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SUPPLY CHAIN ANALYSIS OF SAWDUST PRODUCED BY INNOVATIVE HARVESTERS

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Abstract

The thesis was assigned by Hannu Vilkkilä from JAMK University of Applied Sciences Natural Resources department who is the inventor of the special machinery used in the sawdust picking process.

The objective of the thesis was to find out what it costs to deliver sacks of sawdust or pellets from the roadside of the logging area to the end customer. This thesis mainly focuses on the logistics costs of the sawdust supply chain.

The work was implemented in a way that first the actual supply chain of the sawdust had to be determined and the closest supply chain was used as a reference which in this case was the supply chain of woodchips. After the supply chain was determined the costs had to be estimated and then the actual estimated cost for sawdust sacks was acquired.

The results show the transportation cost difference in different distances the sawdust is picked up from.

It is important to notice that the actual sawdust gathering procedure is in an early phase and that the system will be developed more as time passes and so should this sawdust transportation system but nevertheless this thesis gives a basis to work on.

Keywords
Sawdust, supply chain, bio energy

Miscellaneous

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1 INTRODUCTION

The core point of this research is to determine the cost of logistics for sawdust produced by harvesters delivered from the roadside of the logging camp to the customer.

The reason this kind of a research must be done is because there is a new invention that allows the sawdust to be picked, dried and packed in the field during the logging operations by the harvester machine.

This research was initiated by Hannu Vilkkilä who is the representative of the host organization JAMK University of Applied Sciences Natural Resources Department.

The sawdust produced by harvesters during the logging operations is a by-product so it does not have any value or cost when it is gathered. The reason this research must be done is to determine the value of the sawdust so it will be possible to name the price for the customers. This sort of operation has never been done before so it is essential that the logistical costs will be determined.

1.1 Research objectives and focus

This thesis focuses on the logistics costs the sawdust accumulates when it is moved from the forest to the roadside and from there to the customer. It is pre-determined that the form of sawdust will be either just plain sawdust or pellet and this research examines the reasonable possibilities to package them and what transportation methods to use to transport them and the possible need for temporary warehousing.

The customer base is divided in two sections, a large-scale consumer and a small-scale consumer. The environment for the research is the country of Finland and all the transportation costs, laws, rules and regulations of the country apply to this research. The felling operations considered are final cutting and improvement cutting. In addition the thesis also describes the supply chain of the sawdust.

1.2 Research methods

This research creates a hypothetical model since it is impossible to determine the exact costs of operations at this stage of the project. Many of the values used in this research are approximate values and based on previous data acquired from similar operations done before.

There will be four different configurations of the cost model. The plain dust delivered to the large-scale customer, the plain dust delivered to the small-scale customer, the pellet delivered to the large-scale customer and the pellet delivered to the small-scale customer.

The research methods are examining previous cases related to the subject, acquiring knowledge about forest transportation and its costs. All the cost data will be inserted into a formula that determines the hypothetical cost of operations. This should give a sort of a guideline what the costs will be if the plan would be executed.

What makes this research a difficult case is that there is no real data about delivering sawdust from the forest in a manner that is used in this case, but it is possible to get some reference from the supply chain of wood chips.

Interviewing professionals from the field of forest industry is also an important method of research in this case. It will provide some facts and figures to work with and provide an inside view of the forest industry, which is not so familiar to a logistics student, to make the most optimal decision concerning the logistics operations of the case. One part of the research is also learning about the actual machinery that will pick up the dust, dry and pack it by visiting the premises where the machine is being built and tested.

2 THEORETICAL BASIS

2.1 Supply Chain

2.1.1 Management

Supply chain management basically means taking care of the supply chain of a certain product or service as a whole. This includes everything that has something to do with the value of the product when it is delivered to the customer from the original provider or manufacturer. All these things are related to each other and must be taken into consideration when considering the value that is building up for the product or service. (Skjøtt-Larsen 2007, 20).

There are five main operations in the usual supply chain.

1. Demand management – which means work that has something to do with finding out what the demand is for the product and even creating demand by marketing.

2. Distribution – this means the methods to actually provide the goods to the customer such as transportation and distribution channels.

3. Production – this includes everything that is related to the production of the product, such as where it is produced, how it is produced and what it costs.

4. Purchasing – production needs raw material and equipment which is obtained by purchasing activities.

5. Returns – this basically means defects and recycling for reuse. (Skjøtt-Larsen 2007, 30).

The purpose of supply chain management is to bring all these stages into a larger system so it is possible to control and balance them in relation to each other. It is very important to be aware of the demand of the product to balance all the other activities to fit it. That leads to reducing inventories and costs and finally creates a bigger strategy for the company or producer of product that can lead to market advantage and all in all better results, customer satisfaction and profits. (Skjøtt-Larsen 2007, 31).

Some of the most important factors in creating a successful supply chain are trust and commitment between parties and an information system suitable for the situation. (Stadtler 2008, 501).

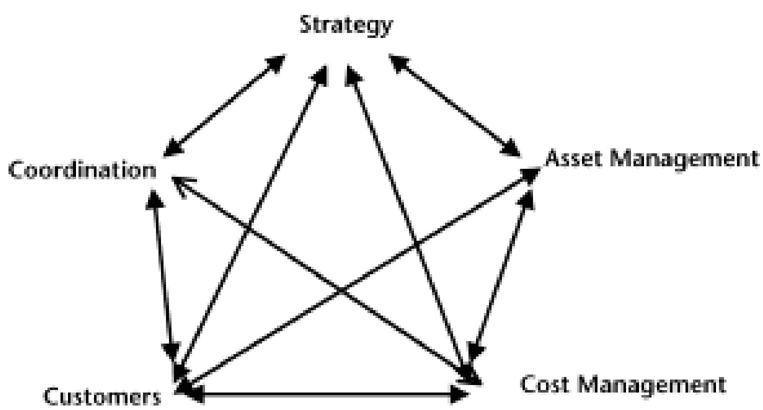

FIGURE 1. The management concept of the supply chain. (Skjøtt-Larsen 2007, 31).

2.1.2 Analysis

Supply chain analysis is done to improve the supply chain of the company or product. Supply chain analysis is not a onetime thing but an ongoing process that tries to improve the supply chain all the time. There are many different kinds of supply chains and that makes it so difficult to perform a proper supply chain analysis. There is no ultimately correct answer for supply chain problems. Managing the supply chain is about balancing the theoretical process model and the real life situation. One of the important things in supply chain analysis is to recognize all the players that contribute to the supply chain in one way or another. (Stadtler 2008, 37).

Process modeling and measuring performance of the supply chain are important. Process modeling is creating a model of the supply chain and how it should work in theory as shown in the part 2.1.1. Measuring the performance of the supply chain and all the activities in it is important to see whether the supply chain strategy is working and that the future goals are reachable. (Stadtler 2008, 49).

2.1.3 Transportation

Transportation, a part of the supply chain that is probably the most important aspect of it considering this project since it causes a notable amount of the logistic costs, on which this project is focused on.

Transportation is something a company, in most cases, must do if it wishes to provide the customer with goods. Transportation really only creates costs and it should be avoided or at least try to reduce the costs of it. Transportation should be optimized to create the least amount of costs because it only increases the cost of the product without increasing the actual value of the product to the customer. Same goes with warehousing where the product does not generate any value but only causes costs.

In Finland the length of the transportation routes are long because Finland is such a sparsely populated country. In this project it is very important to take in to consideration where to it is reasonable to deliver the sawdust from the forest so that its price will still be competitive when considering other similar products. Of course the railway transportation would be the cheapest of all but the infrastructure of the railway network and the actual felling areas which are always changing and the volume of the sawdust make it rather impossible to use the railways.

The following Figure 2 shows possibilities of delivering goods from the factory to the customer. It can be straight line transportation to the customer if the volumes are big and it is cost effective. If it is not cost efficient to deliver the goods straight to the customer it is possible to deliver the goods to a distribution centre where the goods are delivered onwards. Even smaller batches of goods can be delivered to the customer by transporting the goods to a transshipment point where from the goods are delivered in small amount straight to the customer. (Stadtler 2008, 232).

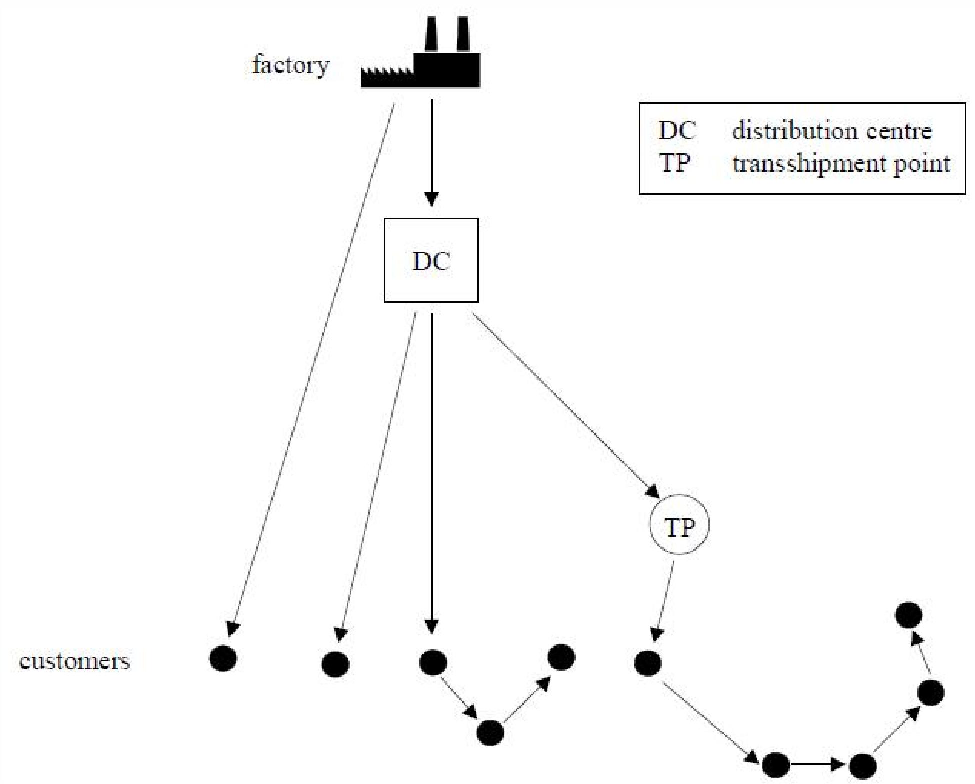

FIGURE 2. Distribution paths. (Stadtler 2008, 233).

2.2 Bioenergy

Bioenergy is low-risk and environmental source of energy that is produced by forestry and farming. One of the challenges of bioenergy is to produce it cost effectively. Nowadays environmental friendliness is an important value and it lets bioenergy to step in to the action. (Richardson 2002, 14)

Pellet and sawdust can be used as fuel. It is renewable and safe way to replace fossil fuels.

2.2.1 Forestry

Finland is the most forest covered country in Europe. That means forestry is a big field of business in Finland. The industrial usage of forest in Finland started back in 19^{th} century. In 2010 the amount of forest industry out of GDP was about 5 percent. Finland is very dependent on the success of the forest industry and therefore inventions like this new machinery are definitely needed. During the recent recession the pulp and paper industry in Finland took a 20% loss in production capacity and this tells new innovations are also needed to keep Finland competitive and attractive for export. (Metla 2012)

2.2.2 Forestry products & their usage

The most usual forestry products are logs of wood used to produce woodchips that can be used in paper and pulp factories as well as electricity plants. Other products from forest industry are for example the bark from trees, tree stumps, sawdust, wood charcoal and pieces of wood which is used mainly by private persons at their summer cottage or just for warming the house.

2.3 Sawdust

Sawdust currently is mainly gathered from mills that cut wood but this new invention makes it possible to gather the sawdust while cutting wood in the forest and better yet it will be dried up at the same time. Sawdust is used for burning in various factories and electricity and heat plants. Moisture percentage of sawdust is around 50% and the heat value it produces when burned is 18.9 -19.2 MJ/Kg which is about 5.3 kWh/kg. (Alakangas 2000, 69) The sawdust in this case is probably dryer than 50% of moisture so the kWh/kg will be bigger.

2.4 Pellet

Pellets are made by pressing; an example of a pellet pressing factory process can be seen in the Figure 3. Pellets are basically just sawdust or woodchips.

The size can vary between 10 - 30 mm of length and a diameter of 8 - 12 mm. Pellet is used to warm up buildings and it requires proper burning equipment. Pellet must have a low moisture percentage (~8 - 10%) and they produce heat value of about 14 - 17.5 MJ/kg which is about 3.9 - 4.9 kWh/kg. (Alakangas 2000, 76)

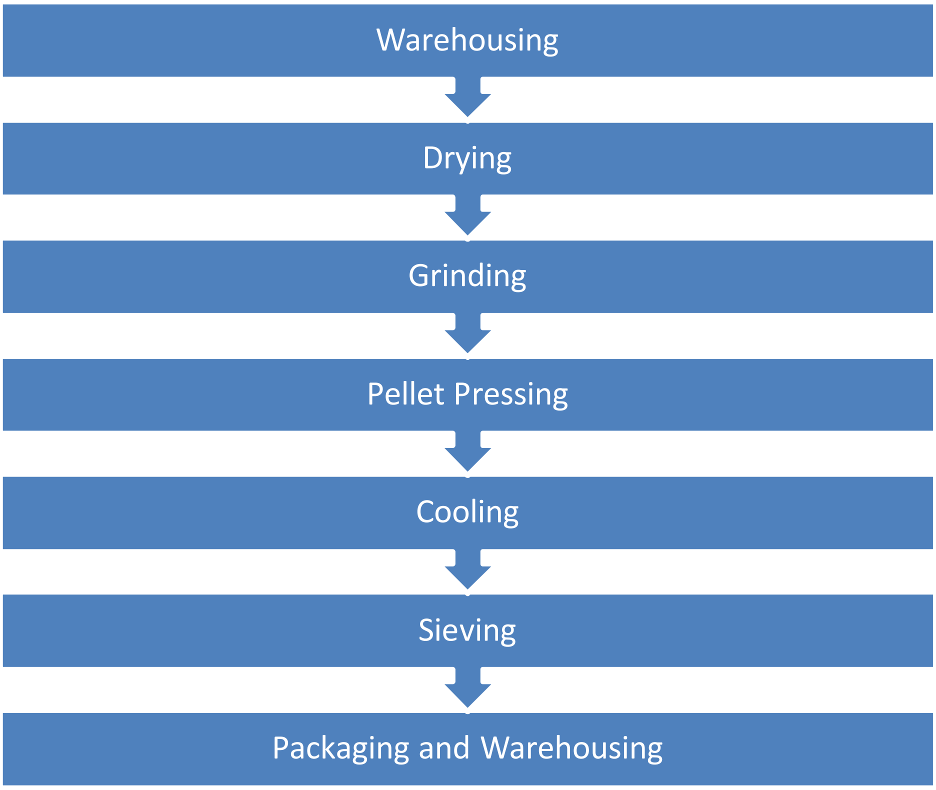

FIGURE 3. An example of a basic pellet pressing process. (Vapo 2009)

2.5 Supply chain of wood chips

The supply chain of wood chips can be used as a base model for this case to plan the supply chain of the sawdust.

The resources for wood chips which are logging residues, small diameter wood and tree stumps are delivered straight to the place where they are used or just made into wood chips already at the roadside warehouse. There are hubs where the residue and chips can be delivered to be made into bigger batches or mixtures of biomass. At the hubs it is also possible to produce wood chips. (Lähdevaara 2010, 11 - 12)

In detail the supply chain goes as follows. The supply chain starts in the forest where the material for wood chips is acquired when cutting down the forest. The logging residues like tree branches and leaves will be piled up in the forest, transported from the forest to the roadside where the wood chips are made with a wood chipping machine. From the roadside wood chipping area the wood chips are transported to the place where they are needed, for example a power station, to produce heat. Same supply chain applies for the tree stumps and small diameter wood. It is also possible to not to do the chipping process at the roadside. All the materials gathered from the forest to the roadside can be transported straight to the customer where the chipping will be made by them. The third way is to transport the chip material to a hub where the chipping process will be done and after that the wood chips will be delivered to the customer. (Lähdevaara 2010, 38)

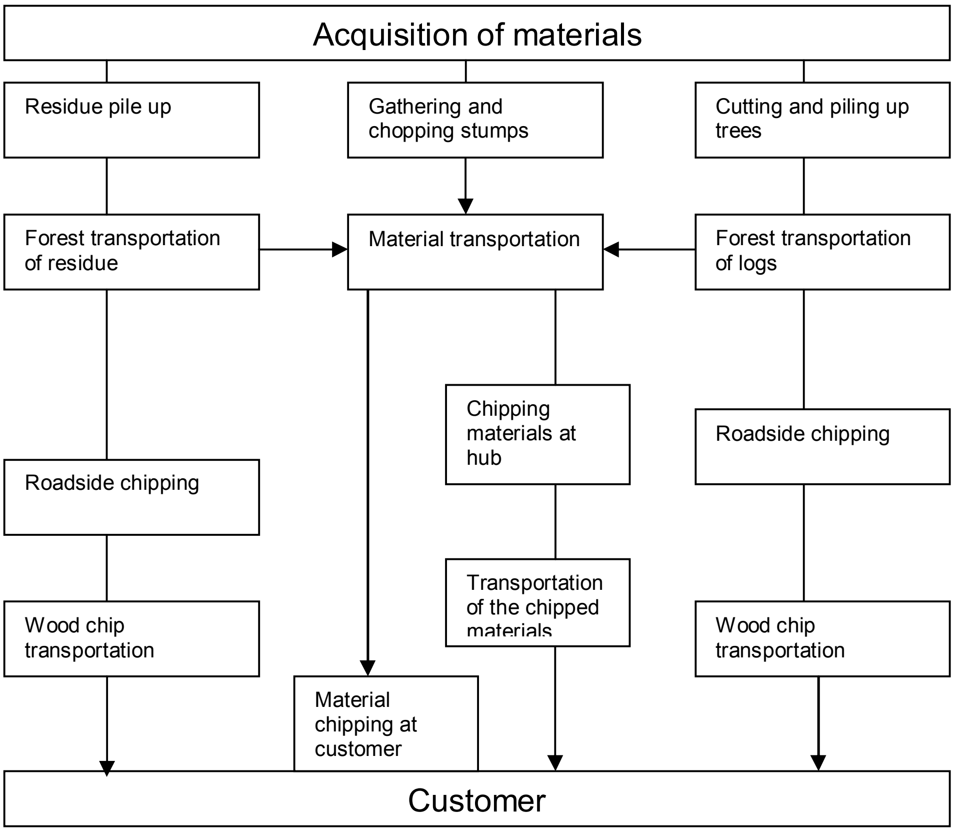

FIGURE 4. Different supply chains. (Lähdevaara 2010, 38)

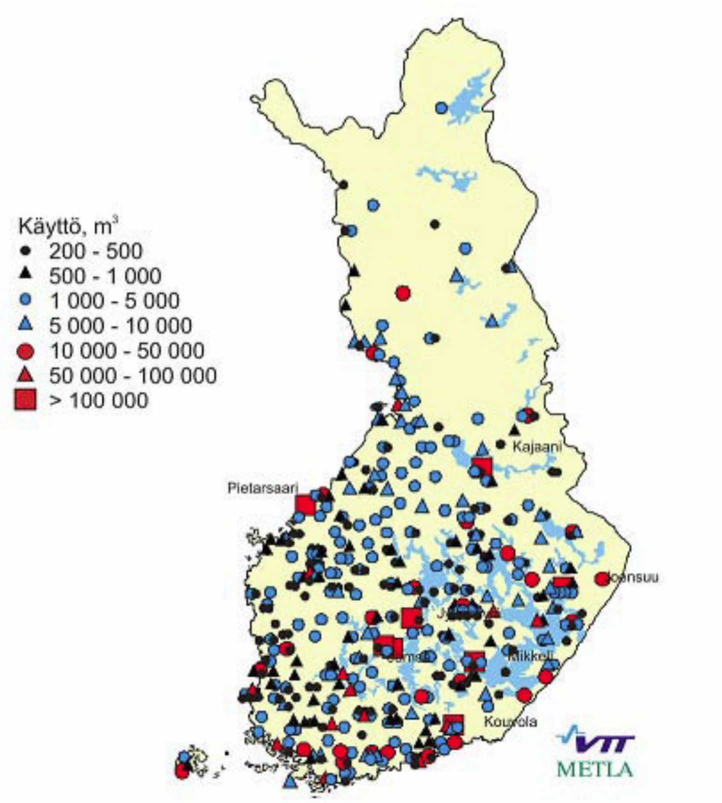

FIGURE 5. Power and heat plants that are using wood chips in Finland in 2009. (VTT 2010, 14)

3 RESEARCH

3.1 General information about the solution

As mentioned before there will be four different configurations, two configurations for plain dust and two for the pellet. The dust and pellets will be packed in a sack which will be described in detail later. The two different end users will be large-scale and small-scale customer. These customers have different needs so therefore two configurations are needed.

The phases which will be analyzed in each configuration are the procedures and costs of woodlot operations and transportation of the sacks of dust to the roadside warehousing area, the warehousing costs and operations at the roadside and the transportation of the dust sacks from the roadside to the end customer or distribution centre. All in all the main cost factors will be handling costs, forest transportation costs, warehousing costs and long distance transportation. These costs vary for each configuration and after calculating all the costs for each configuration the costs will be compared between each other.

Main idea is to transport the sawdust from the forest with a truck, straight to combustion plant or deliver to some retailers to sell onwards. The logging site should be less than 100 km away from the delivery place and if not the sawdust sacks, bales and briquettes should be delivered to some warehouse where they can be moved onwards. The most optimal situation for transportation is that the distance for transportation is very short and the amount of time used for warehousing is zero. The sawdust should not get mold because it is already dried during the picking process with the harvester so the only possibility for wasted products are the sacks which could break and cause loss. The packing material and method also causes costs. (Ritvanen 2011, 95)

3.2 Sawdust in detail

3.2.1 End users

The sawdust in this case is a little bit bigger than the normal fine sawdust you get when you use a saw by hand. It is from a harvester which uses chainsaws that cut a little bit bigger, so called chips, from the wood.

In Finland the sawdust is mainly used for chemical pulp and burning for energy. Usually the sawdust is very wet (~50%) but in this case the amount of water can be reduced because the machine dries the sawdust and that makes the transportation easier and cheaper due to light sacks which need to be transported.

3.2.2 Transportation

For transportation the sawdust must be packed in a sack to avoid moisture. It is not reasonable to transport sawdust long distances since it does not have very high density and that makes the transportation quite uneconomical.

On the forest roads sometimes it is not possible to drive a truck with a trailer so the most reasonable option for a transportation vehicle is to pick a truck with the longest possible wheelbase.

Transportation vehicle must be chosen to be suitable for the amount of sawdust that is to be delivered and from where to where.

FIGURE 6. An example of a truck with a trailer that picks up tree stumps. (Kuljetus Tero Seppälä Oy 2013)

A similar delivery vehicle like in Figure 6 could be used to pick up sacks of sawdust if the amount of sawdust is a lot. Having a crane on the truck is quite important since otherwise it will be problematic to load the sacks on the vehicle.

FIGURE 7. An example of a truck that can be used to pick up sawdust sacks. (Mascus 2013)

It is also possible to deliver the sacks with the rest of the forest residue to the customers or to a hub using a special truck designed for that with a cargo space called Energy boxx.

In case of smaller amounts of product, a smaller truck or a van can be used to pick up sawdust sacks from various logging sites in a row and the deliver the sacks to the customer or a hub. Picking the 200 kg 1 m^3 sacks requires a lift of some sort.

FIGURE 8. A smaller truck to deliver smaller amounts of sacks. (Mascus 2013)

3.2.3 Cost

Transportation, warehousing and packing costs are the only costs to be considered. The usage costs of the drying and packing machine are also a factor but not that relevant in the logistics part where this thesis focuses on.

3.2.4 Pros & Cons

Sawdust is a side product from tree felling which means it’s practically free. On the other hand the sawdust and woodchips that are used in power stations for burning and creating heat energy must be of uniform quality and must not be too big. The low moisture of the dust is also important when used for burning.

3.3. Pellet in detail

3.3.1 End users

The end users for pellets are customers who use pellets for heating, like power plants and private customers.

3.3.2 Transportation

The problem with pellet transportation is the question of is there enough pellets for economical transportation from a single felling area. It might be possible to use smaller trucks to gather from a certain area of the country from all the logging sites but then there should be some kind of a picking system to lift the pellet sacks on the bed of the truck. The size of the pellet sack is quite an important factor here. If it is not possible to have a pellet pressing machinery at the forest clearing area, there is also a possibility that the sacks of sawdust will be delivered to a pellet pressing site and from there the pellets will be transported onwards. This of course increases the costs of making the pellets significantly.

Depending on the amount of pellet material received from a certain logging site a small truck or a van can be used to pick up the materials from the roadside warehousing area. In case the amount of pellets is small the pellet sacks can be delivered by the harvester operators back to a certain area where the small amounts of pellets can be added up to bigger batches.

3.3.3 Cost

The difference in cost compared to sawdust is that the pellets have to be produced by pressing and that requires proper equipment. The rest of the costs come from transportation, warehousing and packing.

3.3.4 Pros & Cons

Advantages of pellets are uniform quality of it and that it fits in smaller space since it is compressed. Pellets are easy to stack in a warehouse and handle.

If the pellets would be used in this model there would have to be a machine that can produce the pellets either attached to the harvester machine or separately somewhere near the logging area and it should be easily movable with the machine. It is also important to consider whether or not the amount of sawdust is enough to produce reasonable quantities of pellets for transportation and selling it to the customers.

3.4 The invention

These are the photos of the prototype of the machine used to pick, dry and pack the sawdust while cutting trees. It has not been yet tested if it is possible to attach a pellet pressing machine on the harvester and how it would work in practice but it should be noted that there are possibilities to modify the system and tailor it for the user. The figures 9 through 13 show the process of sawdust gathering when the gathering machine is attached on a harvester. Figure 14 shows the inside view from the cockpit.

FIGURE 9. The prototype fitted on a digging machine transformed into a harvester.

FIGURE 10. The machine collects the sawdust from the claw that grips the log and cuts it.

FIGURE 11. Sawdust goes through the pipes.

FIGURE 12. Sawdust goes through the pipes in to a drying system.

FIGURE 13. Final collection point of the sawdust.

FIGURE 14. All the activities can be controlled from the cockpit.

The sack filled with sawdust must be removed by hand by the operator of the machine. The sack can be left on the ground and it will be picked up later by the forwarder.

3.5 Packaging

The size of the sack used in this model is 1 m^3. The smaller sacks can also be packed in a bigger sack to make the transportation of the sacks easier. The sacks shown in Figure 15 can be used to pack the pellets also if the load capacity of the sacks is enough. The sacks should be water proof to prevent the sawdust getting moist, since the sawdust has already been dried up during the picking process with the harvester.

The density of the sawdust in this case has not been yet completely determined because of the lack of amount of the sawdust received from the actual operational machinery so a approximate value of 0.2 will be used, which is between normal sawdust and wood chips. So a sack of 1 m^3 full of sawdust will weigh about 200 kg.

In case of pellets the weight of a 1 m^3 is about 700 kg when the moisture percentage is around 6 - 10%. The pellets have to be packed airproof since the pellets absorb moisture from the air very easily. (Vilkkilä 2013)

The pellet sack has to have an inside sack or a smaller plastic sack is to be used to prevent the pellets getting exposed to moisture. If the pellet sacks are stored at the roadside warehouse longer than a day, special rain coverage is needed. The downside of a smaller plastic sack is it gets broken more easily and therefore can cause loss of products. (Vilppo 2013)

FIGURE 15. Example of a 1 m3 sack full of sawdust. (Vtraco 2012)

FIGURE 16. Stacked up smaller 15 kg pellet sacks on a pallet. (Gairelita 2006)

3.6 Customers

3.6.1 Large-scale

The large-scale customers are power plants and paper factories. The amount of sawdust and pellet delivered to these customers must be quite big to make it profitable to deliver the goods straight to the destination.

There are about 500 power stations in Finland, big and small, that can use pellets and woodchips for producing heat energy. Most of the power stations are in western Finland which means around 39%, in southern Finland there are about 30% of all the power stations, 5% in eastern Finland and 10% in the northern part of Finland. (Motiva 2012)

3.6.2 Small-scale

The small-scale customers are individual customers who want to buy the sawdust in smaller amounts. These customers can be served from a hub where the merchandise is delivered in bulk straight from the forest. This small-scale customer base includes also agricultural markets unless the amount bought by them is large enough to make it profitable to deliver straight to them.

The small-scale customers can be for example private owner's houses, schools, farms, hotels, motels and retirement homes. Basically anything that can use sawdust or pellets for heating.

3.7 Phases of the supply chain

In this chapter the whole supply chain of the sawdust will be gone through and what happens in each step is explained.

3.7.1 The forest

The harvester machine is used for felling the trees, delimbing them, which means cutting all the branches off, and bucking the tree into pre-determined length logs. In this case the harvester machine also gathers the sawdust produced by cutting the trees, dries the sawdust and stores it into a sack which will be left in the forest alongside with the logs. The main cost factors for the sawdust in this phase is the time the harvester operator has to spend changing and attaching the sacks.

3.7.2 Forest transportation

A forwarder will pick up the logs and sacks of sawdust and pellet and transport them to the roadside storage area. A forwarder is a machine which picks up logs and carries them from the forest to the roadside.

3.7.3 Roadside

At the roadside the sacks and logs are stored for transportation so they can be easily picked by the truck that transports them further. Protection from rain must be used if the sacks are not enough to prevent the sawdust getting wet. For example the sacks can be covered with protective water proof material.

3.7.4 Long distance transportation and picking

The sacks will be picked up by a truck from each stand marked for cutting if the amount of sawdust from one logging area is not enough to fill the whole truck. So basically a truck will pick up the sacks from various different logging areas from certain area of Finland and then deliver them to the customer. It is also possible that the harvester operators take the sacks with them to the harvester depot and the sacks will be moved onwards from there.

3.7.5 Warehouse for customer

The final destination for the sawdust sacks is either a warehouse where the sacks can be picked up by the customers or a delivery straight to the customer but only in cases where the volume is large e.g. energy plants.

FIGURE 17. Supply chain.

3.8 Transportation model

Since the quantity of sawdust or pellets can sometimes be rather small it is advisable to use a certain picking model to handle the transportation of the product to make it more economically reasonable. The idea is to use a truck to pick up the sacks from various different logging sites and then deliver them straight to the customer, not just pick up the sacks from one logging area and deliver small amounts each time. The Figure 18 gives an example how the picking would be done. As an example a truck would drive the route 2 marked yellow, pick up the sacks from each logging sites and deliver them to the small power plant. Another option would be the route 1 where a truck from the farm could come buy and pick up the sacks straight to the farm.

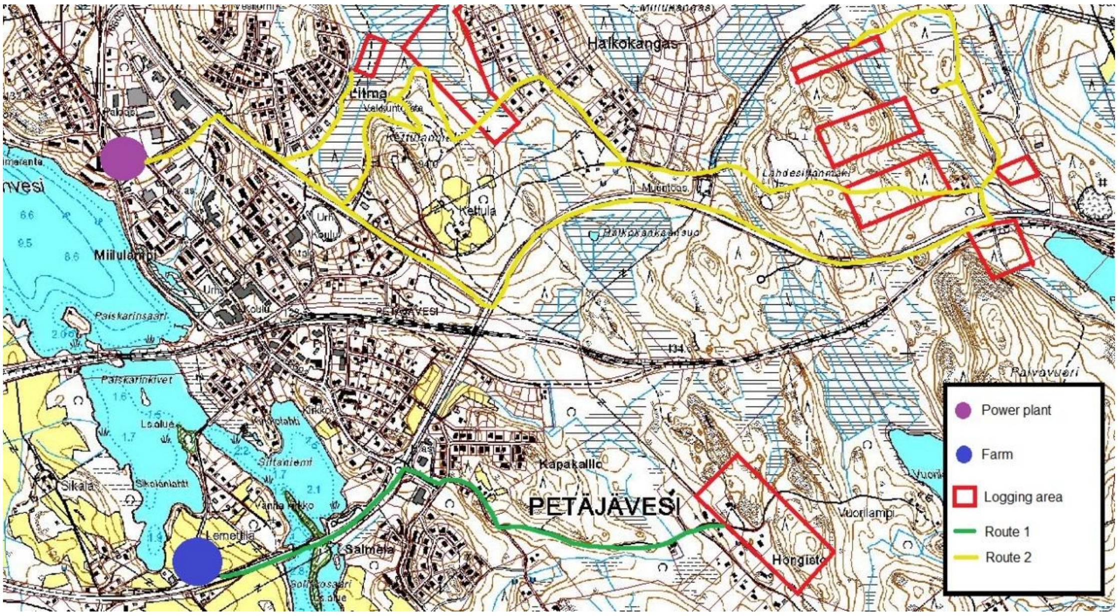

FIGURE 18. Example of the transportation model

The following transportation cost chart shows the transportation costs for a sack of sawdust when it is picked up from a certain distance. The speed, loading time, amount of sacks and price per hour for the transportation can all be changed and automatically the costs are calculated again and shown in the chart.

Speed	50	km/h
Loading time	1	h
Amount of sacks picked up	50	
Price:	70	€/h

Distance km	**Price €**	**Price for 1 m3 sack €**
50	140	2,8
100	210	4,2
150	280	5,6
200	350	7
250	420	8,4
300	490	9,8
350	560	11,2

FIGURE 19. Transportation cost calculations

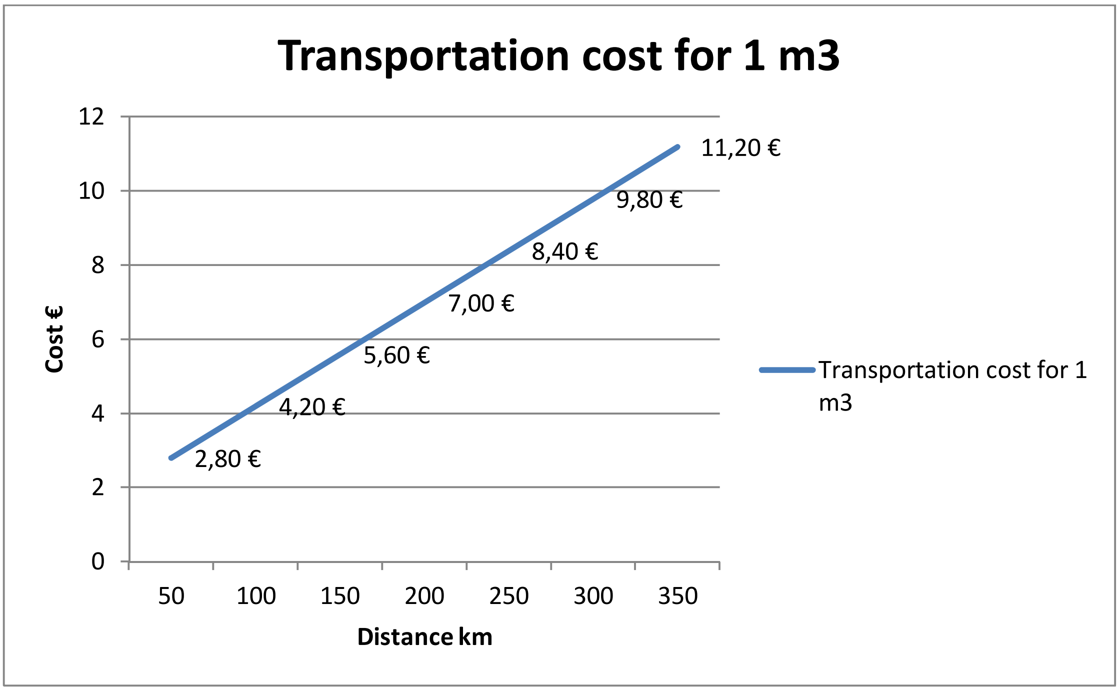

FIGURE 20. Transportation cost chart

3.9 Cost calculations

This chapter aims to define the costs and shows the difference in costs when comparing the different supply chain configurations. The cost calculations show an example of a situation where the size of the logging area is 1 ha and the amount of wood is 250 m^3 / ha. In the central Finland the average logging area size is 500 m^3 / ha. Each configuration has been visualized by a process chart that shows the actual supply chain. At the end of each configuration there is a table which shows how the costs are accumulated. The more detailed calculations are available at the end of the thesis in the appendices section.

It is also possible that the harvester operator will pick up the sawdust or pellet sacks gathered during his 8 working hours and deliver them to the hub or storage area when he leaves the logging site. This eliminates the need for a special pick up transportation service and all the sacks can be delivered in bulk from the hub area or just sold from there. This option can be seen in the chapter Configuration 5. (Vilppo 2013)

3.9.1 Configuration 1

The first configuration model is delivering sawdust to a large scale customer. As can be seen on Figure 21 the figure includes an option of using a hub if the amount of sawdust sacks is not enough to make transportation economically viable.

The supply chain starts when the trees are cut down and the sawdust is gathered in to a sack by the harvester machine. The sack is then manually removed by the harvester operator. After the tree felling process a forwarder will pick up the sacks from the forest and pile them up with the rest of the forest residue and logs to the roadside storage area. From the roadside storage area it is possible to deliver the sacks with or without the rest of the forest residue straight to the large-scale customer or deliver the sacks to a special hub where bigger batches of sawdust sacks will be made ready for delivery to the end customer. Since the customer buys in bulk the best option is probably just to deliver the sacks from various different loggings sites with a one truck straight to the customer.

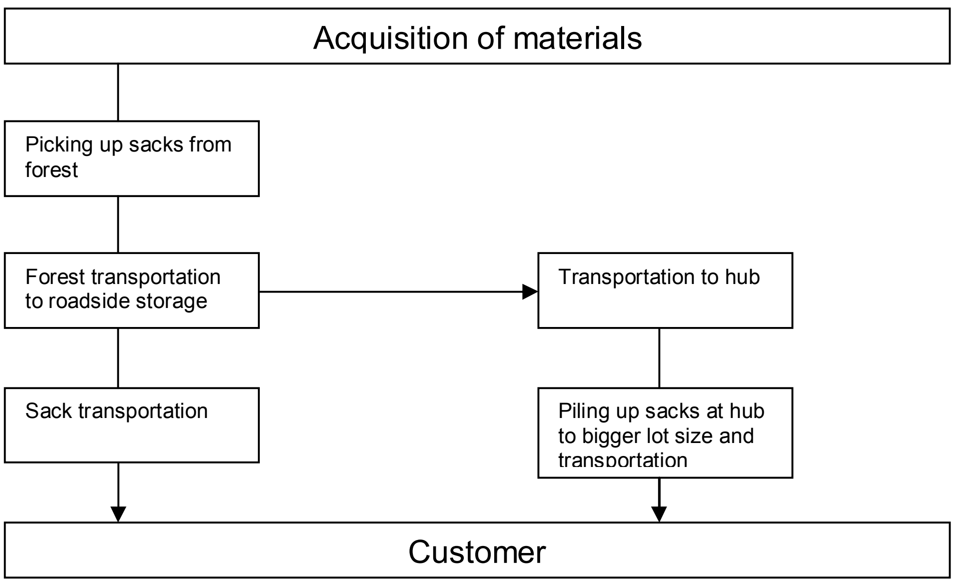

FIGURE 21. Supply chain of sawdust to a large scale customer.

The following costs are calculated by using the transportation model explained in the chapter 3.8.

TABLE 1. Cost of 1 m^3 of sawdust to a large scale customer. Calculations are presented in detail in Appendix 1.

Cost factor	**Cost €/m^3**
Harvester	1.67
Forwarder	4.38
Long distance transportation	11.2
Packaging	5
Total	22.3
Cost per kWh	2.1 cents/kWh

To give an impression on how much the distance causes costs, the TABLE 2 shows a situation where the 50 m^3 load of sawdust sacks is gathered from 150 km distance rather than the 350 km distance as shown in the TABLE 1.

The following costs are calculated by using the transportation model explained in the chapter 3.8.

TABLE 2. Cost of 1 m^3 of sawdust to a large scale customer with a shorter picking distance. Calculations are presented in detail in Appendix 2.

Cost factor	**Cost €/m^3**
Harvester	1.67
Forwarder	4.38
Long distance transportation	5.6
Packaging	5
Total	16.64
Cost per kWh	1.6 cents/kWh

3.9.2 Configuration 2

The second configuration model is delivering sawdust to a small scale customer. As can be seen on Figure 22 the supply chain of sawdust for small-scale customer goes along the lines of the supply chain of sawdust to large-scale customer. The only difference being that there is no transport from the roadside storage to the small-scale customer but the small-scale customer can come and buy the sacks of sawdust straight from the felling area or roadside storage area. Either that or then the customer buys from the hub storage.

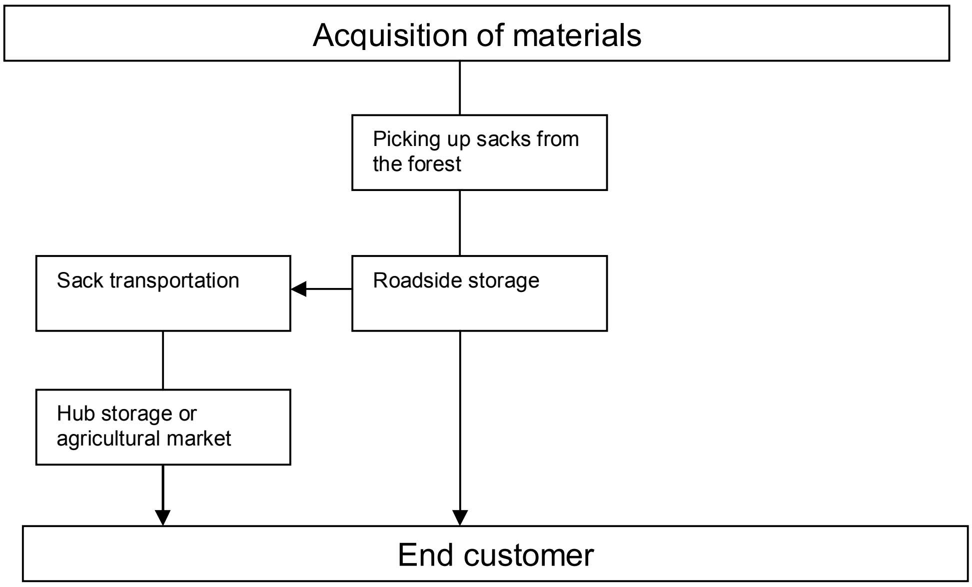

FIGURE 22. Supply chain of sawdust to a small scale customer.

The following costs are by calculated by not using any sack transportation because it is assumed that the customer would purchase the product straight from the roadside storage.

TABLE 3. Cost of 1 m^3 of sawdust to a small scale customer without transportation. Calculations are presented in detail in Appendix 3.

Cost factor	**Cost €/m^3**
Harvester	1.67
Forwarder	4.38
Packaging	5
Total	11
Cost per kWh	1.04 cents/kWh

3.9.3 Configuration 3

The third configuration model is delivering the pellet sacks to a large scale customer. The Figure 23 shows the possible ways the pellet sacks reach their customer.

The supply chain starts from the forest where the trees are cut and sawdust is collected. In the Figure 23 can be seen on the left side supply chain which is an option where the pellets are not made on the spot but at a special pellet producing factory. The bags of sawdust are delivered from the forest to the roadside storage where they are picked up from and transported to the pellet pressing factory and from there in bigger batches to the customer.

The middle supply chain of Figure 23 shows an option of producing the pellets at the felling area or at the roadside storage. This option divides to two ways from the roadside storage, one being the option to transport the pellets sacks straight from the roadside storage to the end customer and the other option being transportation to a hub to create bigger pellet sack batches and then delivering them to the end customer. Since the customer buys in bulk it is probably the wisest decision to just deliver the sacks straight to the customer without using any hubs. Simply put the method is just picking up sacks from various different logging sites.

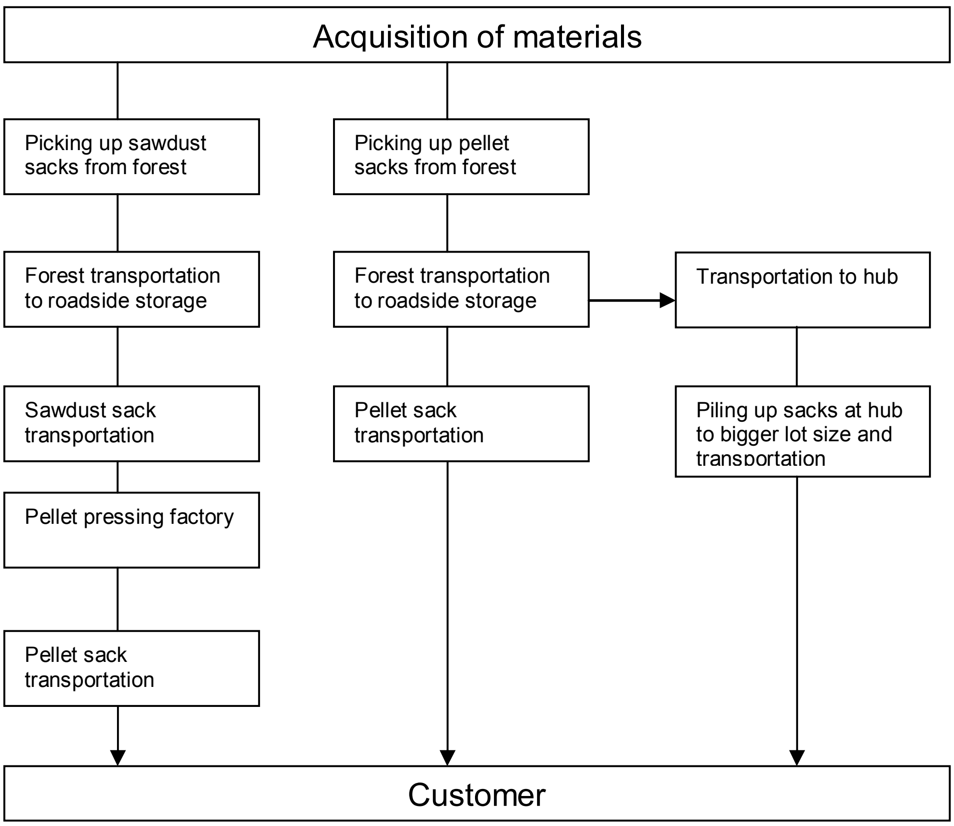

FIGURE 23. Supply chain of pellets to a large scale customer. Figure shows the options for supply chain considering possibility of pellet pressing with the harvester.

The following costs calculated are calculated using the transportation model explained in the chapter 3.8. The costs follow the left side of the supply chain shown in Figure 23.

TABLE 4. Cost of 1 m^3 of pellets to a large scale customer. Calculations are presented in detail in Appendix 4.

Cost factor	**Cost €/m³**
Harvester	1.67
Forwarder	4.38
Long distance transportation	11.2
Packaging	5
Pellet pressing	70
Pellet transportation to customer	1.78
Total	75.7
Cost per kWh	2.6 cents/kWh

3.9.4 Configuration 4

The fourth configuration model is delivering the pellet sacks to a small scale customer. The main difference with the above supply chain of pellets to large-scale customer is that there will be no single deliveries of pellet sacks to the end customer that buys in lower amounts than an agricultural market would buy.

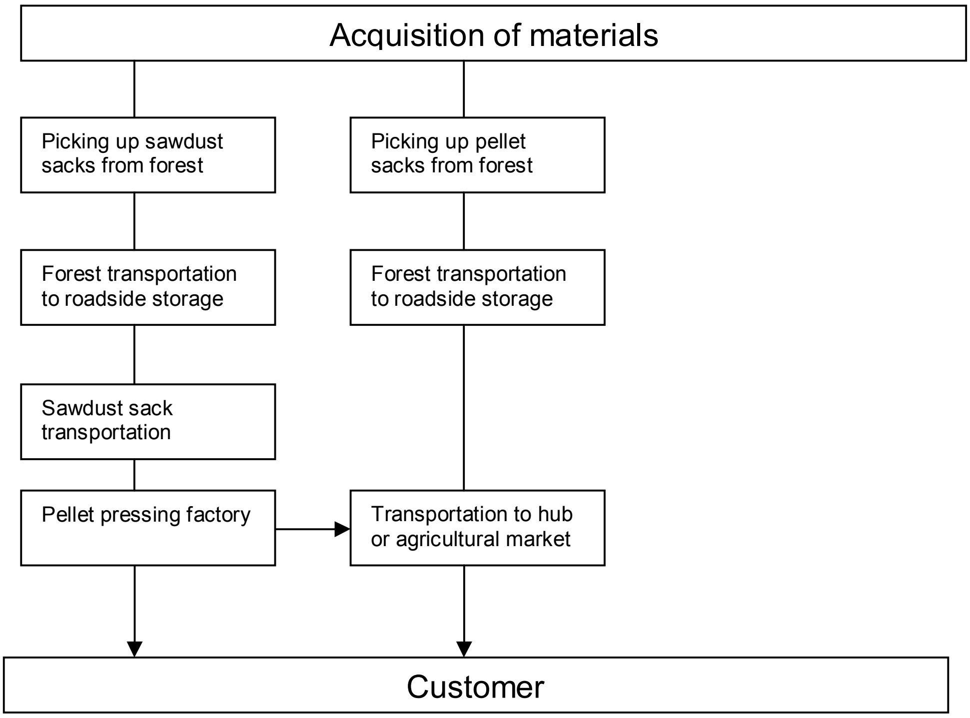

FIGURE 24. Supply chain of pellets to a small scale customer.

The following costs calculated are calculated using the transportation model explained in the chapter 3.8. The costs follow the left side of the supply chain shown in Figure 24.

TABLE 5. Cost of 1 m^3 of pellets to a small scale customer. Calculations are presented in detail in Appendix 5.

Cost factor	**Cost €/m^3**
Harvester	1.67
Forwarder	4.38
Long distance transportation	11.2
Packaging	5
Pellet pressing	70
Total	73.92
Cost per kWh	2.6 cents/kWh

3.9.5 Configuration 5

This configuration shows the costs for the sawdust when it is delivered to a hub storage area by the harvester operator after the end of his working shift. The transportation to the hub is practically free since the harvester operator has to go to the storage area anyway after the end of the shift. The harvester operator can use a pickup truck or a trailer to transport the sacks gathered during the work shift.

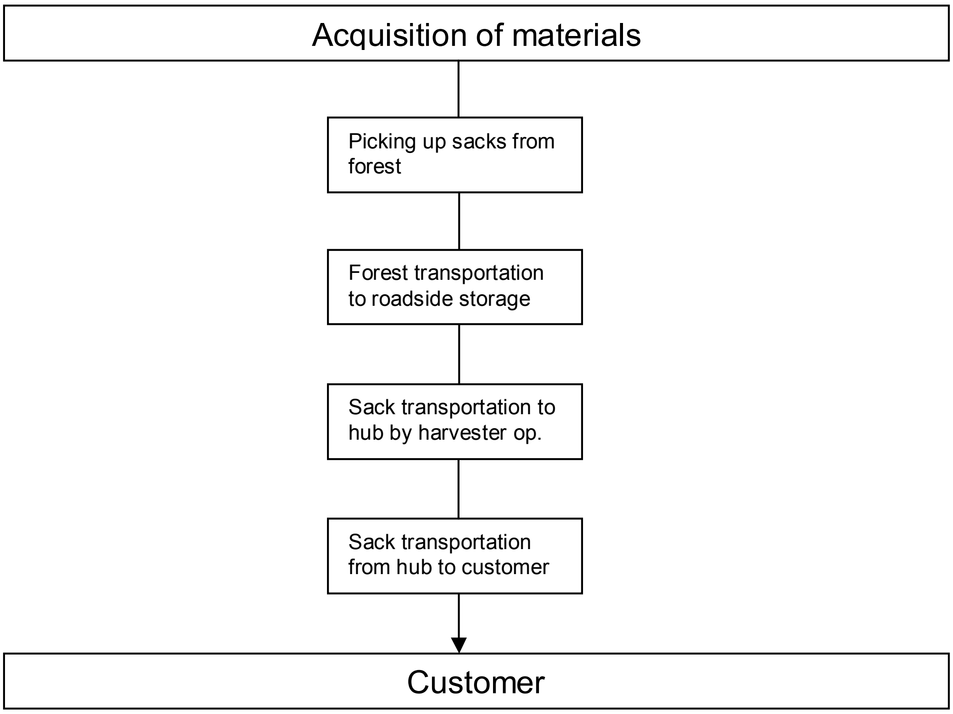

FIGURE 25. Supply chain of sawdust to customer from the hub.

TABLE 6. Cost of 1 m^3 of sawdust to the customer from the hub. Calculations are presented in detail in Appendix 6.

Cost factor	**Cost €/m^3**
Harvester	1.67
Forwarder	4.38
Transp. from hub to customer	1.78
Packaging	5
Total	12.82
Cost per kWh	1.2 cents/kWh

4 COMMENTS & CONCLUSION

The conclusion we can draw from the numbers is that the major cause of costs is the transportation. By increasing the amount we deliver at a time we can reduce the costs a lot. One cost efficient option is also that the customers buy the sacks straight from the forest. The only thing needed is some marketing to let customers know where the product is available. If it is possible the most profitable option should be always used if there is enough demand and possibility of doing it in practice.

One point to consider is the quantity of sawdust. There has to be a decent amount of it so that it is reasonable to sell to large scale customers, otherwise it can be just sold to private persons which this case refers as small scale customers.

Reliability of the sawdust picking system is also a factor to consider. Since the picking system is attached to the harvester, it must be found out that in a case when the picking system fails and breaks down does it actually prevent the actual harvester machine from working and doing its actual job which is the logging operation. That will cause some delays and costs when losing time repairing the picking device if it even is possible for the harvester operator to perform.

Some additional costs have to also be considered like what is the price of the sawdust picking machine and how much is the maintenance cost of it. Repair costs have to be taken into account as well as the harvester operators must be taught to use the picking machine. It is also important to note whether or not it is possible to attach the machine on a regular harvester or does it have to be a totally new one that it is built on to.

The pellet pressing machine is also a rather open question. Is it possible to attach the pellet pressing machine on the harvester or should it be a separate machine at a hub where the sawdust sacks are taken to. There are also other possibilities like briquetting presses to create different products out of the sawdust.

When we look at the costs we can also see that the cost of a sack where the sawdust is packaged in is rather high. The price is not absolutely final and of course if a system like this would be built there could be some deals to buy the sacks in bulk and probably make the price lower than it is in the calculations.

The excel calculations are highly based on estimated figures but they should at least give a base to develop on and some sort of a guideline and direction where the costs are coming from. Nevertheless I believe that I have achieved the goal of the thesis which was to estimate the supply chain costs and find out what is needed to examine and develop the supply chain for sawdust produced by innovative harvesters.

The impact this sawdust gathering machine has on the Finnish forestry is quite valuable. Finland has set a goal to double the usage of forest residues as fuel up to 25 TWh by the year 2020 and by getting the potential 0.5% more out of the 55 million m^3 wood logged each year by collecting the sawdust is supporting this renewable energy plan. (Energiateollisuus 2013)

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APPENDICES

Appendix 1: Cost calculation for sawdust to a large scale customer

Sawdust to large scale customer

Lets assume the felling area is 1 ha and the amount of wood is 250 m3 / ha
Lets assume the amount of sawdust is 0,5% from ha
Lets assume the harvester can do 250 m3 / 8h, 250 m3 cut wood is 0,5*250 m3 sawdust which is 1,25 m3 of sawdust i
1,25 m3 of sawdust in bulk m3 is 4 times the solid m3 amount, which is 5 m3
Lets assume 5 sacks of sawdust will be gathered in one work day of 8h
The following site is used as reference for the costs
http://nuke.biomasstradecentres.eu/Portals/0/D2.1.1%20-%20WOOD%20FUELS%20HANDBOOK_BTC_EN.pdf

Harvester costs

Cost factor	Cost €	Description
Harvester 100 € / h	1,666666667	Side product so no cost, except the time it takes to remove the sack from the harvester and attach new one which is about 1 min, and assume 5 sacks a day

Forwarder costs

Lets assume the forwarder fills his 8 m3 load in 30 mins, out of that is 5 m3 of sawdust

Cost factor	Cost €	Description
Forwarder 70 € / h	4,375	Cost must be divided between forest residue, logs and sawdust sacks

Long distance transportation

Lets assume the sacks will be picked up from 10 different logging sites, 5 per each site

Cost factor	Cost €	Description
Transportation 70 € / h	560	with an average speed of 50 km/h, a distance of 350 km can be covered in 7 hours and leaving 1 hour for loading and unloading and breaks

	Cost €	
Total long dist. transp.	11,2	11,2 € per 1 m3 sack

Note: The cost will be lower if there are more sacks to pick up from one place

Sack cost

Cost factor	Cost €	Description
Sack	5	

FINAL TOTAL	22,24166667	Final cost for 1 m3 of sawdust in sack

It is assumed that 1 m3 of sawdust in a sack weighs about 200kg
The heat value for 50% moisture sawdust is 5,3 kWh/kg
200kg*5,3kWh/kg= 1060 kWh
22,24 € / 1060 kWh= 0,020982704 **2,1 cents per kWh**
Note: price will be lower for more dryer product
(Also something to consider is the usage costs of the drying machine on the harvester)

Appendix 2: Optional cost calculation for sawdust to a large scale customer

Sawdust to large scale customer option 2

Harvester costs

Cost factor	Cost €	Description
Harvester 100 € / h	1,666666667	Side product so no cost, except the time it takes to remove the sack from the harvester and attach new one which is about 1 min, and assume only one sack of sawdust per day

Forwarder costs

Lets assume the forwarder fills his 8 m3 load in 30 mins, out of that is 1 m3 of sawdust

Cost factor	Cost €	Description
Forwarder 70 € / h	4,375	Cost must be divided between forest residue, logs and sawdust sacks

Long distance transportation

Lets assume the truck can transport 50m3 at a time and that there w ill be enough from the logging sites to fill the load in 3 h

Cost factor	Cost €	Description
Transportation 70 € / h	280	with an average speed of 50 km/h, a distance of 150 km can be covered in 3 hours and leaving 1 hour for loading and unloading and breaks

	Cost €	
Total long dist. transp.	5,6	5,6 € per 1 m3 sack

Note: The cost will be much lower if there are more sacks to pick up from one place

Sack cost

Cost factor	Cost €	Description
Sack	5	

FINAL TOTAL	16,64166667	Final cost for 1 m3 of sawdust in sack 16,64

It is assumed that 1 m3 of sawdust in a sack weighs about 200kg
The heat value for 50% moisture sawdust is 5,3 kWh/kg
200kg*5,3kWh/kg= 1060 kWh
16,64 € / 1060 kWh= 0,015699686 **1,6 cents per kWh**
Note: price will be lower for more dryer product
(Also something to consider is the usage costs of the drying machine on the harvester)

Appendix 3: Cost calculation for sawdust to a small scale customer

Sawdust to small scale customer

Lets assume the felling area is 1 ha and the amount of wood is 250 m3 / ha
Lets assume the amount of sawdust is 0,5% from ha
Lets assume the harvester can do 250 m3 / 8h, 250 m3 cut wood is 0,5*250 m3 sawdust which is 1,25 m3 of sawdust i
1,25 m3 of sawdust in bulk m3 is 4 times the solid m3 amount, which is 5 m3
Lets assume only 5 sacks of sawdust will be gathered in one work day of 8h

Harvester costs

Cost factor	Cost €	Description
Harvester 100 € / h	1,666666667	Side product so no cost, except the time it takes to remove the sack from the harvester and attach new one which is about 1 min, and assume only one sack of sawdust per day

Forwarder costs

Lets assume the forwarder fills his 8 m3 load in 30 mins, out of that is 5 m3 of sawdust

Cost factor	Cost €	Description
Forwarder 70 € / h	4,375	Cost must be divided between forest residue, logs and sawdust sacks

Long distance transportation

Lets assume the sacks will be bought by customer straight from the roadside storage
So no long distance transportation cost

Sack cost

Cost factor	Cost €	Description
Sack	5	

FINAL TOTAL	11,04166667	Final cost for 1 m3 of sawdust in sack

It is assumed that 1 m3 of sawdust in a sack weighs about 200kg
The heat value for 50% moisture sawdust is 5,3 kWh/kg
200kg*5,3kWh/kg= 1060 kWh
11 €/1060 kWh= 0,010416667 **1,04 cents per kWh**
Note: price will be lower for more dryer product
(Also something to consider is the usage costs of the drying machine on the harvester)

Appendix 4: Cost calculation for pellets to a large scale customer

Pellets to large scale customer

Harvester costs

Lets assume it is possible to press pellets using the harvester

Cost factor	Cost €	Description
Harvester 100 € / h	1,666666667	Side product so no cost, except the time it takes to remove the sack from the harvester and attach new one which is about 1 min, and assume only one sack of sawdust per day

Forwarder costs

Lets assume the forwarder fills his 8 m3 load in 30 mins, out of that is 1 m3 of sawdust

Cost factor	Cost €	Description
Forwarder 70 € / h	4,375	Cost must be divided between forest residue, logs and sawdust sacks

Long distance transportation

Lets assume the sacks will be picked up from 10 different logging sites, 5 per each site

Cost factor	Cost €	Description
Transportation 70 € / h	560	with an average speed of 50 km/h, a distance of 350 km can be covered in 7 hours and leaving 1 hour for loading and unloading and breaks

	Cost €	
Total long dist. transp.	11,2	11,2 € per 1 m3 sack

Note: The cost will be much lower if there are more sacks to pick up from one place

Sack cost

Cost factor	Cost €	Description
Sack	5	

Sawdust cost	22,24166667	Final cost for 1 m3 of sawdust in sack

Pellet pressing cost

Lets assume pressing machine can produce pellets 50kg / h (machine used: http://www.energian.net/ecoworxx/index.html)

Note: 100kg of pellets requires about 100kg so 600 kg of sawdust is needed to fill m3 of pellet

So 600/200 = 3 sawdust sacks is needed

Cost factor	Cost €	Description
Pressing machine usage 0,6 € / h	7,2	600kg / m3 sack
Sawdust cost 22,24 € / sack	66,725	3 sawdust sacks

Note: plus man hour cost

Transportation from the pellet pressing area to the customer

Using a semi trailer with about 90 m3 cargo space and 60ton limit load with a delivery time of about 2 h

Cost factor	Cost €	Description
Transport 80 € / h	160	

Cost for 1 m3 of pellets	1,777777778	Transport cost divided for 90 1 m3 sacks

TOTAL COST	**75,70277778**	75,7 € / m3 of pellets = 127 € / ton

Pellet price per tonne is about 260 € / ton at the moment (http://www.pelletspris.com/pellets_af_b.php?m

1 m3 of pellets weighs about 600 kg
The heat value for pellet is about 4,9 kWh / kg
600 kg * 4,9 kWh / kg 2940 kWh
75,7 € / 2940 kWh= 0,025749244 **2,6 cents per kWh**

Appendix 5: Cost calculation for pellets to a small scale customer

Pellets to small scale customer

Harvester costs

Lets assume it is possible to press pellets using the harvester

Cost factor	Cost €	Description
Harvester 100 € / h	1,666666667	Side product so no cost, except the time it takes to remove the sack from the harvester and attach new one which is about 1 min, and assume only one sack of sawdust per day

Forwarder costs

Lets assume the forwarder fills his 8 m3 load in 30 mins, out of that is 5 m3 of sawdust

Cost factor	Cost €	Description
Forwarder 70 € / h	4,375	Cost must be divided between forest residue, logs and sawdust sacks

Long distance transportation

Lets assume the sacks will be picked up from 10 different logging sites, 5 per each site

Cost factor	Cost €	Description
Transportation 70 € / h	560	with an average speed of 50 km/h, a distance of 350 km can be covered in 7 hours and leaving 1 hour for loading and unloading and breaks

	Cost €	
Total long dist. transp.	11,2	5,9 € per 1 m3 sack

Note: The cost will be much lower if there are more sacks to pick up from one place

Sack cost

Cost factor	Cost €	Description
Sack	5	

Sawdust cost	22,24166667	Final cost for 1 m3 of sawdust in sack

Pellet pressing cost

Lets assume pressing machine can produce pellets 50kg / h (machine used:
Note: 100kg of pellets requires about 100kg so 600 kg of sawdust is needed to fill m3 of pellet
So 600/200 = 3 sawdust sacks is needed

Cost factor	Cost €	Description
Pressing machine usage 0,6 € / h	7,2	600kg / m3 sack
Sawdust cost 22,24 € / sack	66,725	3 sawdust sacks

Note: plus man hour cost

The customer will buy the product from the pellet pressing area so no further transp. costs

TOTAL COST **73,925** 74 € / m3 of pellets = 123,34 € / ton
Pellet price per tonne is about 260 € / ton at the moment (http://www.pelletspris.com/pellets_af_b.php?m

1 m3 of pellets weighs about 600 kg
The heat value for pellet is about 4,9 kWh / kg
600 kg * 4,9 kWh / kg 2940 kWh
74 € / 2940 kWh= 0,025144558 **2,5 cents per kWh**

Appendix 6: Cost calculation for sawdust to customer from the hub

Harvester costs

Cost factor	Cost €	Description
Harvester 100 € / h	1,666666667	Side product so no cost, except the time it takes to remove the sack from the harvester and attach new one which is about 1 min, and assume 5 sacks a day

Forwarder costs

Lets assume the forwarder fills his 8 m3 load in 30 mins, out of that is 5 m3 of sawdust

Cost factor	Cost €	Description
Forwarder 70 € / h	4,375	Cost must be divided between forest residue, logs and sawdust sacks

Transportation from the hub storage to customer

Using a semi trailer with about 90 m3 cargo space and 60ton limit load with a delivery time of about 2 h

Cost factor	Cost €	Description
Transport 80 € / h	160	

Cost for 1 m3 of pellets	1,777777778	Transport cost divided for 90 1 m3 sacks

Sack cost

Cost factor	Cost €	Description
Sack	5	

FINAL TOTAL	12,81944444	Final cost for 1 m3 of sawdust in sack

It is assumed that 1 m3 of sawdust in a sack weighs about 200kg

The heat value for 50% moisture sawdust is 5,3 kWh/kg

200kg*5,3kWh/kg= 1060 kWh

12,82 € / 1060 kWh= 0,012093816 **1,2 cents per kWh**

Note: price will be lower for more dryer product

(Also something to consider is the usage costs of the drying machine on the harvester)