added value

Regional operating scheme for the procurement of fresh logging residues

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Table of content

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1. Introduction

Harvesting of roundwood creates logging residues – tops, branches, non-merchantable roundwood, small-diameter trees - originating primarily from final-fellings. Logging residues can be chipped to make wood-chip fuels that can later be used by heating and power plants.

According to the preliminary data of the Natural Resources Institute Finland (2022), heating and power plants consumed 23.7 million cubic metres (46 terawatt hours, TWh) of solid wood fuels in 2021, up by 23% from the previous year. The consumption of wood chips increased by 24% from the year before, totalling 9.4 million cubic metres. The consumption of logging residues increased by 7% to 2.7 million cubic metres (Figure 1.). The consumption of wood chips was 5.9 million cubic metres in the combined production of heat and power, and in heat production 3.6 million cubic metres. Combined with wood chips burnt in small-scale housing (0.6 million cubic metres), the total consumption of wood chips reached 10 million cubic metres. The main fraction of the wood chips in Finland comes from the tending of young stands. The share of these small-sized trees as raw material for forest chips at heating and power plants is already more than half of the wood chips.

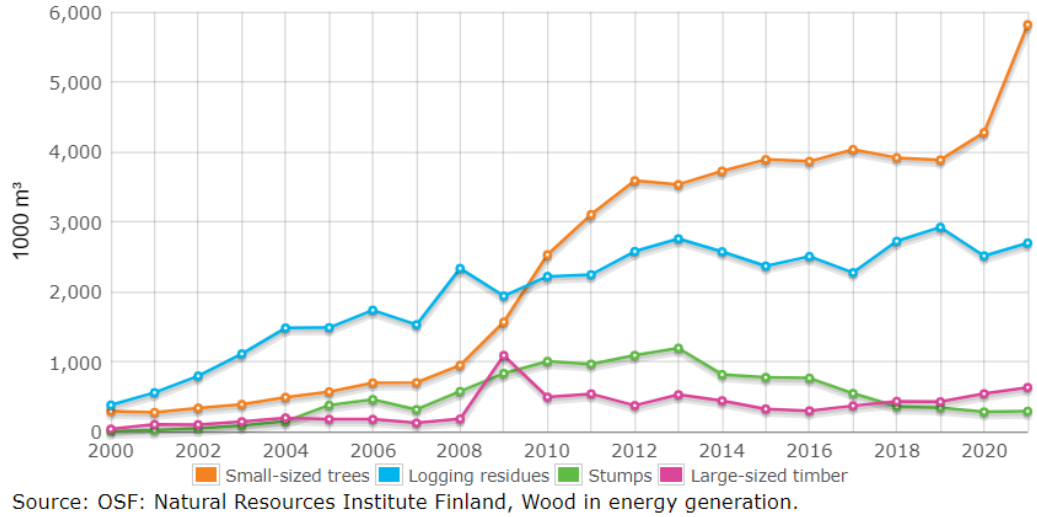

Figure 1. The consumption of wood chips in heating and power plants by raw material in Finland (Natural Resources Institute Finland 2022).

In Sweden, the production of decomposed unprocessed forest fuels corresponded to 21 TWh in 2020 (Swedish Energy Agency 2021). In fact, the production has decreased by 30 % since 2013. Logging residues and firewood (i.e. split and cut wood from roundwood intended for wood boilers, wood stoves, etc.) are the two main forest fuel assortments. Together they account for 74 %, while wood chips produced from roundwood account for 22 % of the total production (Figure 2). Thus, the use of other assortments, such as small-sized trees from early clearings, stumps and wooden waste from parks and gardens, is currently very limited.

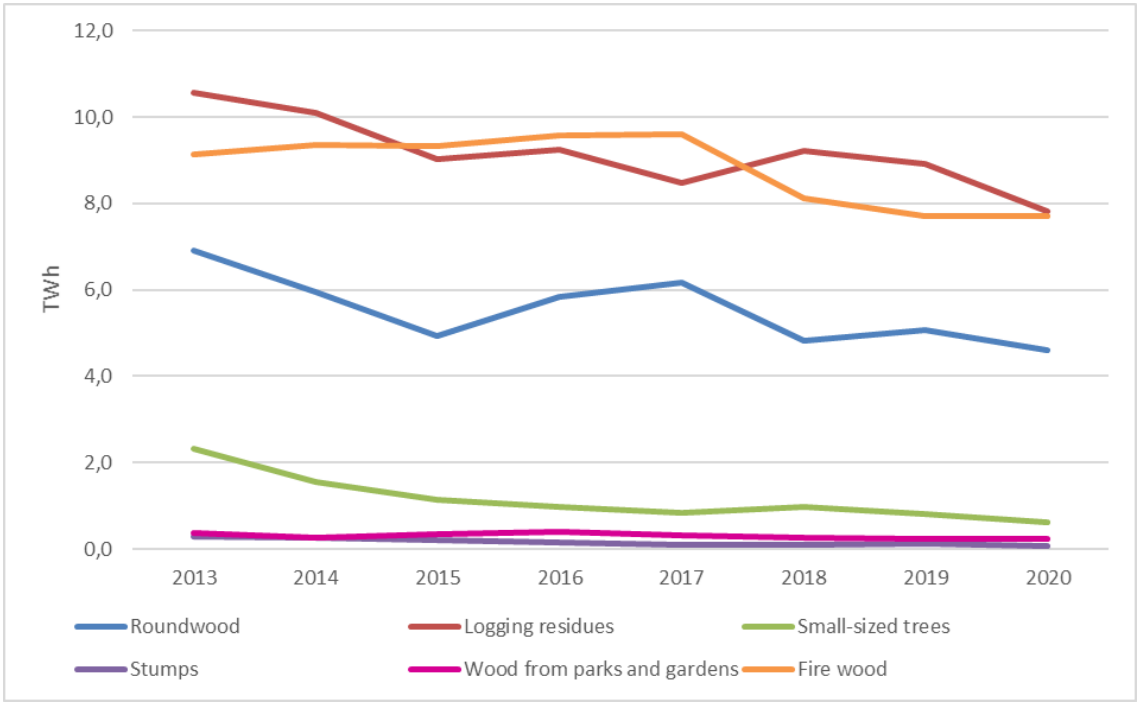

Figure 2. Production of decomposed unprocessed primary forest fuels of domestic origin in Sweden (Swedish Energy Agency 2021).

Both economic and ecological factors must be considered when choosing the potential areas for energy wood harvesting. Extraction of logging residues is currently limited mainly to spruce dominated stands on semi-fertile or fertile soils. In final-fellings of spruce stands the volume of logging residue produced is usually 20–30 % of the volume of roundwood harvested (Best Practices for Sustainable Forest Management, 2022). Pine-dominated stands are usually left outside of the procurement chain since the procurement is not economically reasonable due to the low yield of logging residues. The procurement of logging residues is profitable, if the volume of roundwood is more than 200 solid cubic metres per hectare and the size of the harvested area is at least one hectare (Best Practices for Sustainable Forest Management, 2022). The procurement of logging residues makes it easier to carry out the soil preparation activities when regenerating the forest. Cultivation, especially mechanical planting, becomes easier. Procurement of logging residues has also been found to promote the survival of seedlings and emergence of full-dense seedling stands of birch and spruce (Best Practices for Sustainable Forest Management, 2022).

Besides of energy use, logging residues are a potential feedstock to produce high value -added compounds that could be used for new biorefining businesses (bio coal, biofuels, etc.). Logging residues, especially needles, contain high amounts of valuable compounds, e.g., vitamins, bioactive extractives and proteins. Forest biomass-based extractives are potential raw material to produce a range of value-added products, for example, pharmaceuticals or cosmetic ingredients. These nature-derived ingredients open possibilities for replacing fossil-based products.

In energy use, logging residues are usually dried, to maximize the energy content and the quality of the residues. There would be special requirements for the supply chain if valuable chemical compounds were produced. For example, the freshness of logging residues is highlighted when procuring feedstock for the extraction of valuable chemical compounds. Logging residues need to be collected and refined as fresh as possible.

The aim of this study was to describe how the procurement of fresh logging residues could be best organized with regard to the current forest logistics in Finland and Sweden. To get the information about the current practices, and the potential challenges and opportunities related to the procurement of fresh logging residues, Finnish and Swedish forestry operators, with experience in procurement of logging residues, were interviewed. Furthermore, the current situation regarding to the utilization of the logging residues was examined. Based on the

information received from the interviews, a regional operating scheme for the procurement of fresh logging residues was drafted.

2. Method

In order to develop a regional operating scheme for the procurement of fresh logging residues, Finnish and Swedish forestry operators were interviewed. The current practices and experiences in procuring logging residues were discussed with the forestry operators. In addition, they were asked for thoughts and ideas on how it would be possible to procure fresh logging residues in a profitable way.

In total, eight interviews were conducted. Five in Finland and three in Sweden. The aim was to interview operators who have experience in procuring logging residues. The interviewees were representatives of different forestry operators: a contractor (1), large forest industry companies (3), a sawmill (1), bioenergy supply organizations (2) and a wood supply organization (1). Some of the interviewees work only in the Botnia-Atlantica project area (2) and some operate in a wider area in Finland or in Sweden.

Interviewees were first contacted by email. The email included a cover letter that briefly described why the information would be collected through interviews. The interviews were conducted online via Microsoft Teams or Zoom and one hour was reserved for each interview. The interviews were recorded, so it was possible to check the answers and write the notes accurately afterwards. In Finland, the interviews were video recorded. In Sweden, a voice recorder was used to record the meetings. In Finland, interviews were conducted in January and early February 2022. In Sweden, the interviews were done during the period November 2021 – January 2022. There were 1 or 2 interviewers present during the interviews. A questionnaire was prepared for the interviews, and it was sent to the interviewees in advance (Appendix 1). During the interviews, approximately the same questions were asked to all interviewees. As the interviewees represented different types of forestry companies, not all questions were relevant for everyone to answer. The order in which the questions were asked also varied between the interviews because the interviews proceeded like conversations and the interviewees sometimes answered several questions at the same time.

In the beginning of the interviews the project was introduced, and interviewees were told why information was collected. Then the interviewees introduced themselves and the organization they represented. Then the operator's current practices regarding the procurement of logging residues were discussed. If the operator did not currently procure logging residues, their previous experiences were usually discussed. This was followed by discussions on the possibilities of procurement of fresh logging residues and on the demand and supply of logging residues in general.

3. Results

3.1. Current practices in procurement of logging residues

All Finnish interviewees are currently actively procuring logging residues. Logging residues are typically transported to heat and power plants, where they are burnt to generate energy. According to the interviewees, the demand for logging residues was low in Finland few years ago, but currently the demand is high, because the use of peat is being substituted by energy wood. The interviewees also believed that demand for logging residues will remain high for the next 10 to 15 years if the situation continues to be similar and political decisions allow for the procurement of logging residues and use of wood energy.

Based on the Swedish interviews, the business around logging residues is currently limited in Sweden, especially in the northern parts of the country. One of the interviewees said that they actively procure logging residues from final-fellings for heating plants, but only in southern Sweden. Two other interviewees said that logging residues had been collected in the past from traditional final-fellings, but today it is no longer common practise. One interviewee told that they actively procure a significant amount of logging residues that are “pushed out”, e.g., when forest areas are converted to agricultural lands, or from roadside clearings, road and railway constructions and other similar infrastructure projects. One interviewee said that currently logging residues are not a big business for them, because there is limited market demand.

Based on the interviews, the procurement practices for logging residues are very similar in Finland and Sweden. Logging residues are generally procured on spruce-dominated final-felling areas, where the accumulation of logging residues is high. When the operators have procured logging residues in northern parts of Finland or Sweden, they have also harvested logging residues from pine-dominated areas, since the forests are more pine-dominated in the North. According to Finnish interviewees, logging residues are harvested from almost all the spruce-dominated final felling areas when it is profitable.

The interviewees were asked whether the sites suitable for harvesting logging residues have a minimum proportion of spruce. Three interviewees said it has been 50%, and one interviewee said it is 70%. Three interviewees mentioned that when selecting a suitable site, they usually estimate the possible accumulation of logging residues. One interviewee said that at a suitable site, the accumulation of logging residues should be at least 50 m3/batch/storage. According to another interviewee, the accumulation of logging residues should exceed 40 solid cubic meters/ha. The minimum size of the site suitable for harvesting logging residues was 2 hectares according to two interviewees, 4 hectares according to one interviewee and 1 hectare according to one interviewee. Some of the interviewed organisations didn't have any guidelines on the minimum proportion of spruce or on minimum size of the suitable site. Almost all interviewees mentioned that the choice of a suitable site is influenced not only by the size of the stand and the proportion of spruce, but also by the accessibility of the site from the nearest road, transport distances, ecological restrictions or the distance to other logging residue harvesting sites. The maximum transportation distance between the harvesting site and the industry is considered to be between 50 and 100 km, both in Finland and Sweden. Distances longer than that will normally lead to too high transportation costs. The average transport distance is usually 40-60 km.

Based on the interviews, the common practice is that harvesters pile the logging residues along strip roads and the piles are left to dry at the logging site before they are transported to roadside storage with forwarders. Forwarding is usually done during summer (from May until September), and most often a particular contractor has specialized in forwarding logging residues. However, one of the Swedish interviewees said that in areas where they have plenty of space for roadside storage, they take out the logging residues directly after logging and let it dry by roadside. According to the Best Practices for Sustainable Forest Management in Finland (2022), it is recommended that at least 30% of logging residues should be left at the logging site so that the nutrients remain in the forest. Three interviewees mentioned that they followed this recommendation.

Based on the interviews, the logging residues are transported to roadside using same forwarders as when forwarding roundwood, but the residue forwarders usually have special grapples without plates between the forks to avoid the stones and soil to be lifted off with the residues. The productivity of terrain transport is also improved by expanding load spaces, for example, by expanding it backwards with additional bolsters. According to one interviewee, the bottom of the load space can also be closed, for example, by using the bottom of an oil tank. In addition, logging residues can be stacked sideways on the load space, which makes it possible to drive with a wide load. Some forwarders are equipped with a scale, meaning that both weight and volume of the procured logging residues can be measured at the site.

During roadside storage, the piles are usually covered, and logging residues can dry more. Logging residues are transported to the end-user when demand is high in winter, usually within one year after forwarding. Based on the interviews, logging residues are often chipped before transportation from the roadside storage. When the material is chipped, it lands directly into the truck's container. Then the chips are transported to the end user or to a terminal by chip trucks. Some interviewees told that the truck transportation of residues takes place in the form of unprocessed logging residues. If the end user has a stationary crusher, the logging residues can be transported without chipping. Trucks with closed containers are used for transporting loose logging residues. According to one interviewee, the load can also be compacted using logs on the top. In this way the load becomes tight, and nothing falls from the load. These kinds of compacted containers have had very good energy contents, and the interviewee told that the containers without the logs on top have had a lower energy content.

Based on the interviews, fresh logging residues were currently forwarded from the logging site to roadside storage only in special cases. For example, if the landowner wanted so, or if the logging residues were logistically better to take to the roadside with the same forwarder that was used to forward the roundwood after harvest. According to one interviewee, fresh logging residues have been forwarded in the winter from sites that have

problems with bearing capacity during summer. One interviewee said that they only harvest fresh logging residues, but they do not carry out final-felling of forest areas. Instead, they harvest logging residues from the roadsides and areas that will be converted to agricultural lands. Fresh logging residues have been delivered in the same way as dry logging residues and the fresh logging residues have been then dried only by the roadside. In some cases, the same contractors did the forwarding of both fresh logging residues and roundwood, while in other cases different contractors were used for different assortments.

3.2. Possibilities for harvesting fresh logging residues

3.2.1. Equipment and logistics

According to the interviewees, the same equipment and machinery that are currently used for harvesting logging residues would also be suitable for harvesting fresh logging residues. Some of the interviewees thought that if fresh logging residues were procured, it would be easiest that the same forwarder could handle both roundwood and fresh logging residues. The forwarder should only have special grapples to handle logging residues. This option could be cost-effective compared to the current practice. Currently, a forwarder must return to the site sometime later for the procurement of logging residues. Thus, moving the machine to the site twice increases the costs. Some interviewees thought that it would be most effective if a different contractor would come to forward the logging residues immediately after forwarding roundwood. In this case, the load space of the forwarder would be customized to handle the logging residues and the driver would be accustomed to handle logging residues.

As one of the challenges, several interviewees highlighted the timing of information flow and logistics when harvesting fresh logging residues. Currently, there are contractors working in the summer only to forward logging residues. If logging residues are harvested also in winter, up-to-date information would be needed to organize the logistics: when and where the roundwood is harvested and the logging residues are available for forwarding. This is especially important if the logging residues are forwarded by another contractor than the one who is responsible for forwarding the roundwood. According to one interviewee, forwarders are now fully occupied with forwarding roundwood in winter, so additional resources would be needed to forward fresh logging residues, or one machine would have to work in many shifts. Currently, the aim of silviculture is to maximise the yield of the most valuable roundwood assortments in the forest, so the resources are reserved for that and the machines are in use all the time. Additional resources for forwarding capacity or additional shifts require that there should be sufficient demand for fresh logging residues. According to one interviewee, “a few thousands of solid cubic meters” could mobilize additional resources. On the other hand, the fact that logging residues would be harvested all year round, would allow contractors to be employed throughout the year, when they now only forward logging residues during the summer.

According to the interviewees, the biggest challenge in harvesting fresh logging residues would be the roadside storage. There is already now limited space on the roadside in most places to store roundwood only. Thus, there is usually no space to store the logging residues at the same time. The most valuable assortments are a priority, so roundwood must be transported to the roadside first, when usually there is no storage space left for fresh logging residues. Two interviewees thought that fresh logging residues would not necessarily need roadside storage, and the logistics just must be well organized. One of the interviewees said that it is difficult to avoid the storage, or it increases waiting times for trucks or forwarders and thus also transportation costs.

When fresh logging residues are transported to the end-user, the truck transportation of residues takes place in the form of loose logging residues. The transportation costs of loose residues are higher compared to wood chips because of the low bulk density. Another factor is that more water will be transported if the logging residues are fresh when transported to the industry. In winter, there can be also snow and ice in the transport, which can increase the costs. The costs for logging will increase to some extent if the machine operators need to prepare for removal of logging residues if they have not done it before. However, the interviewees did not believe that procurement of fresh logging residues would have a major impact on harvesting costs. Some interviewees said that if the price of fresh logging residues were determined by weight, the price could even decrease because fresh logging residues weigh more, and the loads would be heavier.

3.2.2. Quality of fresh logging residues

Many interviewees believed that the logging residues could not be procured fresh during the summer because of the rapid changes in needles when it is warm. On the other hand, according to the interviewees, winter conditions can cause challenges to the procurement of logging residues because the frozen needles will fall and break already during harvesting. Procurement of fresh logging residues can also be difficult if it is snowing a lot and the residues are covered in snow. On the other hand, in winter the bearing capacity is usually better when the soil is frozen, and harvesting is possible even in sites that are not possible to go to during the summer. One interviewee said that logging residues need to be used to improve bearing capacity and that is why they have not collected logging residues in winter. For this reason, the interviewee believed that procurement of logging residues would not be possible in winter.

When procuring and storing logging residues, the cleanliness and hygiene of logging residues may need to be considered more carefully, if they will be used for other purposes than energy production. In that case, harvesting would be slower, which could increase costs. If the same drivers who are now harvesting the roundwood would also handle the fresh logging residues right after the harvest, they would need additional training. On the other hand, procurement of logging residues in winter could improve the cleanliness of the residues when there is snow, and the soil is frozen.

3.2.3. Ecological sustainability

Some of the interviewees mentioned that the ecological sustainability needs to be noticed when harvesting fresh logging residues. Currently, the Best Practices for Sustainable Forest Management in Finland recommend that at least 30% of logging residues should be left at site to maintain nutrient balance of the forest. This recommendation was mentioned by most of the Finnish interviewees. The current recommendation assume that the logging residues are dried at site, so the needles fall off before the procurement. If the logging residues are harvested fresh, the amount of logging residues left at the site should possibly be reconsidered. Two of the interviewees had doubts whether fresh logging residues could be harvested in an ecologically sustainable way.

3.2.4. Changes in operations and equipment

Interviewees were asked about their opinions on some equipment and on possible changes in practices to forward fresh logging residues. Almost all interviewees had experience in bundling of logging residues, but they were not doing it anymore. They said that it was too costly and inefficient compared to the current practices, although it could slightly increase the efficiency of long-distance transport.

The interviewees were asked if it would be possible to change the bucking optimization in the cut-to-length harvesting, so that longer treetops would be left, which would be easier to forward. The interviewees considered it possible, but they did not see it as a realistic option in terms of current pricing and demand. When the prices of pulpwood and logs are higher than the price of the logging residues, forest owners want to maximize the amount of logs and pulpwood and the harvesting is done accordingly. The interviewees were also asked whether the forwarding order could be changed so that the logging residues would be forwarded first and thereafter the roundwood would be taken to roadside. They all agreed that if the roundwood is the most valuable assortment, it also has to be transported first to the roadside.

3.2.5. Demand and supply of logging residues

Currently, logging residues are already widely utilized in Finland. Many of the Finnish interviewees thought that in many places they already harvest all the logging residues that can be harvested cost-effectively. Some of the logging sites are also out of question due to small size, long distances, difficult terrain, or ecological restrictions. Some of the interviewees were asked whether they see any challenges if the demand for logging residues would increase in the future. However, that was not generally considered as a challenge. Currently, the demand for logging residues is high in energy use but this was not the case a few years ago, so the situations can change. Demand is affected by political situations and decisions, and it is challenging to estimate the demand for logging residues in energy use in the future. It has already been seen that the decline in the use of peat is increasing the demand for energy wood in Finland, and also Swedish interviewees had noticed an increasing interest to substitute peat with logging residues. Interviewees believed that demand would remain high in the near future, but it may be affected by political decisions, such as banning the use of wood for energy production. According to one interviewee, the availability of logging residues is also affected by the demand for other wood products and thus

the amount of final-fellings. Demand for timber or sawn wood has been high recently, so a lot of final-felling has been done and there has been logging residues available.

In Sweden, one of the interviewees said that it would not take very long time to start up the business around logging residues if there would be a demand. They have the systems for it. However, it takes some time to become good at it. It would also require that the high demand could be predicted to be stable for a long time in order for contractors to be willing to invest in needed equipment. Another interviewee believed that the future for logging residues looks quite good now because many of the heating plants need to substitute peat with something else. Thus, many customers are currently interested in discussing long-term agreements for logging residues. In addition, also other customer segments have shown an increasing interest in logging residues, for example, pellets producers.

One of the interviewees believed that there can be a demand for new products produced from logging residues in the future, but it may take some time before large amounts of logging residues are needed for new purposes. By then, new alternatives to the wood fuel might already be developed. Therefore, the potential increasing demand for logging residues for other than energy purposes may not compete with the energy use of logging residues.

One interviewee mentioned that the demand for logging residues is currently seasonal, as energy wood is needed mainly in winter, and the procurement of the logging residues is done during the summer. The demand and utilization of logging residues would be needed all year round to stabilize the seasonality and to decrease the contractor costs and unit prices.

Based on the interviews, forest owners are willing to sell logging residues when they are selling roundwood. The procurement of logging residues facilitates the cultivation process and brings additional income to the forest owner in connection with the timber trade. The advantage of procuring fresh logging residue is that the forest owner can start regeneration work faster, already the next spring after the harvest, if the logging residues are immediately removed.

4. Discussion: the regional operating scheme for the procurement of fresh logging residues

This study shows that the possibilities to procure fresh logging residues are good if there only is enough demand. Currently used equipment and practices are suitable for procuring fresh logging residues from the logging site to the roadside. Especially in Finland, there are already well-established practices and equipment, and logging residues are actively procured. That part was considered quite simple.

The logistics and the resources to handle logging residues can cause challenges to procurement of fresh logging residues. As long as roundwood is more valuable than logging residues, harvesting and transport of roundwood is a priority. For the foreseeable future we can thus expect that extraction of logging residues will take place after roundwood has been removed. However, this can be done in (at least) two ways. The first option is that the same forwarder that first forwards the roundwood could immediately after that forward the fresh logging residues. The grapples should be replaced with an energy grapples and the load space of the forwarder could be expanded if necessary or the bottom of the loading space could be covered. The second option is that another contractor comes to procure the fresh logging residues immediately after the first contractor has forwarded the roundwood. This other operator can already have a forwarder adjusted for forwarding of logging residues.

The lack of storage space on the roadside would be a challenge. Only few places have enough space that both roundwood and logging residues can be stored at the same time. Even if fresh logging residues need storage only for a short time, it can be difficult to avoid roadside storage completely. If the logging residues are not stored at all, it increases the waiting times for either the forwarder or for the truck that is transporting the logging residues to the end-user. In that case, the supply chain would become very “hot” (i.e. sensitive to disturbances) and it requires additional resources and demand for fresh logging residues.

The results of this study show that demand strongly regulates the development of different operating methods. The greater the changes needed to current practices are, the greater the demand for fresh logging residues

should be. Therefore, the regional operating scheme for the procurement of fresh logging residues would consist of the following three different operating options that could be used to procure fresh logging residues depending on the demand for the residues (Figure 3):

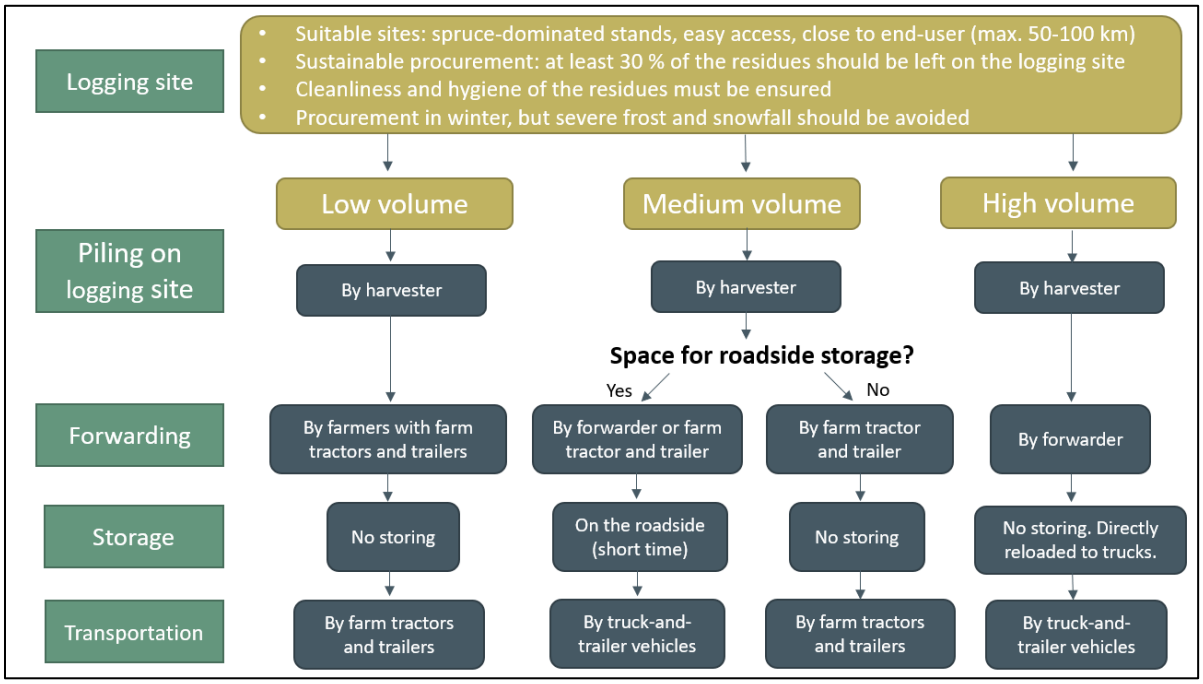

Figure 3. Based on the opportunities and challenges brought up by the interviewees, guidelines have been prepared for the procurement of fresh logging residues.

- If the demand or volume for fresh logging residues is low (some hundreds of cubic metres), procurement could be carried out by farmers. They could operate in addition to their daily work and handle small volumes of logging residues. In this case, it is not necessary to purchase separate equipment, as farmers could handle the procurement with farm tractors and trailers. The benefit of the farm tractor based harvesting chains is that, in addition to the use of the tractor in logging residues procurement, the tractor can be used for other purposes by the farmer. Farmers often have tractors equipped with various forest implements, e.g., loaders, trailers and felling heads for harvesting. The farmers could collect the logging residues from the site as soon as the roundwood has been collected and transport the residues directly to the end-user without storage. The disadvantages are short operating distance (<50 km) and limited capacity (Alakangas & Virkkunen 2007). However, this should not be a major problem since transportation distances are today quite short and in a situation with low demand the logging sites closest to the end user will most likely be prioritized for extraction of logging residues.

- If the demand for logging residues were a little higher (some thousands of cubic metres), the harvesting of fresh logging residues could be carried out in the winter by the same contractors who are currently handling logging residues during the summer. Harvesting fresh logging residues during the winter could allow contractors to specialize in procurement of logging residues and to be able to work all year around with that assortment. However, as highlighted in the interviews, the challenge during the winter is that there is not enough storage space on the roadside for logging residues. It would be possible to operate in the sites with enough storage space, so that after forwarding the roundwood, the forwarder also takes the fresh logging residues to the roadside. Then the logging residues should be transported to the end-user by large truck-and-trailer vehicles as soon as possible. The bottom and the sides of the load space must be closed. The trucks should be equipped with cranes for loading and unloading the material. Fingered grapples are suitable for loading uncomminuted forest fuel. The load can also be compacted with the crane or using logs on the top of the load.

If there is not enough storage space next to the logging site, farm tractors with trailers could transport fresh logging residues further (100-400 meters) to the roadside where logging residues could have their own storage. Logging residues could be transported from the roadside to the end-user by large trucks as soon as possible. The advantage of farm tractors is that they are faster than forwarders and they would not break the roads.

One option would be to avoid storage of the logging residues by the roadside and to procure the logging residues, for example, with a machine like a HavuHukka-trailer (Figure 4.) or similar machines. A farm tractor can be used as the traction engine. The specialty of the trailer is the hydraulically sealing sides of the load space that enable the continued short-distance transport of the logging residues directly from the site to the end-user (Halme 2009). In this case, a roadside storage is not required. In the early 2000s, 20 trailers have been manufactured in Finland, and some of them are currently in use. The trailer is loaded when the sides are unfolded, and the volume of the trailer is about 70 cubic meters. After loading, the sides are turned to the vertical position, when the load space is compressed into 46 cubic meters. The availability of the device could be a challenge and it might need some additional development.

Figure 4. HavuHukka-trailer. (Source: Puhakka Asko/MetsäVerkko).

- If the demand for fresh logging residues becomes high (tens of thousands of cubic metres) logistics can be reorganized to harvest fresh logging residues and it would be possible to invest in additional resources. In that case, it could be reconsidered whether it is possible to forward logging residues to the roadside first, before roundwood. Probably in the near future, roundwood will be forwarded to the roadside first. Immediately after that the fresh logging residues would be forwarded to the roadside and the loose residues will be loaded directly to the truck for the transportation to the end-user. This would increase waiting times for either the forwarder or for the truck, which would increase transportation costs. In both cases, the forwarding of the logging residues can be handled either by the same forwarder which handles the roundwood or by a different contractor, which only handles the logging residues.

When logging residues are utilized for purposes other than wood energy, the cleanliness and hygiene of the residues must be ensured. New practices in procurement of logging residues require additional training for forwarder drivers. According to the interviewees, the quality of needles changes rapidly during the summer so fresh logging residues could probably only be harvested in winter. If possible, the procurement of fresh logging residues should not be done during severe frost and snowfall because then the needles easily break or will be covered in snow. If the fresh logging residues are stored by the roadside, even for a short time, it should be ensured that fresh logging residues remain clean and dry during roadside storage. Logs can be added under the piles and the residues should be piled on dry places, not in the ditch.

If logging residues are used as a source of ingredients, for example, in the cosmetics or pharmaceutical industries, it should be examined whether bio-oil should be used in equipment and machinery when harvesting and transporting the residues. Some of the interviewees found this challenging if bio-oil was not used on all the machines. All kinds of customized and special arrangements increase costs. In that case, it is essential to make sure that in the situations where oil has been leaked, the logging residues are not used for these purposes.

Based on the interviews, a suitable site for harvesting logging residues is a spruce-dominant (more than 50% of spruce) and the size of the logging site is at least 2 hectares. Nevertheless, even a smaller site could be suitable, if it is close to the road or to another site, where the logging residues are harvested from. Currently, profitable harvesting of the residues requires that the roundwood removal from the site has been at least 200 solid cubic meters (Best Practices for Sustainable Forest Management, 2022). The residues should not be forwarded long distances to the roadside storage. When forwarding loose material, the forwarding distance from the site to the roadside storage is recommended to be less than 300 metres (Best Practices for Sustainable Forest Management, 2022). Based on the interviews, the long-distance transport of loose logging residues should not exceed 80 km, but on average transport distances should be shorter, about 40-50 km.

When harvesting fresh logging residues, more nutrients are removed from the site because the logging residues are harvested with needles. This nutrient depletion may affect the growth of the future tree generation, especially in spruce-dominated stands. Currently, it is recommended to harvest logging residues in the way that as much of the needles as possible remain in the forest to maintain the nutrients of the soil and stands (Best Practices for Sustainable Forest Management, 2022). According to the recommendations, energy wood is not harvested at all from poor soils. If the fresh logging residues are harvested and the needles do not have time to fall on the site, the ecological sustainability of the logging residue procurement must be ensured. Currently, there are recommendations for harvesting fresh logging residues, and these recommendations should be followed in the future as well (Best Practices for Sustainable Forest Management, 2022):

- It is recommended that at least 30% of the total amount of logging residues are left at site, so that the residues are distributed as evenly as possible over the entire harvesting area.
- Outside the frost periods, the amount of logging residues should be ensured by pruning approximately every fifth of the conifers outside the residue heaps. In addition, there are always some small-diameter trees, the bottoms of logging residue heaps and broken branches and tree-tops left in the felling area.
- When the trees have been felled during severe frost, the amount of logging residues that remain at the site is usually sufficient.

Currently, the harvesting of fresh logging residues is not very common. If it would be done to a greater extent, probably a more detailed examination would be required to estimate what is a sufficient amount of logging residues that should be left at the site.

5. Conclusion

Based on the interviews, harvesting of fresh logging residues is possible if the sustainability issues are considered. Procurement of fresh logging residues would be organized if there were sufficient demand to make it profitable. Currently, the procurement resources and logistics have been calculated and organized on the basis that roundwood must be forwarded from the logging site first. Procurement of large amounts of fresh logging residues would require additional resources. In Finland, logging residues are actively procured all the time, so equipment and practices for harvesting fresh logging residues can be activated quickly. In Sweden, where procurement currently is lower, increasing the harvesting of logging residues would require more effort. The operators' interest in harvesting fresh logging residues and investing in new equipment would require long-term contracts and demand for fresh logging residues.

Further examination is required to clarify what is meant by fresh logging residues. Is it possible to harvest fresh logging residues in summer and how quickly the residues must be forwarded and transported to the end-user? It must also be examined whether the logging residues must consist purely of spruce logging residues or whether there may also be pine residues. Separating the logging residues would make the harvesting slower and increase costs.

In the future, there can be also changes and developments available for the procurement chain of logging residues. For example, it could be possible to use fresh logging residues and wood chips in energy production (Leppänen et al. 2016). If fresh logging residues can be utilised for energy production as well, the procurement practices could be adjusted to handle fresh logging residues and there would be more resources available for the supply chain. Also, fast track supply chain for logging residues has been under development. The fast track supply chain is based on roadside chipping of logging residues, in which chips from final-fellings harvested during spring, summer and autumn are transported straight to the power plant with maximum of half month roadside storing (Leppänen et al. 2016). This kind of new practices could support and develop the use of the fresh logging residues. The increasing use of forest energy might also require new bio-terminals, when the harvesting and procurement of forest energy can be done directly at the terminal, which reduces the need for roadside storage.

In Finland, the demand for logging residues is high in energy use, but it is difficult to predict what the situation will be in the future. In the next few years, forest energy will be increasingly needed to replace imported fuels. The interviews were conducted before the war was launched by Russia on February 24, 2022 in Ukraine. The changes in energy production and the banning of energy wood imports from Russia will affect the availability of wood fuel for energy plants. According to the estimates, the demand for wood fuels at energy production plants will increase by 6.4–8.3 million cubic metres from current levels by 2030 (Finnish Forest Centre 2022). Furthermore, availability of other solid by-products and the substitution of peat with other renewable fuels, as well as the improvement of energy efficiency in production facilities affect the demand for wood chips. Of course, logging residues are not the only source of forest energy and the main fraction of the wood chips in Finland comes from the tending of young stands.

The demand for logging residues is also affected by political decisions and increasing EU regulation of energy production and logging volumes. Increasing fuel costs and the availability of labour and equipment for harvesting and transport can cause challenges to demand growth. The value of domestic wood is likely to increase in the near future. On the other hand, increasing demand for logging residues could be accelerating growth in the sector.

Currently, there are enough logging residues available for the energy production. In the future, the supply could be affected by many things, such as changes in logging volumes or in logging methods. For example, if continuous cover forestry would become more common, it could affect the amount of logging residues available. Similarly, the demand for wood products affects the amount of final-fellings that are carried out.

The supply and demand of the logging residues is affected by multiple factors, so it is difficult to predict how the other possible ways to utilize logging residues to produce valuable biochemicals and ingredients would affect on the supply and demand of the logging residues.

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APPENDICES

Appendix 1. Interview questions

Background questions

- Name of the company
- Name and a title of the interviewee
- Briefly describe the company's operations (products/services offered, customers, working area, number of employees, turnover etc.)

Logging residues procurement currently in your organisation? (if it is not done currently, you can describe how it has been done before):

- From what kind of stands do you take out logging residues? *(only from spruce stands? minimum % of spruces on a compartment? minimum size of the compartment? from what kind of habitats?)* What time of the year they are taken out?
- What is the proportion of the logging sites where you take out logging residues from?
- Who is responsible for the procurement of logging residues?
- What kind of machinery is used to take out logging residues from the site (and transported short distances)?
- How soon after logging the residues are taken out from the site?
- How are the logging residues stored, where and for how long time? (*at the logging site? Roadside? Terminal?*)
- How the logging residues are transported (longer distances)? Where? What kind of machinery is used?
- How long distances the residues are transported? Are the residues transported as loose residues or as chips?
- Have the logging residues been chipped? When and where? Who is responsible for chipping?
- Who is the end user of the logging residues? When the residues are sold to the end user?

Have you done forwarding of freshly cut residues? If yes, how did you do that? Why that was done?

How it would be possible to handle the procurement of fresh logging residues?

- Would it be possible to start doing it now in appropriate sites?
- What should be changed in the supply chain? *(What kind of ideas do you have, how it could be done? Would it be possible to change the driving order at the logging site to take out first residues and after that timber?)*
- How it would effect on the costs of the procurement?
- Could you use the existing machinery / forwarder to transport logging residues?
- Would you be interested in bundling of logging residues? Have you done that before? What would be needed for that?
- Would it be possible to do whole tree harvesting?
- Would it be possible to take out long tops?
- Could you separate needles before chipping? What would be needed for that?
- Do you use or would it be possible to use only bio-oil for a harvesting chain (incl. harvester, forwarder)?

How much logging residues could be taken out? What is the amount of logging residues from one harvesting chain?

Are forest owners interested in selling logging residues?

What do you think, is the demand of logging residues increasing or decreasing in the future? If it would be increasing, are there any obstacles?

Other thoughts or ideas regarding to the procurement of fresh logging residues?