicants (Asikainen et al. 2009) were not discussed. Life-long training was thought to be potentially useful, but it needs to merge better with work. It could utilise low seasons or be organised in shorter courses. These would help the workers update their skills and could help in reaching the productivity targets.

8. Concluding remarks

Overall, this study provides a wealth of information on how experts in the field of forest energy perceive its future in Europe in 2030. It also offers suggestions for actions to take, for example in the cases of technological development and attracting new workers into forestry.

The future of forest energy seems in many ways quite positive. Among the experts, there is trust in technological development and in policy action to support wider adoption of forest energy. It seems probable that forest energy can offer an environmentally sustainable alternative source of energy, and that issues regarding competitiveness of forest energy against other energy sources can be resolved. There is also plenty of scope for technological development, which can even offer business possibilities.

However, there are also challenges that need to be addressed. Weak competitiveness against other energy sources might only be addressed with external support. Possibly an even more challenging issue is how to ensure sufficient supply of wood for forest energy (cf. Mantau et al. 2010). The estimates of the expert panel fell short of those in Mantau et al. (2010) both in terms of use of forest energy and in terms of labour shortages. Increasing labour demand in forest biomass supply is also a positive signal, as the sector will offer job opportunities in the future. These issues need to be resolved, if forest energy will serve its role as a part of the EU renewable energy targets. This report contains plenty of suggestions on how to address them, and will hopefully serve as a starting point for action.

As a final note, it is necessary to highlight the fact that the contents of this report are only some future possibilities. For example, Nuutinen et al. (2009) and Mantau et al. (2010) contain other possible futures. What happens to the future of forest energy in Europe in 2030 will depend on the actions of researchers, politicians, forest and energy industry, and, maybe first of all, on the development of the global energy demand.

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Appendixes

The surveys used in this study can be found in the appendixes. The formatting and layout of the surveys was different in the Webropol system used, but the content was the same.

Appendix 1 – Survey for the first round

This study explores the future of forest energy in Europe in 2030. The main themes of the project are trends affecting forest energy sector, future machinery and technological solutions, and workforce and educational requirements. This survey is the first part of a two-round Delphi process. The study is a part of COST action FP 0902.

Background information

1. What is your current professional role?			
Expert	Researcher	PhD student	Student

2. What is your field of expertise?			
Energy	Forestry	Environment	Other, please specify

3. In which country do you currently live in?
4. Age

Operational environment

5. There are several on-going trends which might affect the use of forest energy by 2030. Some of these are listed below. Please rate these according to the **likelihood** of them taking place. Please think about your country, unless otherwise specified.

	Very likely	Somewhat likely	Neutral	Somewhat unlikely	Very unlikely
Energy and climate policy will support the use of renewable energy, including forest biomass.					
Energy use per person will continue to increase					
Forests will be used for carbon capture and storage					
Increasing criticism of land use changes and of increased use of land for energy biomass production reduce the use of bioenergy.					
Efficient subsidies will be in place to support the use of forest biomass for energy production.					
There will be a marked shift from traditional wood processing industry to energy industry in terms of wood consumption.					
The use of recycled products and of recycled fibre will continue to increase in forestry industry.					
Harvesting of wood will be increasingly mechanised.					

Energy value of paper will affect on the price of paper more.					
Forest sector entrepreneurs will be in charge of harvesting and forestry work also in the future.					
The harvesting companies will operate internationally.					
The importance of planted forests for energy production will increase.					

6. Please rate these trends according to the **desirability** of their taking place. Think about the situation in your country, unless otherwise specified.

	Very desirable	Somewhat desirable	Neutral	Somewhat undesirable	Very undesirable
Energy and climate policy will support the use of renewable energy, including forest biomass.					
Energy use per person will continue to increase					
Forests will be used for carbon capture and storage					
Increasing criticism of land use changes and of increased use of land for energy biomass production reduce the use of bioenergy.					
Efficient subsidies will be in place to support the use of forest biomass for energy production.					
There will be a marked shift from traditional wood processing industry to energy industry in terms of wood consumption.					
The use of recycled products and of recycled fibre will continue to increase in forestry industry.					
Harvesting of wood will be increasingly mechanised.					
Energy value of paper will affect on the price of paper more.					
Forest sector entrepreneurs will be in charge of harvesting and forestry work also in the future.					
The harvesting companies will operate internationally.					
The importance of planted forests for energy production will increase.					

7. Are there other trends, which might affect the future of forest energy in 2030?

8. By 2030, what will happen to the use of forest biomass for energy in Europe in relation to current situation?		
Increase	Remain the same	Decrease

9. Please give an estimate, in percentages, of how much the use of forest biomass for energy will change in Europe by 2030?

10. How much will harvesting of industrial roundwood and energy wood increase in your country by 2030? Please give your estimate as a percentage in relation to current situation.	
Harvesting of industrial roundwood, increase	
Harvesting of energy wood, increase	

11. What will be the shares of different types of biomass out of all bioenergy in your country in 2030? Please give percentages adding up to 100.
- Forests
- Trees outside forests
- Short rotation energy forests (willow, poplar etc.)
- Other energy crops
- Agricultural residue
- Organic waste
- Garbage

12. What types of forests will be the most important source of forest energy in your country in 2030? If you choose more than one, please rate them according to importance, 1 for the most important.
- Forest grown for the purpose of forest energy
- Other types of farmed forests, e.g. plantations
- Forests available for wood supply (forests, where conventional forestry is practised)
- Protected forests

13. In 2030, will the plants producing bioenergy **in your country** be:	
Only using biomass	Hybrid plants, using e.g. both coal and biomass

14. Who will be the main customers for forest energy in your country in 2030? Rate the ones you find relevant in order of importance, 1 for the most important.
- Traditional forest industry
- Heat and power production
- Biorefineries
- Households
- Other, please specify

15. In 2030 **in your country**, will wood for energy use be a by-product of the forest industry or is it sourced separately?	
A by-product of the forest industry	Sourced separately

16. In 2030 **in your country**, will forest biomass be sourced equally all year round, or are there seasonal variations?	
Seasonal variations	Sourced all year round

17. What forms of transport will be used for forest biomass **in your country** in 2030? Please rate the relevant ones according to importance, 1 for the most important.
- Road
- Railways
- Waterways

18. In 2030, who will own the forestry machines **in your country**? Please rate the relevant ones according to importance, 1 for the most important.
- Machine operators
- Forestry entrepreneurs
- Companies which hire them to other companies or to drivers
- Large forest industry and energy companies
- Other, please specify

19. Which factors or actors limit the use of forest bioenergy **in your country** in 2030? Please rate the relevant ones according to importance, 1 for the most important.
- Attitudes of forest owners
- Forestry contractors
- Capacity of customers
- Price competitiveness
- Availability of technology
- Availability of forest energy for users
- Weak competitiveness against other energy sources
- Other, please specify

<u>Future machinery and technological solutions</u>

20. Please think about the year 2030 and estimate the need for technology development **in your country** in terms of machines used to harvest wood (logging residues, small diameter trees, stumps, damaged roundwood) for energy use.

	Many new solutions	Some new solutions	Few new solutions	Current technology is sufficient	
There is a need to develop many new technological solutions					The current harvesting technology for energy wood is sufficient

21. What are the key challenges in harvesting wood for energy use **in your country** in 2030? For example, are they connected with planning the felling operation, or with storing the harvested energy wood before in can be used?

Driver-assisting systems help the driver of a forestry machine e.g. to optimise driving in the forest. The goal of developing these systems is not a fully automatic machine, but a machine which makes work easier and more comfortable.

22. In what ways do you think driver-assisting systems would be of most use in the forestry process **in your country** in 2030? Please mark 1 for the most important and rate others according to importance.
- Planning the felling operation (e.g. terrain, placing of the tracks)
- During felling (e.g. efficient working, unnecessary movements of the feeder)
- Monitoring the quality of felling (e.g. spacing of tracks, damage caused by harvesting)
- Planning the forest transport (e.g. location of timber assortments, terrain)

- Routing of the forest transport (e.g. shortest route to storage)
- Guidance concerning the loads during forest transport (e.g. efficient loading and off-loading posts)
- Economical felling and harvesting (e.g. fuel efficiency)
- Maintenance of the machine (e.g. locating faults)
- Alertness level monitoring (e.g. tired driver, breaks)
- Guidance for the entire machine chain (e.g. placing of timber stacks)

23. Which of these technological solutions would offer most potential for harvesting wood for energy use **in your country** in 2030? Mark 1 for the most important and rate other relevant ones according to importance.
- Multi-tree handling
- Partial debarking of stems for drying
- Multipurpose harvesting heads for roundwood and energy wood

24. Are there other technological solutions which might help with harvesting energy wood in the future?

Workforce and education

25. Are there current labour shortages in the forestry sector **in your country**?			
No labour shortages	Some labour shortages	Bad labour shortages	Very severe labour shortages

26. If there are labour shortages **in your country**, which parts of the forestry sector are most affected by the shortages? You can choose more than one alternative.
- Harvesting machine operators
- Energy wood truck (chip and other energy wood) operators
- Wood procurement managers
- Pulp and paper mills
- Woodworking industries
- Heating plant operators
- Other, please specify

27. Are there seasonal fluctuations of labour demand in the forestry sector in your country at the moment?		
No seasonal fluctuations	Some seasonal fluctuations	Plenty of seasonal fluctuations

28. Would it be possible to mitigate the impact of seasonal fluctuations in employment and what measures would need to be taken?			
Not possible to mitigate the impact	Possible to mitigate with complementing employment in other positions in forest and energy sector	Possible to mitigate with complementing employment outside forest and energy sector	Other, please specify

29. Does forestry sector in your country attract enough new workers?			
More new workers available than needed	Enough new workers available	Small lack of new workers	Would need plenty of new workers

30. If forestry does not attract enough new workers, what actions should be taken in order to enhance the attractiveness of the field by 2030? You can choose more than one.
- Image marketing to increase the attractiveness of forestry as an employer
- Development of better machinery
- Mitigation of seasonal fluctuation of employment
- Better working environment
- Better pay
- More control over the work performed, e.g. timing of breaks
- Other, please specify

31. Who should do take action to enhance the attractiveness of forestry sector as an employer in your country? Please rate the relevant ones in order of importance, starting with 1.
- Large forestry companies
- Smaller forestry sector enterprises
- Educational institute
- The state
- Research institutes
- Other, please specify

32. Does the current educational system in your country give the drivers enough skills to be able to operate forestry machines for the harvesting of energy wood in 2030?				
Yes, the system is fully sufficient	The system is satisfactory	The system needs some improvements	The system needs large improvements	The system needs a complete overhaul

33. If the current educational system in your country could be improved, what are the main areas that should be developed by 2030? Please rate the ones you find relevant in order of importance, 1 for the most important one.
- Use of technology in teaching
- Simulators and computer games for teaching
- Teaching students skills needed in cut-to-length harvesting
- Teaching about organisation of work and the efficient use of machinery
- Productization of driver education
- Refresher courses for experienced drivers
- Recruitment of students
- Paying particular attention to recruitment of women
- Other, please specify

34. Is the current level of knowledge of energy wood procurement managers sufficient for increased use of forest energy in your country by 2030?			
Completely sufficient	Sufficient	Somewhat limited	Extremely limited

35. If the level of knowledge of energy wood procurement managers could be improved, what areas should receive particular attention? Please rate the ones you find relevant in order of importance, 1 for the most important.
- Quality management
- Energy technology
- Logistics
- Information systems
- Other, please specify

36. Do you have any other comments on the future of forest energy in Europe in 2030 or on this survey?

Thank you for your answers!

SUBMIT.

Appendix 2 – Survey for the second round

Background information

1. In which country do you currently live in?

2. What is your professional role?			
Expert	Researcher	PhD student	Student

3. What is your main field of expertise?			
Energy	Forestry	Environment	Other, please specify

4. Age

Trends affecting future of forest energy in Europe by 2030

5. There are several on-going trends, which might affect the use of forest energy in Europe by 2030. Some of these are listed below. Please rate these according to the likelihood of them taking place, and think about the situation in your country.

	Very likely	Somewhat likely	Neutral	Somewhat unlikely	Very unlikely
Energy use per person will continue to increase					
Energy and climate policy will support the use of renewable energy, including forest biomass.					
Other renewable energy forms (e.g. solar, wind, and hydropower) will be more prominent than bioenergy.					
Technology converting biomass to energy will be considerably more efficient than today.					
Productivity per hectare in silviculture and agriculture will increase significantly because of advances in tree breeding, more intensive forestry management and genetic modification.					
Nature protection programmes and/or forest certification limit felling of wood for energy use.					
Ecological concerns, for example about fertility depletion, will limit the use of bioenergy.					
Management of biodiversity and ecosystem services will be integrated with forest energy production.					
Harvesting of wood will be increasingly mechanized.					

There will be increasing tensions between energy industry and wood and paper industry caused by limited availability of wood.					
Timber construction will become more prominent, and thus there will be less wood available for energy use.					
Increasing criticism of changes in land use and of increased use of land for energy biomass production reduce the use of bioenergy.					
Land use will shift from bioenergy crops to growing food.					
The use of recycled products and of recycled fibre will continue to increase in forestry industry.					

6. Please rate the trends according to the desirability of them taking place, and think about the situation in your country.

	Very desirable	Somewhat desirable	Neutral	Somewhat undesirable	Very undesirable
Energy use per person will continue to increase					
Energy and climate policy will support the use of renewable energy, including forest biomass.					
Other renewable energy forms (e.g. solar, wind, and hydropower) will be more prominent than bioenergy.					
Technology converting biomass to energy will be considerably more efficient than today.					
Productivity per hectare in silviculture and agriculture will increase significantly because of advances in tree breeding, more intensive forestry management and genetic modification.					
Nature protection programmes and/or forest certification limit felling of wood for energy use.					
Ecological concerns, for example about fertility					

depletion, will limit the use of bioenergy.					
Management of biodiversity and ecosystem services will be integrated with forest energy production.					
Harvesting of wood will be increasingly mechanized.					
There will be increasing tensions between energy industry and wood and paper industry caused by limited availability of wood.					
Timber construction will become more prominent, and thus there will be less wood available for energy use.					
Increasing criticism of changes in land use and of increased use of land for energy biomass production reduce the use of bioenergy.					
Land use will shift from bioenergy crops to growing food.					
The use of recycled products and of recycled fibre will continue to increase in forestry industry.					

7. Are there other trends which might affect the future of forest energy by 2030?

8. In the previous round of this Delphi study, the following limits to use of forest energy were either deemed important by the respondents or raised by them. Please suggest ways to address these in your country by 2030.
- Price competitiveness of forest energy
- Weak competitiveness of forest energy against other energy sources (renewable and nonrenewable)
- Attitudes of forest owners towards forest energy
- Availability of forest energy for users
- Restrictions on use of forest energy on environmental grounds (legislation, other regulations)
- Attitudes of general public towards forest energy

<u>Technological development</u>

9. In the previous round of this Delphi the respondents thought these challenges to harvesting of energy wood were important. Please rate them according to importance you think they will have in 2030 in your country, 1 for the most important.

- Traditional forest ownership and forest management lead to no willingness to participate in energy biomass production
- Issues with measurement and quality of forest energy
- Site-specific planning of felling operations
- GPS data for landscape and terrain
- Forest road network needs improvements in terms of quality and density
- Interaction between operations and machines to form an economical supply chain
- Development of integrated harvesting methods
- Harvesting systems for steep terrain
- Harvesting of scattered forest resources
- Extraction from remote locations on difficult terrain
- More sensors to prevent damaging of future trees
- Environmental impact of harvesting energy wood to the soil
- Drying of harvested stems and roundwood before chipping to control forest pests
- Cost and quality efficient handling of bulky, low-value product
- Transportation technology and intermodality infrastructure
- Storing energy wood before use
- The impact of seasonal demand variations on the storage needs of forest energy production
- Finding the right type of wood biofuel for the right users
- Development of silvicultural technologies to create synergy between energy wood production and growth of forests

10. Can you suggest ways of addressing the most important challenges to harvesting energy wood in your country by 2030?

11. Driver-assisting systems are one possibility for technological development. Please look at the following aspects of driver-assisting systems and rank those relevant to situation in your country according to importance, 1 for most important.
- Borders of stands marked for cutting
- Terrain
- Placing of tracks
- Efficient methods of working
- Bulk handling
- Avoiding unnecessary movements of the feeder
- Location of different wood grades
- Location and viability of tracks
- Working in a way that places less stress on the machine
- Fuel efficiency
- Placement of timber stacks
- Quality of stacks
- Optimal size of stacks

12. In the previous stage of Delphi, the respondents were asked to list other technological solutions to help with harvesting energy wood. Please give your opinion of how much development potential these have in your country by 2030.

	Great	Good	Some dev.	Weak dev.	No dev.

	dev. potential	dev. potential	potential	potential	potential
A fully automatic harvesting system					
Multipurpose machine for harvesting and processing the whole tree into units ready for forest transport					
Flexible medium sized harvesting machines for mountain terrain					
Multipurpose harvesting heads for round wood and energy wood					
Stump extraction					
Bundling forest residues					
Automatic bunching of energy coppices					
Processing technology for broadleaved trees					
Self-moving chippers for naturally afforested areas and non-even age coppices					
Multi-tree handling					
Roadside crushing solutions					
Improving energy density before transport					
Partial debarking of stems for drying					

13. Please assess these technological solutions according to how much research and development (R&D) efforts (money, research, collaboration etc.) they would require.

	Requires a lot of R&D efforts	Requires some R&D efforts	Requires little R&D efforts	No R&D efforts required
A fully automatic harvesting system				
Multipurpose machine for harvesting and processing the whole tree into units ready for forest transport				
Flexible medium sized harvesting machines for mountain terrain				
Multipurpose harvesting heads for round wood and energy wood				

Stump extraction				
Bundling forest residues				
Automatic bunching of energy coppices				
Processing technology for broadleaved trees				
Self-moving chippers for naturally afforested areas and non-even age coppices				
Multi-tree handling				
Roadside crushing solutions				
Improving energy density before transport				
Partial debarking of stems for drying				

Labour issues

14. Are there current labour shortages in the forestry sector in your country?			
No labour shortages	Some labour shortages	Bad labour shortages	Very severe labour shortages

15. In your opinion, will there be labour shortages in the forestry sector in your country in 2030?			
No labour shortages	Some labour shortages	Bad labour shortages	Very severe labour shortages

16. Does the forestry sector in your country currently attract enough new workers?			
More workers available than needed	Enough new workers available	Small lack of new workers	Would need plenty of new workers

17. In your opinion, will the forestry sector in your country attract enough new workers in 2030?			
More workers available than needed	Enough new workers available	Small lack of new workers	Would need plenty of new workers

18. In your opinion, which of the following actions would be the most useful for attracting qualified workers to forestry in your country by 2030? Please rank all that apply, 1 for the most important.
- Better pay
- Image marketing to increase the attractiveness of forestry as an employer
- Better working environment
- Development of better machinery
- Mitigation of seasonal fluctuation of employment
- More control over the work performed, e.g. timing of breaks
- Decrease time when working alone
- Increased mechanisation of forestry, less manual and motor manual operations

- Improving vocational training and life-long training

19. Who should be responsible for undertaking actions to increase attractiveness of forestry as an employer? Please choose all that apply.

	Large forestry companies	Smaller forestry sector enterprises	Educational institutes	The state	Researc h institutes
Better pay					
Image marketing to increase the attractiveness of forestry as an employer					
Better working environment					
Development of better machinery					
Mitigation of seasonal fluctuation of employment					
More control over the work performed, e.g. timing of breaks					
Decrease time when working alone					
Increased mechanisation of forestry, less manual and motor manual operations					
Improving vocational training and life-long training					

In the following questions, please think about the situation in your country in the time leading up to 2030.

20. How can the availability of qualified labour be improved?

21. How much better should pay in the forestry sector in your country be, so that it would attract enough new workers?

22. What type of image marketing would increase the attractiveness of forestry as an employer?

23. What actions would improve the working environment of forestry sector in your country to attract enough new workers?

24. How could machinery be developed to attract enough new workers?

25. What actions would mitigate seasonal fluctuation of employment to attract enough new workers?

26. How could the workers be given more control over the work performed?

27. What actions could decrease the time forestry employees spend working alone?

28. What actions could improve the rate of mechanisation of forestry?

29. What actions could improve the vocational and life-long training so that new workers would be attracted to forestry?

30. Do have any other comments on the future of forest energy or on this questionnaire?

SUBMIT.

Thank you for your participation!