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Tuuli Laitinen, Jarno Föhr, Kalle Karttunen,
Mika Immonen and Tapio Ranta

Container logistic innovations in forest-energy sector: Markets, future service concepts and technical improvements

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The report presents the findings of the project “Container Logistic Innovations” (“Konttilogistiikkainnovaatiot” in Finnish), which was carried out in co-operation with LUT Savo Sustainable Technologies and LUT Technology Business Research Center in years 2013–2014. The project was funded by TEKES New knowledge and business from research ideas (TUTLI) instrument which is focused on the promotion of commercialization of the academic research findings.

We aim to describe how customer needs and technical development may create new service markets around container logistics in the forest-based bioenergy sector. The readers are provided with a general presentation of the logistic service ecosystem where different actors operate.

The responsible director of the project was Professor Tapio Ranta. We want also acknowledge Dr. Mikko Pynnönen for his support to customer value analysis, Dr. Lauri Lättilä for his effort on simulation models and Dr. Olli-Jussi Korpinen for his contribution on GIS-based logistic calculations.

More information about the project is available at
http://www.lut.fi/web/en/tbrc/projects/container-logistical-innovations.

In Lappeenranta, on 9 June 2014,

Authors

Euroopan unioni
Euroopan aluekehitysrahasto

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EU:lta
2007–2013

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Hakusanat: *konttilogistiikka, logistiikkapalvelu, bioenergia, metsäbiomassa, palvelumalli, innovaatio*

Raportti käsittelee Konttilogistiikka Innovaatiot kaupallistamishankkeen tuloksia. Hankkeen tavoitteena oli edistää uusien konttilogistiikan palvelumarkkinoiden syntymistä bio-energialogistiikka sektorille. Tulokset kuvailevat biomassalogistiikan Euroopan markkinoita, uusien markkinoiden mahdollistajia ja tarvittavia palvelukokonaisuuksia. Raportti kuvaa myös miten konttilogistiikan kokonaispalvelu synnyttää arvoa eri markkinasegmenteissä. Palvelukonseptin analyysi toteutettiin concept mapping, QFD ja liiketoimintaverkostoanalyysi työkaluilla, joilla selvitettiin verkoston tärkeimmät toimijat ja niiden väliset yhteydet. Tienvarsihaketuksen tehokkuutta arvioitiin logistiikka kustannuksen simulaation, RFID järjestelmän demonstraation ja konttien jäätymistestien avulla.

Euroopan Unioni on asettanut 20% tavoitteen uusiutuvien energioiden käytölle, josta biomassalla voidaan kattaa kaksi kolmannesta. Euroopan puupolttoaineiden tuotanto vuonna 2012 oli 139,9 miljoonaa kiinto- m3 ja puupartikkelien tuotanto 69 miljoonaa kiinto- m3. Erityisesti puupartikkelit ovat sopivia konttikuljetuksiin, joiden markkina on 180,6 miljoonaa irto- m3 vuodessa tarkoittaen noin 4,5 miljoonaa konttikuljetusta. Intermodaalit biomassa kuljetukset ovat erityisen lupaava sovelluskohde komposiitti konteille jäätymättömyyden vuoksi, joka nopeuttaa merkittävästi lastien purkuvaihetta. Konttilogistiikan kokonaispalvelukonsepti kattaa seuraavat palvelut: konttien vuokraus ja huolto, terminaalipalvelut, RFID-seuranta palvelut, logistiikan simulaation ja tietojärjestelmien integroinnin. Kuljetusyrittäjien näkökulmasta konttivuokraus mahdollistaa kapasiteetin nostamisen ilman suuria investointeja. RFID-seuranta tehostaa koko logistiikkaketjun seurantaa ja suunnittelua. Logistiikan simulaatiolla voidaan optimoida polttoainetoimituksia käyttöpaikoille.

ABSTRACT

Authors:
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The report presents the results of the commercialization project called the Container logistic services for forest bioenergy. The project promotes new business that is emerging around overall container logistic services in the bioenergy sector. The results assess the European markets of the container logistics for biomass, enablers for new business creation and required service bundles for the concept. We also demonstrate the customer value of the container logistic services for different market segments. The concept analysis is based on concept mapping, quality function deployment process (QFD) and business network analysis. The business network analysis assesses key shareholders and their mutual connections. The performance of the roadside chipping chain is analysed by the logistic cost simulation, RFID system demonstration and freezing tests.

The EU has set the renewable energy target to 20 % in 2020 of which Biomass could account for two-thirds. In the Europe, the production of wood fuels was 132.9 million solid-m3 in 2012 and production of wood chips and particles was 69.0 million solid-m3. The wood-based chips and particle flows are suitable for container transportation providing market of 180.6 million loose- m3 which mean 4.5 million container loads per year. The intermodal logistics of trucks and trains are promising for the composite containers because the biomass does not freeze onto the inner surfaces in the unloading situations. The overall service concept includes several packages: container rental, container maintenance, terminal services, RFID-tracking service, and simulation and ERP-integration service. The container rental and maintenance would provide transportation entrepreneurs a way to increase the capacity without high investment costs. The RFID-concept would lead to better work planning improving profitability throughout the logistic chain and simulation supports fuel supply optimization.

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1 INTRODUCTION

1.1 Aim and structure of the report

The report presents the results of the commercialization project Container logistic services for forest bio-energy, which was accomplished to prepare ideas gathered from research to product-service concepts for industrial applications. The overall goal of the report is to provide viewpoints and valuable information for further business development that are based on logistic services (see Figure 1). The results are based on a TEKES funded research project *Container Logistic Innovations* (Konttilogistiikkainnovaatiot in Finnish), which was carried out as a co-operation project between LUT Savo Sustainable Technologies and LUT Technology Business Research Center. The major idea of the project was to introduce and promote new business that is emerging around container logistic services in the bioenergy sector. This report aims to assess the European markets of the container logistics for biomass, enablers for new business creation and required service bundles for the concept. We also demonstrate the customer value of the container logistic services for customer segments. The report also demonstrates how process follow-up data can be utilized for performance analysis.

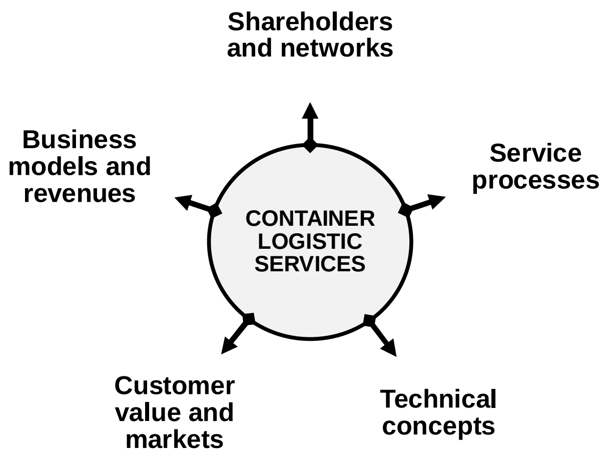


Figure 1 Viewpoints of the commercialization analysis.

The report has three separate sections. The first section presents the key concepts and background information and general trends that are enabling the new service businesses in the bioenergy sector. The second section presents the results of the accomplished research, which is divided into the market analysis, concept analysis and performance assessment of the road side chipping chain. The market analysis consists of customer segmentation for the container logistic services, customer value analysis and market size assessment. The concept analysis presents the results based on concept mapping, quality function deployment process "QFD" to connect customer needs and services and business network analysis. The business network analysis aims to recognize the key shareholders and their mutual connections. The performance of the road side chipping chain is analysed from the technical functionality perspective using the logistic cost simulation and the RFID system in tracking the transports. The research findings are summarized in the third section of this research and recommendations for future service design are proposed.

1.2 Drivers for forest-based biomass in the Europe

How much energy can be derived from biomass depends on many factors: market forces, economic incentives and the speed of technological change. The EU has set the renewable energy target to 20% in 2020. Biomass could account for two-thirds of the renewable energy target by then. For this to become reality, biomass use will roughly have to double. Wood accounts for approximately 80% of the biomass used for renewable energy. There is a clear potential to intensify forest utilisation for energy in the EU. Only 60%–70% of the annual increment of EU forests is harvested. At present, about 42% of the harvest is eventually used for energy. Significant expansion potentials locate in smaller private forest holdings and are related to forest residues and complementary fellings, such as first thinnings. Recent projections for 2030 quantify the sustainably realisable potential of wood for energy from EU forests as high as 675 million cubic meters per year, provided intensive wood mobilisation efforts are applied. (European Commission, 2014.)

1.3 Volume of forest-based biomass logistics

1.3.1 Finland

Wood fuels are the second most important energy source in Finland, after oil products. More than half of the fuel is solid wood; the rest is black liquor. In 2012, the total energy use of solid wood fuels was 24.3 million solid cubic meters (Table 1). The use of forest chips reached a new record in the same year. Heat and power plants, together with households, used 8.3 million solid cubic meters of forest chips. The National Forest Programme of Finland has set the annual target for forest chips use to 10–12 million cubic meters by the year 2015. (Ylitalo, 2013.)

Table 1 The energy use of forest-based biomass in Finland in 2012 (source Ylitalo 2013).

Solid wood fuel Energy use (million solid m^3)	Forest chips	Bark	Particles	Wood chips*	Waste wood	Fire-wood	Total
Heat and power plants	7.6	6.5	2.0	0.8	-	-	17.6
Households	0.7	-	-	-	1.3	4.7	6.7
Total	**8.3**	**6.5**	**2.0**	**0.8**	**1.3**	**4.7**	**24.3**

**Industrial side streams*

1.3.2 Europe

In the Europe, the production of wood fuels was 132.9 million solid cubic meters in 2012 when the coniferous and non-coniferous wood fuels are count together (Table ***2***). The production of wood chips and particles, used for energy or in wood product industry, was 69.0 million solid cubic meters in the same year. The chip and particle production is concentrated in the Northern Europe, especially in Finland and Sweden. The same countries are also the largest producers of wood fuel in the Northern Europe. In the Western Europe, the top countries producing wood chips and fuel are Germany, France and Austria. In the Eastern Europe, the top countries are Russia and Poland. The Southern European wood chip and fuel production is concentrated mostly in Spain and Italy. It must be taken into account that the figures of wood fuel include also roundwood used for cooking, heating or power production.

Table 2 The production of wood chips and particles and wood fuel in the Europe in 2012 (FAOSTAT).

Region	**Production Quantity in 2012**					
	Chips and Particles* (million solid m³)	**Countries (top 3)**	**Wood Fuel** Coniferous** (million solid m³)	**Countries (top 3)**	**Wood Fuel** Non-Coniferous** (million solid m³)	**Countries (top 3)**
Eastern Europe	12,6	Russia Poland Belarus	22,5	Russia Ukraine Poland	22,7	Russia Romania Poland
Northern Europe	33,9	Sweden Finland Latvia	9,1	Sweden Finland UK	11,9	Finland Sweden Lithuania
Southern Europe	3,6	Spain Italy Croatia	2,0	Spain Italy Slovenia	21,1	Serbia Italy Spain
Western Europe	18,9	Germany France Austria	11,0	Germany Austria France	32,7	France Germany Austria
Europe total	**69,0**		**44,6**		**88,3**	

***Chips and particles** are suitable for pulping, for particle board or fibreboard production, for use as a fuel, or for other purposes. It excludes wood chips made directly in the forest from round wood.

****Wood fuel** includes round wood that will be used as fuel for purposes such as cooking, heating or power production. It includes wood harvested from main stems, branches and other parts of trees (where these are harvested for fuel) and wood that will be used for charcoal production. It also includes wood chips to be used for fuel that are made directly in the forest from round wood.

1.4 Roadside chipping chain

Roadside chipping chain is the foremost forest chips supply chain for large-scale energy production in Finland. In 2012, the share of the roadside chipping was 50 %–60 % of all chipping chains (Strandström, 2013). The common forest chips from roadside storages are usually made of logging residues or small-sized thinning woods.

According to the chipping by the roadside method, the biomass is transported to the roadside storage using a forwarder and bunched into 4–5 meter high piles (Figure 2). The chipping takes place by the roadside, where the biomass is chipped by the mobile chipper or crusher and blown directly into the truck's container. Thereafter, the forest chips are transported to the power plant. (Alakangas & Virkkunen, 2007)

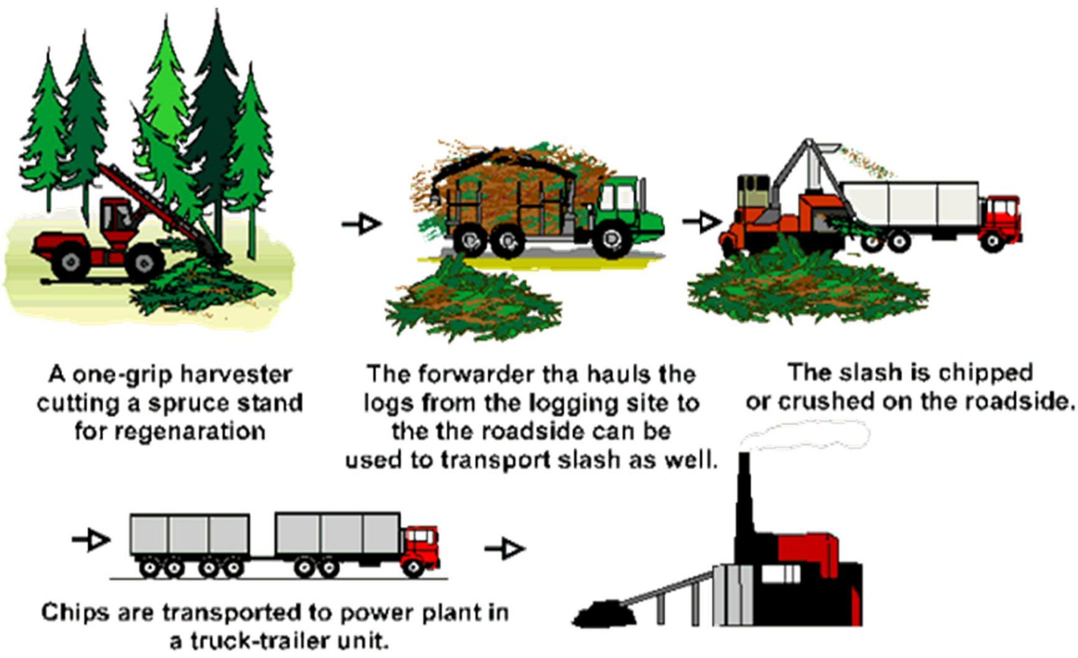


Figure 2 Roadside chipping chain for the logging slash (Alakangas, 1998).

The disadvantage of the roadside chipping method is that the chipper and the chip truck are dependent on each other. It is called a hot chain. The close linkage of chipping and trucking can result in waiting and stoppages, thus reducing operational efficiency. A considerable part of the time consumption of a chipper or chip truck may be wasted in waiting. The smooth interaction of chipping and trucking is the most demanding phase of the system. (Alakangas & Virkkunen, 2007)

The roadside storage area is typically narrow and muddy for machines. There is also a lot of snow on the road in the wintertime, which has to be ploughed or flung away from the road by a tractor. Nevertheless, each biomass supply chain has its advantages and disadvantages, but still, the roadside chipping chain is cost effective compared to the other supply chains.

1.5 Need for new logistic services

New lightweight containers, like composite containers, offer many advantages for biomass transportation (low weight, thermal insulation, intermodality), but customers are not ready to make the purchase decision. Investments require funding. By renting, customers can avoid high investment costs and concentrate on their core business. The rental concept can meet the changing customer needs in road and rail transportation business and encourage trying new solutions. Finnish transportation companies are mainly small or micro-sized, and the financing of investments can be problematic. At the same time, in March 2013, the European Commission gave Finland a permission to revise the regulations on vehicle weights and dimensions and to implement a maximum vehicle weight of 76 tonnes. According to SKAL (2013), only a small number of haulage entrepreneurs is willing to invest in new vehicles to take advantage of the larger permitted weights. Many transportation companies are faced with high investments, or going out of business, if they are unable to make the necessary equipment purchases.

The RFID concept is used to collect location and load data while the vehicles pass the logistic chain. This allows both location tracking and data entry. Data collection enables load statistics, which can be used in load-specific payments and quality control. The RFID system allows the access to more detailed actor-specific quantity and quality information, which can be used in pricing and in the systematic improvement of activities. The collected information interests both suppliers and buyers of biomass logistics. With the automation, unloading times can also be shortened. At the early stages, the most important customers are transportation entrepreneurs. They are offered a real-time maintenance log for a fee, which provides maintenance history and cost control.

Simulation models can be used in the evaluation of the logistical costs in biomass transportation. The main customers are large-scale energy plants, but the simulation model can be used in forest industry, municipal waste business, plants processing raw material (biomass) and companies transporting biomass. At the first stage, the main interest is in forest chips and peat, but there is potential for expanding the model to other material flows. The advantage of simulation is to improve fuel supply and cost-effectiveness. It is possible to support investments and meet the quality standards of power plants. The challenge is to make a reliable analysis and integrate the model to customer’s existing information systems.

1.6 Research process

The process conforms Hamel’s business model analysis method, which divides the service concept into independent elements (customer, interface, strategy, strategic resources and value network) and aligns the resource portfolio of the service provider through a selected business strategy and critical customer requirements (Sainio, 2005; Laaksonen, 2005). Separating the parts of the business model from each other increases the clarity of the objectives of this analysis process. The analyzed business model elements defines critical dimensions of the service product and potential methods for customer’s contributions (Sainio, 2005; Flieβ, 2004; Laaksonen, 2005).

- Value network—determines the complete value creation system, that is, resources, capabilities, suppliers and in-house resources, and thus, it allows the development of efficient production systems and purchasing strategies (Sainio, 2005; Laaksonen, 2005).
- Strategic resources—determine the “heart of the service production”, which enables value creation for the customer, and at the same time, guides the

investment strategy to the direction of increased customer value (Sainio, 2005; Laaksonen, 2005).

- Core strategy–gives guidelines for business development actions, the resource configuration process and the selection of resource portfolio from the aspect of sustained competitive advantage (Sainio, 2005; Laaksonen, 2005).

The analysis was done according to the following six steps:

1. Definition of market offering.
2. Assessment of customer needs.
3. Building of service concepts and activities.
4. Definition of value streams between the service provider and the customers for activities.
5. Definition of required resources and actors for performing activities.
6. Building of illustrations for business networks.

1.7 Definitions of the key concepts

Container system	A set of functionally related elements: containers, handling equipment and unloading equipment.
Container logistic	The overall management of containers in the supply chain.
Composite structure	The surface laminates are tied together strongly with diagonal laminates. The cross-section of the structure is reminiscent of several I beams side by side.
Container rental	A business that rents containers.
Terminal services	A facility for the handling and/or temporary storage of cargo as it is loaded/unloaded or transferred between enterprises.
Simulation	Simulation is modelling real-life phenomena in a virtual reality contexts. Simulation can describe dynamics of a complex systems or interactions in time.
Forest-based biomass	Usually for energy use. Material consist of trees and tree residues.
Logging residues	Materials left on the ground after logging, thinning or other forest operations. Consist of treetops, broken branches and defective logs.
Size-tree	A tree from thinning. Consist of trunk, branches, leafs and needles
Wood chips	Used as energy fuel in a power plant; raw material for producing wood pulp.
Energy content	Description of the potential energy contained in a given fuel. Unit value is MWh.
Service model	The service models create offerings in co-operation with customer. The offerings contain bundle activities which are operated by group of firms. In a service model: (1) *service* is a fundamental basis of exchange, (2) *products* are distribution mechanisms, (3) *value* is delivered through co-creation between the firm, the customer and networks and (4) *intangible* capabilities, skills and knowledge provide competitive advantage (Vargo, Maglio and Akaka, 2008).
Business model	An architecture for product, service and information streams between the actors for producing value for the customer and the participants of model.
Business mapping	The business model map is an input-output map where the output is the offering to customers. The input comes from the value network as a form of resources provided to make the concept work.
Commercialization	Commercialisation is a process which aims at the creation of products or services based on new ideas. The end products of the process should have clearly defined target markets and business potential to cover investment expenses.
Customer value	The perceived or gained benefits for the customer by using a product or service.

2 MARKET SEGMENTS AND CUSTOMER VALUE

2.1 Theory—Customer value creation

The selection of the customer segment is the starting point of building a customer value model (Anderson and Narus, 1998). The knowledge of customer value preference is the key to create a customer-aligned business model. To gain this knowledge, a firm has to create a customer value model of its offering(s). The customer value model can be opened and analyzed by defining the single attributes of value elements that can be technical, economic, service or social in nature (Anderson and Narus, 1998). The elements have to be connected to the firm's offering with the attributes describing the value for customer. These attributes can be derived from the quality dimensions of the offering. Garvin (1987) has presented eight dimensions of product quality, which are performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality. These categories should be combined and modified to fit the assessed offering.

2.2 Customer segments by financial analysis

The market of container logistics concept can be divided into three customer segments: transportation entrepreneurs, rail freight operators (logistic companies) and energy companies (***Table 3***). The financial analysis for each segment was done by analysing companies' financial statements for the year 2012. The sample included 132 Finnish biomass transportation entrepreneurs, 30 Finnish energy companies and 20 European rail freight operators. The data was collected from the Voitto+ database and companies' annual reports. Since the transportation entrepreneur segment was very diverse, a deeper analysis was done with SPSS Statistics (Section 3.2.1).

Table 3 The market segments for the container logistics concept.

Customer segments	Transportation entrepreneurs		Energy companies		Rail freight / Logistic operators	
	(n=132)	%	(n=30)	%	(n=20)	%
Region	Finland	100	Finland	100	Europe	100
Business size	Micro/small	94	Small/medium	80	Large	90
Turnover (MEUR)	< 10	95	10–200	77	200 <	70
Equity ratio	Poor	40	Good	33	Excellent	30
ROI	Excellent	30	Fair	33	-	-
ROA	-	-	-	-	Poor	85
Quick ratio	Satisfactory	35	Good	60	-	-
Current ratio	-	-	-	-	Poor	50

2.2.1 Capital adequacy

The capital adequacy was measured by equity ratios. The ratio indicates how much of the company's assets are financed by equity. A small majority of the European rail freight operators' had excellent (over 50%) equity ratios. The most of the Finnish energy companies had good (35%–50%) equity ratios. Only the Finnish transportation entrepreneurs had mostly poor (less than 15%) ratios. This means that many small transportation companies are in debt, and their buffers against any losses are low. Low Equity ratio contains a high risk if the company's profitability declines for any reason. Recession, or even one bad year, could bring the company down.

2.2.2 Profitability

The profitability of Finnish companies was measured by Return on Investment (ROI), and European companies by Return on Assets (ROA). The Finnish energy companies had mainly fair (3%–6%) return on investment, indicating fairly low profitability. The most of the transportation entrepreneurs had excellent (over 15%) return on investment, but almost as many of them had poor (less than 3%) ROI. This indicates that the segment is divided into profitable and unprofitable companies. Small capital can also sometimes increase the return on investment, even though the earnings are low. The European rail freight operators had mostly poor (less than 5%) return on assets. This means the companies are not using their assets efficiently to generate earnings, and the profitability is low.

2.2.3 Liquidity

Quick ratio measures a company's ability to manage its short-term debts with its most liquid assets. Current ratio indicates the company's ability to pay its current liabilities with its current assets. The higher the ratios are, the higher the liquidity is. The Finnish energy companies had good (1–1.5) quick ratios, and the transportation entrepreneurs had satisfactory (0.5–1) quick ratios. This means energy companies have good financial buffers, but transportation entrepreneurs are less liquid. The European rail freight operators were evaluated by current ratio, which was mainly poor (less than 1). Low current ratio indicates the companies cannot fully pay their current liabilities. Since the most rail freight operators had high equity ratio, they can compensate their short-term funding gap with debt.

2.2.4 Transportation entrepreneurs

The segmentation of the Finnish transportation companies in the sample was done using turnover, ROI, QR and Liquidity ratio as clustering variables the variance of which is described in Figure 3 and Figure 4. The target group was segmented into three segments using Two-step clustering method by IBM’s SPSS Statistics 20. Two-Step clustering is an exploratory classification method which can be applied to recognize similarities between cases of the analysed data set. The selected clustering variables were all scale variables with non-normal distributions. The segmentation was later validated using Kruskal-Wallis test to assess the true differences between found segments (Table 4). The biggest customer segment is Low performance companies (60.0% of samples) (Table 3), which has an acceptable profitability but rather weak financing in terms of liquidity and depth ratio. Good performance and High performance companies represents the second group (23.1% of sample), which has a very good profitability and financing situation. Equity ratio shows that high performance firms have significantly lower business risks involved with their operations than the other groups. The smallest segment is the Crisis companies (9.8% of sample), which are unprofitable and have very weak financing situation indicating high business risks for external funding.

Table 4 Means and standard deviations for the segmentation variables in the company segments.

Segment % of sample	**Crisis** (16.9%)	**Low performance** (60.0%)	**Good / High performance** (23.1%)
	Average (Std. dev.)	Average (Std. dev.)	Average (Std. dev.)
Turnover*[a] [€ 1K]	1084[a] (735.2)	3127 (4177.5)	2629[a] (4184.9)
ROI %* **	−3.2 (24.4)	5.6 (13.7)	21.6[b] (13,8)
Quick ratio*/[c]**	0.39 (0.26)	0.79 (0.50)	3.40 (3.22)
Equity ratio*/[c]**	−41.5 (48.9)	23.4 (16.5)	64.6 (20.2)

*Statistically significant differences found at p<0.05 (Kruskal-Wallis test for independent samples)
***Statistically significant differences found at p<0.001(Kruskal-Wallis test for independent samples)
Post-hoc tests:
[a]) Difference between marked groups statistically significant at p<0.05
[b]) Difference to other groups statistically significant at p<0.001
[c]) Differences between all groups statistically significant at p<0.001

The typical transportation companies in the sample were micro or small-sized businesses with a turnover less than 10 million euros. Majority of the transportation companies had less than 10 employees. Most of the energy companies were medium-sized businesses with a turnover between 10 and 200 million euros, and had more than 50 employees.

Table 5 Distribution of company sizes within industry segments.

		Customer segments		**Total**
Staff	**Crisis**	**Low performance**	**Good/High performance**	
1–4	27.3%	23.1%	**40.0%**	27.7%
5–9	**45.5%**	25.6%	16.7%	26.9%
10–19	22.7%	21.8%	26.7%	23.1%
20–50	4.5%	**28.2%**	16.7%	21.5%
50–	0.0%	1.3%	0.0%	0.8%
	100.0%	100.0%	100.0%	100.0%

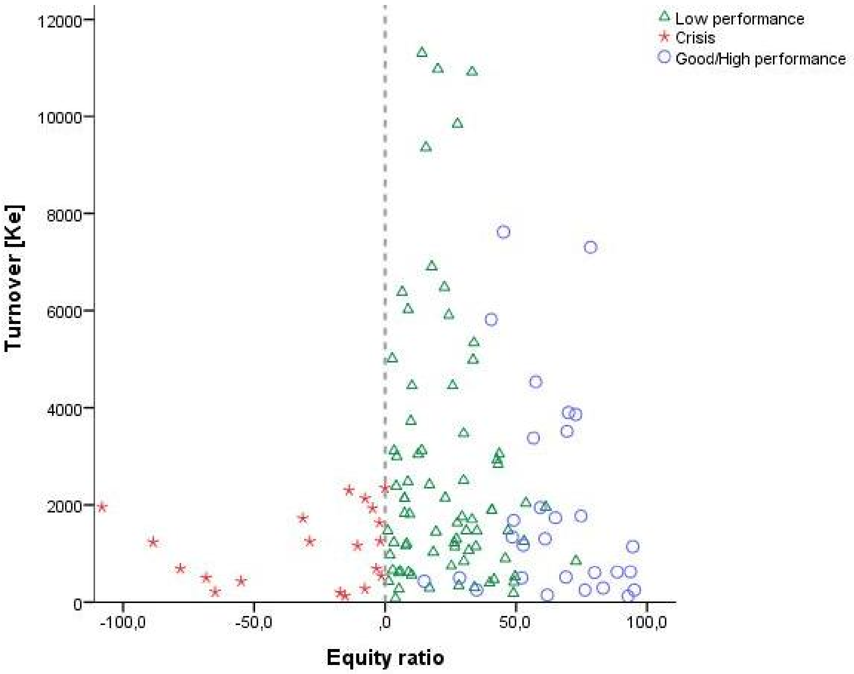


Figure 3 Variance of the turnover and Equity ratio within the sample.

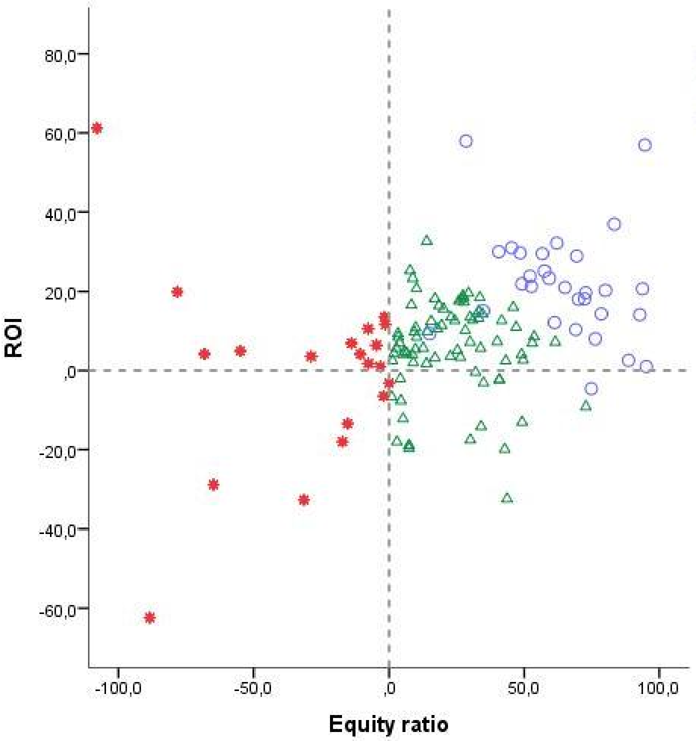


Figure 4 Variance of the ROI and Equity ratio within the sample.

2.3 Market size for composite container system

2.3.1 Finland

Table 1 presents wood that has been reduced to small pieces and is suitable for container transportation: forest chips, bark, particles and wood chips from industrial side streams. In Finland, the energy use of this kind of biomass was 17.6 million solid cubic meters in 2012 (Metla), which is 44.0 million loose cubic meters. If this amount of woody biomass was transported in containers (size of 40 m^3), it would mean 1.1 million container loads per year.

Table 6 The use of wood suitable for container transportation in Finland in 2012.

	Forest chips	Bark	Particles	Wood chips*	Total
Million solid m^3	8.3	6.5	2.0	0.8	**17.6**
Million loose m^3	20.75	16.25	5.0	2.0	**44.0**

*) industrial side streams

2.3.2 Europe

The European flows of wood-based chips and particles, which are suitable for container transportation, are illustrated in Figure 5 (and Appendix 1). The size of the European market was 180.6 million loose cubic meters in 2012 (FAO). It would mean 4.5 million container loads per year (size of 40 m^3). The number does not include forest chips, but illustrates the material flows. As the figure shows, the wood chip transportation focuses around Germany and Central Europe due to wood product industry. In the Eastern Europe, most of the ties are directional, but in the Western Europe, the ties are reciprocal. Especially Russia and Latvia are net exporters of wood chips and particles. Germany is also a net exporter though the import quantity is also high. The highest net importers are Finland, Austria, Poland and Sweden. These countries have a lot of wood processing industry, and their own chip production is also high.

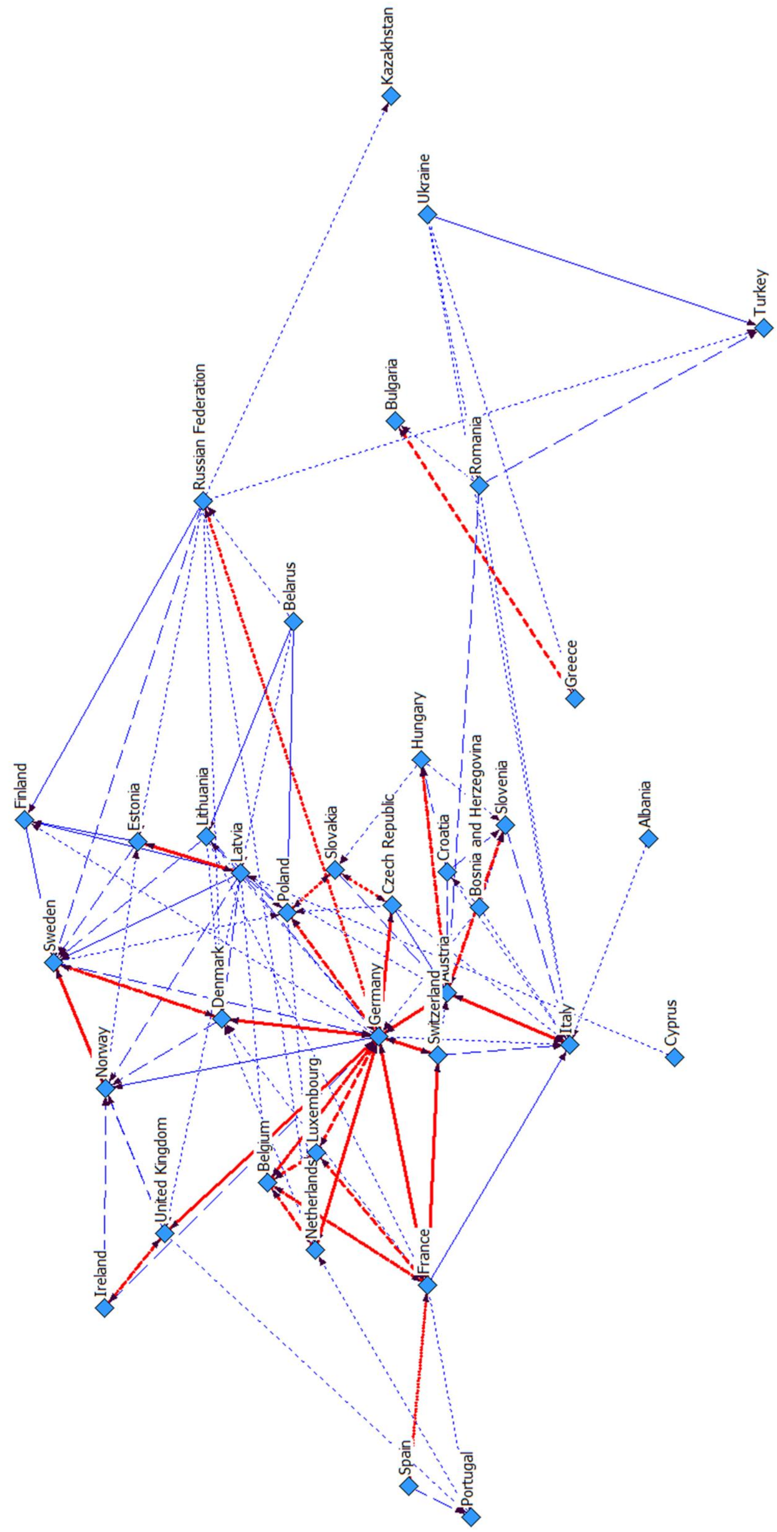


Figure 5 Illustration of wood-based chip and particle flows in the European region (2012); source:FAO (Line type: line weight = relative volume, dash line = minor volume; line colour: blue = directional tie, red = reciprocal tie).

3 CONCEPT AND NETWORK ANALYSIS

3.1 Theory—Concept mapping, QFD methods and industrial networks

3.1.1 Concept mapping

Building a business model on customer needs is essential for the firm for the recognition of the customer value and creation of a suitable business model for capturing the value. A value network of actors and value streams around an organization are thus constructed by identifying the consumed and produced value streams, precisely describing them, and associating them with the required enabling resources (Pynnönen et al., 2008a; Pynnönen et al., 2008b). This can be thought of as a three-phase process consisting of:

i. Offering investigation and decomposition.
ii. Value stream derivation and actor identification.
iii. Resource identification and association.

The business model map is an input–output map where the output is the offering to customers. The input comes from the value network as a form of resources provided to make the concept work. In this analysis, the concept is not necessarily an operating entity, but in many cases it could be. The offering should be designed so that it has relevant value streams that can deliver these values to the customer. The offerings are product and service bundles or packages which include various complementary elements associated with the main deliverable. Value streams are discrete products and service elements assigned to distinct categories and associated with the producing and consuming actor(s). The case firm is of course always associated with a stream either as a producing or a consuming actor. The other identified actors should be assigned a precise, domain-specific role, rather than just recognizing them as customers or suppliers. The actors and value streams can be conveniently presented using an illustration such as in Figure 6.

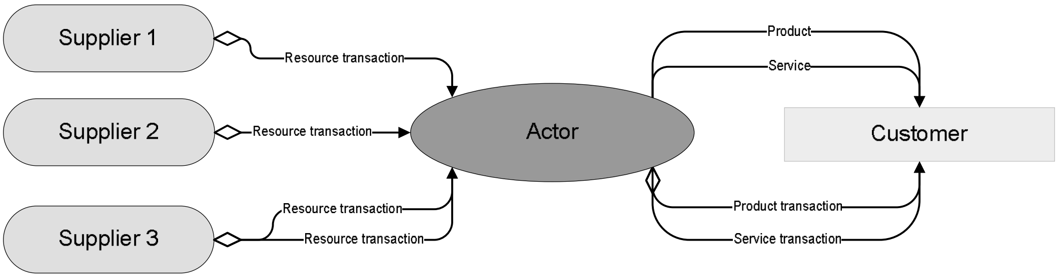


Figure 6 Example of a value stream map diagram.

The analysis reveals actors, customers and value streams that cannot be easily identified until the analysis has progressed. The association of resources with value streams is based on the idea that there are identifiable resources or capabilities that are needed to consume or produce various kinds of value streams. In other words, the resources can be considered as enablers of value streams, and on the other hand, they define the possibilities of a firm to adopt new concepts through the consumption of value streams.

3.1.2 Quality Function Deployment

Quality Function Deployment (QFD) is applied to assess the value of container logistic concept for customer segments. QFD is a method for converting customer demands into quality characteristics and for developing product designs by systematically deploying the relationships of customer demands and product characteristics (Lee and Ko, 2000). The prioritized customer value attributes from the service model are connected to the functions of the smart home construct by applying the QFD matrix. The QFD analysis also reveals the most sensitive value attributes in contrast to the elements of the offerings. The process aims to combine the customer needs to the logistic service concept which consists of multiple service elements and solutions. This way it is possible to assess the relative importance of the elements in the firm's offering in contrast to customers' value preferences.

3.1.3 Industrial networks

The industrial network approach evaluates the value creation potential of an activity through its connection to other activities involved in the production process (Dubois and Pedersen, 2002). Activities can be sequentially interconnected (stages of production), pooled interconnected (common resources) or reciprocally interconnected, in which case two activities have to be harmonized by their outputs, resources or co-ordination levels (Dubois, Hulthén and Pedersen, 2004). By this, activities can be divided into peripheral activities and hubs by the amount or quality of interactions. Peripheral activities have weak connections to the surrounding networks, whilst hubs connect multiple network entities creating control points in the supply networks (Merminod, Paché and Calvi, 2007). Activities can also be divided into specialization clusters by the exhibited technological resources or capabilities which provide a basis for the consolidation of organization management (Roseira, Brito and Henneberg, 2010).

Industrial network can be analysed using social network analysis (SNA) approach to assess relationships between actors. SNA focuses on relationships among network entities, for example, transactions between corporations or communications within user groups. Two essential units in SNA are actors and ties. Actors are presented as nodes in a network that are linked together with ties (Wasserman and Faust 1994, p. 3–4). Centrality measures an actor’s position in a network through a count of direct ties to other actors. Centrality answers the question of who is the most important or central actor in the network (Blume and Durlauf, 2008). Degree centrality (degree) for each actor was calculated using the UCINET 6 degree centrality method from which normalized values are reported. In this report, the network diagrams and centralities are built on expected direct interactions between actors.

3.2 Competing concepts

Austrian company Innofreight rents and takes care of special container systems for the transport of bulk goods. The idea is to develop individually tailored logistics solutions in cooperation with the customers. The focus is on rail freight and combined traffic. The modular design offers compatibility of all components: metal containers, handling equipment and unloading systems. Optional additional features such as integrated weighing modules during unloading, various types of covers and RFID complement Innofreight's offering. Additionally, maintenance packages (full-service) are offered. Innofreight is active in 14 European countries, and the customers are mainly European rail freight operators. In 2012, the company reached a turnover of 14 million euros and had 25 employees. In 2013, about 6 000 Innofreight containers were used to carry wood chips in Europe. This makes Innofreight the market leader. (Innofreight).

Innofreight's business concept is based on business-to-business market (Figure 7). In this analysis, the concept does not include all the additional features. Instead, the mapping focuses on relevant value streams. The input comes from the suppliers, the manufacturers of containers, forklift trucks and unloading equipment. These companies provide the resources that Innofreight purchases to rent. The output, the offering of containers and unloading systems, is rented to *customers*, European rail freight operators and logistic companies, whose core business is transportation. These companies sell the container transportation service to different fields of industry. In forest industry, containers are used to transport recycled paper to paper mills, wood chips to pulp mills and wood chips and particles to wood-based panel production. In energy industry, containers are used to transport biomass to energy production. Steel industry uses containers for mining products, like coke and ore, and waste management for contaminated soil. Containers are also used in mining industry for sulphur transportation.

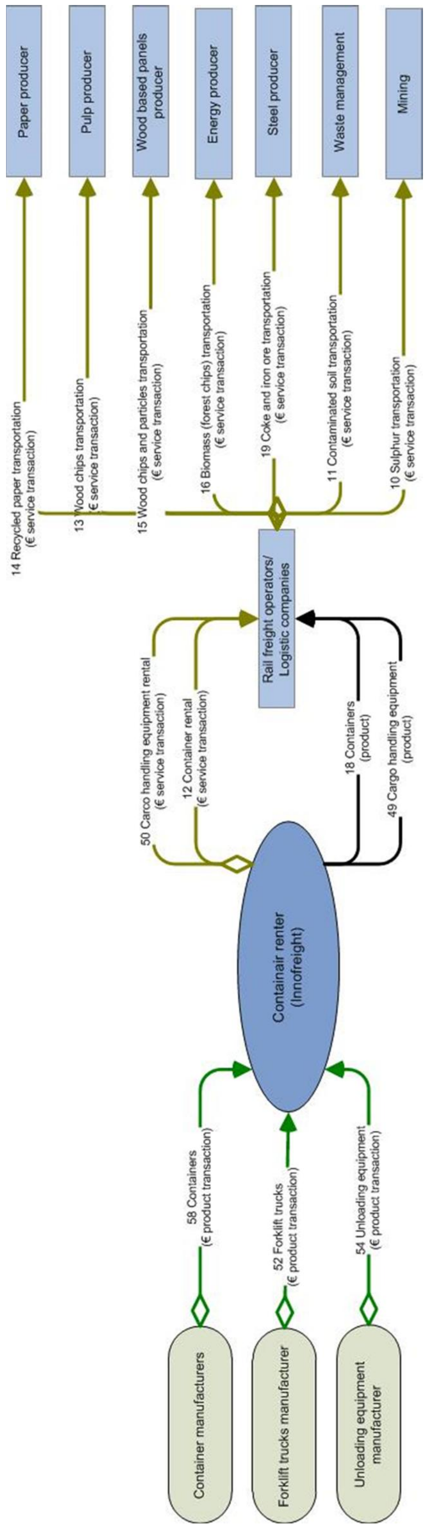


Figure 7 Concept map for Innofreight.

3.3 Concept mapping

Container logistics full-service concept is based on business-to-business market, like the competing Innofreight concept. The container logistics concept is a combination of services, including container rental, terminal services, container maintenance, RFID, simulation and ERP (Enterprise resource planning) (Figure 8). The actor is not necessarily an operating entity, but a network of co-operating companies. The input comes from suppliers, container manufacturer, information system provider, telecom operator and terminal services. The output is the offering for customers, rail freight operators, logistic companies and transportation entrepreneurs.

The offering includes complementary products (containers, unloading equipment, RFID tags and covers) and service elements (rental, maintenance, RFID tracking, simulation), which can be combined according to customer needs. The customers' core business is transportation. Rail freight operators may purchase the road transportation service from transportation entrepreneurs, while logistic companies operate on both road and rail. The container logistic full-service concept's main idea is to support the transportation business with a tailored service and product bundle. The main service packages are container rental and RFID, while other services are formed around these main activities. Simulation is supporting other functions, but its relative importance in customer value creation is fairly low, when customers are in transportation business. The customers can also purchase containers directly from the manufacturer if it fits their business better.

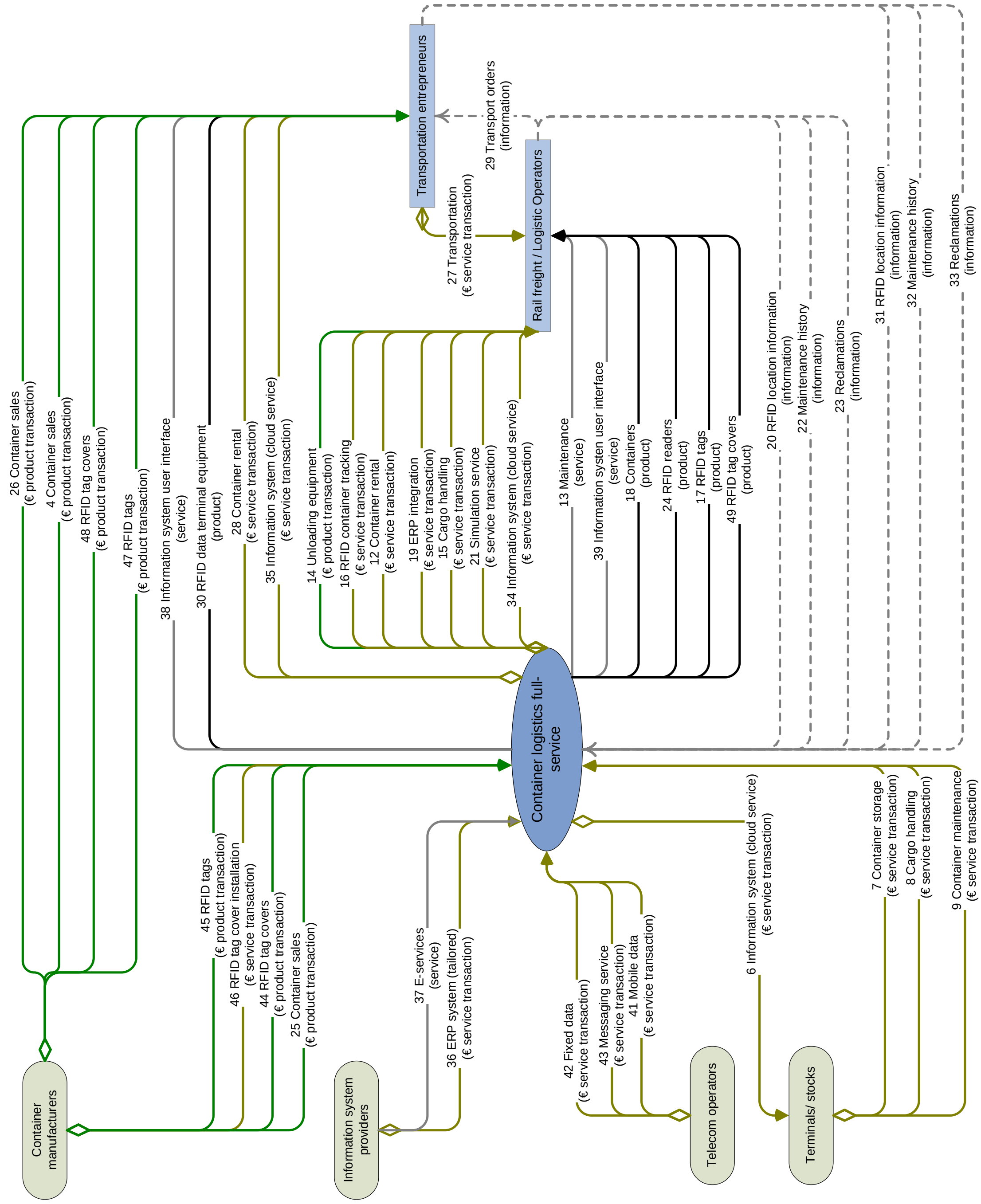


Figure 8 Concept map for container logistic service.

3.3.1 *Container rental service*

Container rental is one of the main elements in container logistics concept. The function would be suitable for a company operating in container or trailer rental business. The service bundle includes container rental, cargo handling and container maintenance (Table 7). In this case, unloading equipment is not rented, but sold to customer. The container renter buys the containers from manufacturer and the complementary services (handling, maintenance, storage) from terminal operator, and then rents the containers with a suitable service package to customers in transportation business. The information flow from customers includes the container maintenance history and possible reclamations.

Table 7 Input and output of value streams in container rental service.

Container rental service	**Value streams**				
	€ Product transaction	**Product**	**€ Service transaction**	**Service**	**Information**
INPUT	Container sales	-	Cargo handling Container maintenance Container storage	-	Maintenance history Reclamations
OUTPUT	Unloading equipment	Containers	Container rental Cargo handling	Maintenance	-

3.3.2 *RFID service*

In the container logistics concept, RFID service supports the container rental. RFID service bundle includes container tracking, cloud services, ERP integration and information system user interface (Table 8). The product bundle consists of RFID readers, tags, tag covers and data terminal equipment. In this case, the container manufacturer sells the containers equipped with RFID tags and provides the tag cover installation. The information system operator provides a tailored ERP system and e-services and the telecom operator messaging and data services. The information flow from customers contains RFID location data.

Table 8 Input and output of value streams in RFID service.

RFID service	Value streams				
	€ Product transaction	**Product**	**€ Service transaction**	**Service**	**Information**
INPUT	RFID tags RFID tag covers	-	RFID tag cover installation ERP system (tailored) Messaging services Fixed data Mobile data	E-services	RFID location information
OUTPUT	-	RFID readers RFID tags RFID tag covers RFID data terminal equipment	RFID container tracking Information system (cloud services) ERP integration	Information system user interface	-

3.4 Customer value of container logistics concept

Customer value of the container logistic service concept was researched regarding customer segments, which are energy producers, logistic operators and transportation entrepreneurs. The three most important customer needs and fit of service are reported in Table 9. We divided the service concept to the service packages for the analysis to increase the unambiguity of value assessment by QFD. The service packages in the final analysis were container rental, container maintenance, terminal services, RFID-tracking service, simulation and ERP-integration service.

Table 9 QFD analysis for container logistics concept.

Customer segments' needs (Top 3)	The relative importance of customer value creation						
	Container rental	**Terminal services**	**Container maintenance**	**RFID**	**Simulation**	**ERP**	**The offering**
Energy companies 1) Reliable fuel supply 2) Flexible transportation (seasonal variation) 3) Lower transportation costs for fuel	2.9%	15 %	0.6%	**43.6%** (21.7%*)	**27.4%**	10.6%	**100%**
Logistic companies 1) High and constant transportation volumes 2) Cost-effective logistic chain 3) Integration with the existing system	**16.6%**	8.0%	9.5%	**46.6%** (21.1%*)	10.8%	8.5%	**100%**
Transportation entrepreneurs 1) Profitable transportation 2) Profitable investments in equipment 3) High capacity utilization rate	**34.5%**	4.3%	9.8%	**47.6%** (15.2%**)	1.8%	2.0%	**100%**
				*Driving arrangements to avoid traffic congestion **Real-time data of shipments			

3.4.1 Energy companies

The most important customer need for energy companies is smooth, reliable fuel supply. Fuel supplies must come in time because the delays and problems show immediately in the energy production. Another important factor is flexible transportation that adapts to seasonal variation. The energy plant's fuel need varies throughout the year, reaching its peak during the coldest months. This leads to variable transportation volumes. Energy companies are also interested in lower transportation costs, since the overhead costs are rising and the fuel transportation distances are getting longer. (Laitinen, 2012).

Container logistic concept could fulfil the customer needs with an offering of simulation, RFID and terminal services (Table 9). Since transportation is not the energy companies' core business and they are not interested in buying container systems (Laitinen, 2012), container rental may not meet the basic needs. According to the QFD analysis, simulation would especially fulfil the need for fuel supply optimization, lower transportation costs, use of different transportation modes and supply chain lead time reduction. For energy companies, the most important RFID feature would be driving arrangements to avoid traffic congestion. This is caused by the seasonal variation and reliable supply, but also the possible roundtrip transports. The terminal services would be useful for container storage during the peak times (as a buffer) and off-peak times (as a storage).

3.4.2 Logistic companies

Logistic companies need high and constant transportation volumes to keep their business profitable. Small and irregular volumes are not worth the risk. Cost-effective logistic chain is essential. Cost savings can be achieved with high payloads and operationally reliable transportation vehicles and equipment. The fleet should be used all year round, which is not the case with special vehicles designed for particular purpose. If the transportation volumes change, the equipment supply should flex as well. New logistic solutions need to be integrated easily with the existing system, since the high investments for new facilities raise the price of transportation. (Laitinen, 2012).

A suitable offering for logistic companies would include RFID and container rental (Table 9). Simulation may be useful, but according to the QFD analysis, other services are not that important. RFID has several useful features for logistic companies: driving arrangements to avoid traffic congestion, actor-specific quality control and integrated devices and interfaces. RFID would fulfil the need of cost-effective logistic chain, high capacity utilization rate, the use of different transportation modes and easy integration. Actor-specific quality control could help with subcontractor tendering. Container rental would especially satisfy the need of flexible equipment supply and easy integration. Simulation could be used for cost estimation of different logistic chains with transportation modes.

3.4.3 Transportation entrepreneurs

For transportation entrepreneurs, the most important customer need is profitable transportation. Since the diesel price, drivers' wages and general costs have risen, the profitability in the transportation sector is under severe strain. The majority of the entrepreneurs need a significant improvement in profitability as well as increased haulage capacity. (SKAL 2012.) The investments in transportation equipment are high when compared to uncertain transportation contracts and risks. Therefore, the investments need to be profitable, and the capacity utilization rate has to be high. If the logistic system is sized according to the peaks, the special equipment is part of the time idle. Transportation companies need to cover the expenses also for the quiet months. By investing in reliable equipment, time savings can be achieved with quick unloading and minimizing the repair costs. (Laitinen, 2012.)

The needs of transportation entrepreneurs could be satisfied with an offering of container rental and RFID (Table 9). Especially container rental would meet the need of profitable transportation, economically efficient investments and high capacity utilization rate. Container rental would provide an alternative way to increase the capacity without high investment costs. RFID offers real-time data of shipments, which would lead to time savings and well-designed driving arrangements. Automatic data also gives an overall picture of the logistic chain, which could improve drivers' negotiating position. Since RFID provides information of container usage and maintenance, this would improve equipment damage tolerance and reparability.

3.5 The shareholders of the concept

The shareholders of the container logistic service concept were determined from business mapping phase. Each shareholder presents potential actors who are able to generate the required value flow in the service system or actors who utilize a particular value flow. The shareholders are connected to the analysed service concepts (Container sales, Container rental, Simulation and RFID service) as a customer, a resource pool or as a user (see Table 10). The customer role of an actor indicates that they are gaining benefits from the use of concepts and probably willing to pay for delivered service or product. Resource pool role of the actor means that they are able to provide valuable resources that are needed during service processes. The user role of an actor denotes activities during which information is provided into service process, but the shareholder does not benefit directly from their contributions.

Table 10 **Shareholders of the Container Logistic Concept and relations to the business concepts.**

Shareholder	Description	Relation to business concept			
		Container sales	*Container rental*	*Simulation*	*RFID*
Energy companies	Producing energy			C	C
Transportation entrepreneurs	Transporting freight by trucks	C	C		C
Rail freight operators	Transporting freight by train	C	C	C	C
Logistic companies	Transporting freight by trucks and train	C	C	C	C
Telecom operators	Providing wireless communication services			R	R
Cloud service	Providing services from virtual cloud servers			R	R
ERP system	Business process management software		R		R
Mobile services	Providing services for mobile devices				R
Container seller	Selling containers	R			R
Container manufacturer	Producing containers	R	R		R
Container rental	Renting containers		R		R
Container maintenance	Providing container maintenance		R		R
Maintenance information services	Providing container maintenance data		R		
Terminal services	Providing terminal services for containers		R		
Unloading equipment (manufacturing)	Producing unloading equipment		R		
Forklift (manufacturing)	Producing forklifts		R		
RFID tag covers (manufacturing)	Producing RFID tag covers		R		R
RFID tags (manufacturing)	Producing RFID tags		R		R
RFID readers (phones/reader ports)	Producing RFID readers		R		R
Forest management association/forest owners	Providing forest management				U
Wood processing industry	Producing wood-based products			C	C
Research institutes	Producing research			R	
Consulting services	Providing consultancy			R	
Spatial data services	Providing geographical data			R	R
		Labels	C = Customer R = Resource producer U = User		

The business network of the Container Logistic Service was built by cross tabulation of the shareholders during which expected direct interactions with directions were recognized. The goal of the cross tabulation was to assess the power of each actor in network as a customer and as a service or material provider. The power to determine service business was measured using normalized degree centrality (see Figure 5). High output degree (OUTPUT deg) indicates the actors' leading role in provision process and high input degree centrality (INPUT deg) increases actors' emphasis to customer role. The network structure and the key player's positions are also illustrated in Figure 6 and Figure 7.

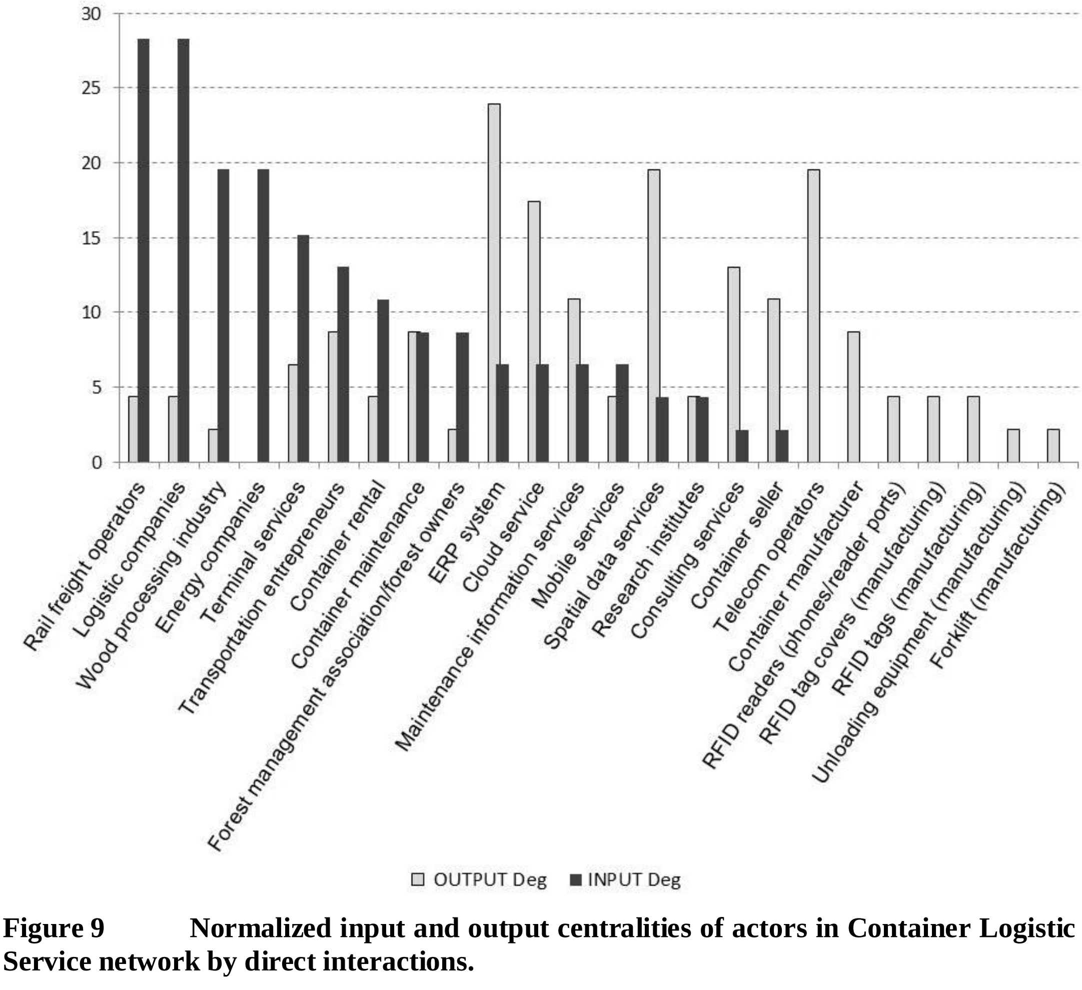


Figure 9 Normalized input and output centralities of actors in Container Logistic Service network by direct interactions.

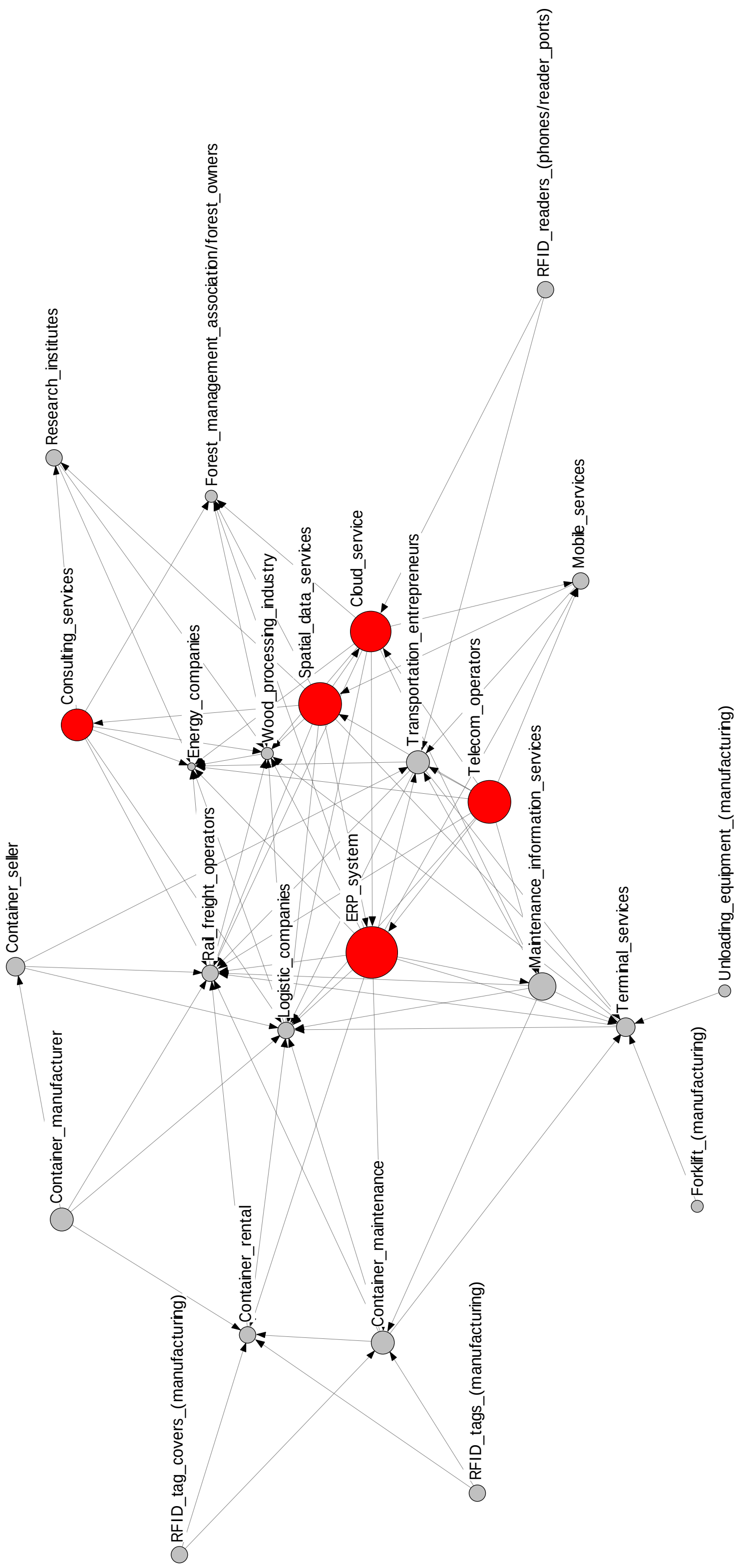


Figure 10 Actors by their outbound centrality (Powerful providers).

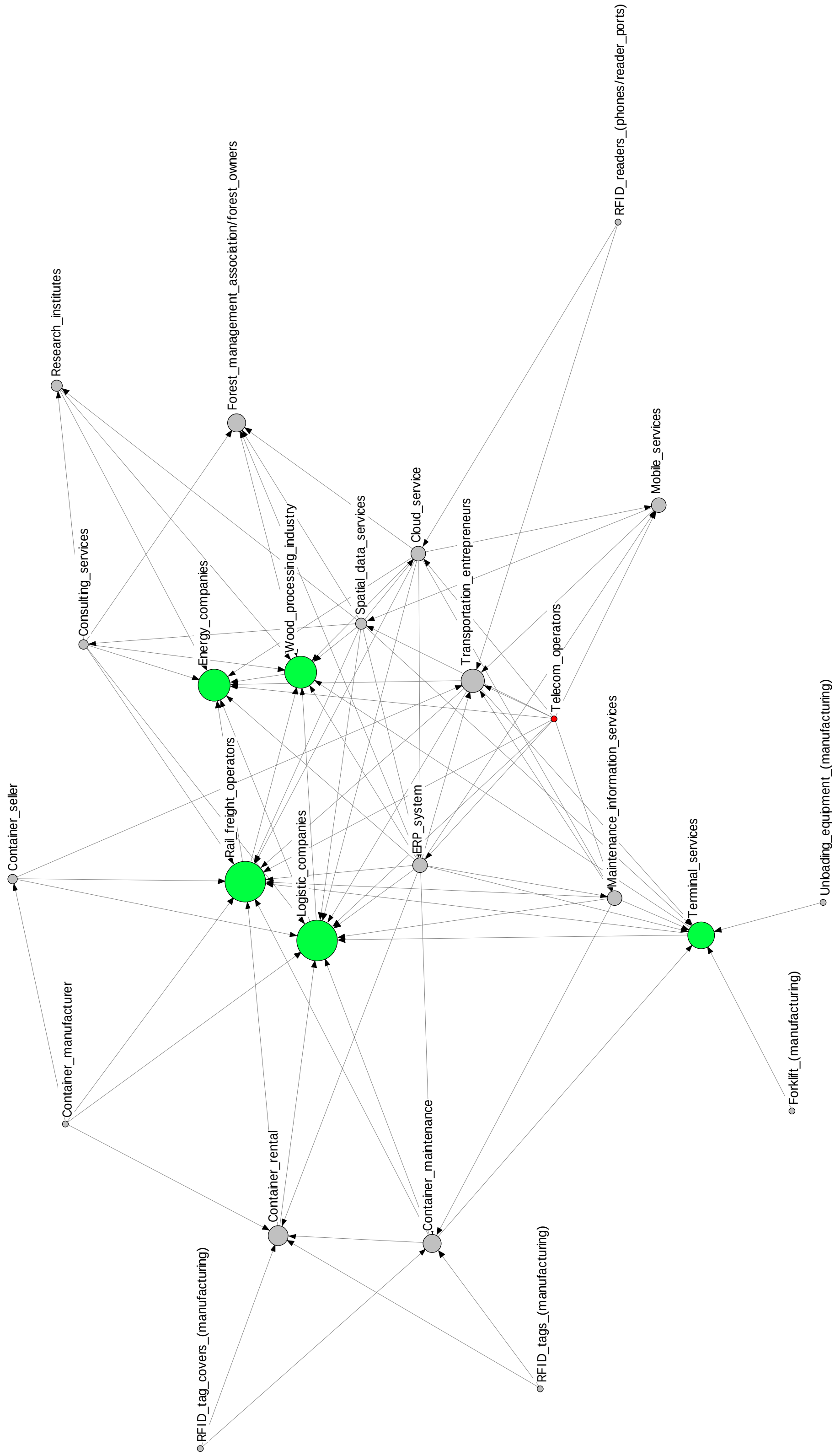


Figure 11 Powerful customers of the concept.

The information intensive business model creates the basis for actors' leading role in the network. Particularly, the actors that gather big data from processes are supposed to have power to determine standards for the service process. Those actors create links between different sub-processes, which provide value for customer. The physical product providers are located in the peripheral positions of the network, which indicates their low power to steer service development. The large logistic operators have integrated customer positions in the Container Logistic Service network, which makes them powerful to define standards and provide gatekeeper position for acceptable solutions. The energy and wood processing companies gathered a moderate number of connections, but their role is clearly the role of the end user.

Service business models in the Container Logistic environment seems to be dependent on ERP providers and cloud service providers, who define a "common language" for the platform. The major customers from logistic service companies must also be involved in the development because the new service concept will be established through the central actors in the network. Furthermore, the success of new physical product concepts is dependent on logistic service providers, who finally determine "de facto" standards throughout their market areas. Major logistic operators are also able to provide high investment rates for the product and information systems, which provides a pathway to the international markets.

The RFID and the composite container product concepts would be beneficial to stay separated due to different customer bases and the dynamics of the markets. The RFID based transport tracking services have potential to grow rapidly if the product and service bundles are built non-specificly for physical products and provide adequate support for different ERP platforms. Thus, developing properly working gateway services between system platforms would provide competitive advantage for the service provider. The growth of the composite container markets depends on the demonstration of benefits for cargo logistics, which supports replacing internments to new products.

4 EFFICIENCY OF ROADSIDE CHIPPING CHAIN

4.1 Technical aspects: freezing tests for composite and metal containers

4.1.1 Introduction to freezing problems and their study

Regions with high demand but low supply volumes require other logistics solutions than conventional supply methods, since transport by truck is economical only for short transport distances (Ranta & Rinne, 2006). This development will bring rail and waterway transport modes into supply logistics. Therefore, a need has emerged to find efficient solutions for integrating separate transport modes. Interchangeable containers have proved to be a promising option. The advantage of container logistics lies in the possibilities for intermodal transport and efficient terminal operations. Interchangeable containers have many advantages in the supply chain, but they will also cause idle times for containers in terminals and long-lasting deliveries. Idle times may cause freezing problems for containers, that are full of biomass, especially during the winter time in the Nordic conditions. Freezing problems occur typically when metal containers are used.

One solution to the freezing problems could be the new container type SuperCont®, developed by Fibrocom, based on a patented channel composite structure wherein the surface laminates are tied together strongly with diagonal laminates (Fibrocom). The cross-section of the structure is reminiscent of several I beams side by side (Fig. 12). This means a lighter, temperature-isolated, and more durable structure, and thus a sustainable transport carrier option. The container is manufactured in 'one-shot' moulding, and therefore, the walls and floor are tied together seamlessly and continuously. This way, the connections between them are very strong.

Figure 12 The channel composite structure.

The next study concentrated on the composite and metal containers´ ability to tolerate biomass freezing on the container inner surface. The biomass containers were put inside the laboratory hall, the temperature of which was −30 °C, and kept there for 24 hours. The purpose of this study was to compare the reliability of metal and composite containers in demanding sub-zero conditions. The aim was to obtain accurate information on forest chip freezing demeanour in interchangeable containers under controlled laboratory conditions.

4.1.2 Material

The freezing tests were carried out with three completely new containers in February 2013. Two of them were metal containers owned by Hyötypaperi Oy and one was a composite container made by Fibrocom Oy. The metal containers were exactly identical with the volume of 37 m^3 and empty weight of 2 600 kg, and the metal plate used on the walls had a thickness of 3 mm. The volume of the composite container was 39.5 m3 and the empty weight 1 900 kg, and the thickness of the walls was 53 mm. The length of the containers was based on the length of the freight container: 20 ft.

The forest chips used in the study were a mixture of whole tree and lopped tree, which was crushed a few days before the freezing tests started. The actual freezing tests were conducted at the MTT Agrifood Research Finland test site in Vihti.

4.1.3 Methods

Six temperature sensors were installed by taping them on the containers' inside walls and floors before filling them with forest chips (Fig. 13). The function of the sensors was to measure the temperatures at the different points on the container inside surfaces. An extra sensor was installed into each container to 1 m depth to measure the internal temperature of the forest chip heap. In addition, two temperature sensors measured the air temperature in the laboratory hall.

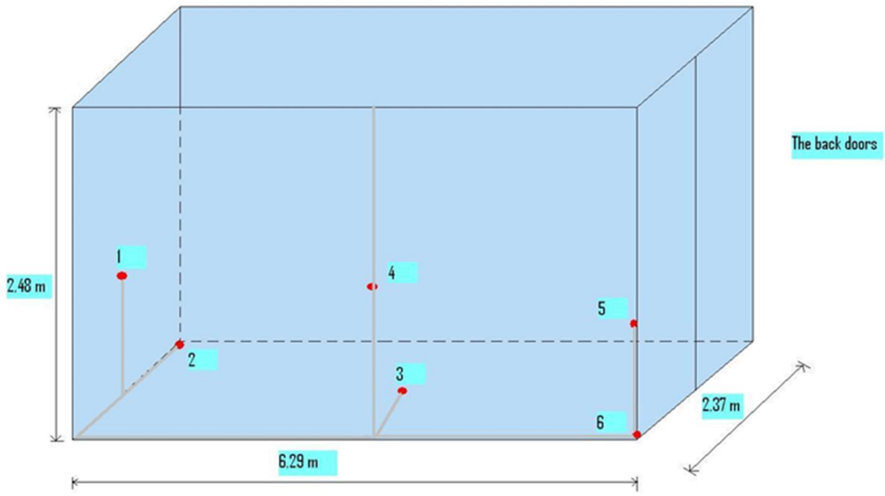


Figure 13 Temperature sensor places in the containers.

The coolant, EC1, suitable for motors, was injected onto the inside surface of the other metal container before filling it with forest chips. The coolant should prevent the freezing of forest chips on the metal surface. Thus, it is possible to compare the treated and the untreated metal container with each other. All the containers were at the mercy of the outside temperature during the period when they were not in the controlled laboratory hall. The outside temperature varied between 2 °C and −4 °C.

The metal containers were kept at −30 °C for 12 hours, and they were kept in the freezing test for the same time. The composite container was similarly kept at −30 °C for 12 hours. The laboratory gauges measured the temperature of the containers once a minute. The roof parts of the containers were not covered with a tarpaulin during the freezing tests.

The containers were unloaded by a truck to the fields of MTT after each test. The containers were weighed before and after the unloading to find out the weight of the frozen forest chips on the inside surfaces of the containers. Two moisture samples were taken from each container during the unloading. The samples were analysed using the oven drying method.

4.1.4 Results

The freezing test with metal containers

Based on the oven drying measurement, the average moisture content of forest chips was 47.0% in the first metal container and 49.1% in the second metal container. The weight of the forest chips was 11.95 t (320 kg/m³) in the first metal container and 11.65 t in the second metal container. The first metal container was treated with a coolant. Figure 14 shows the results of the temperature measurements of forest chips and metal container inside surfaces during the 12-hour freezing test.

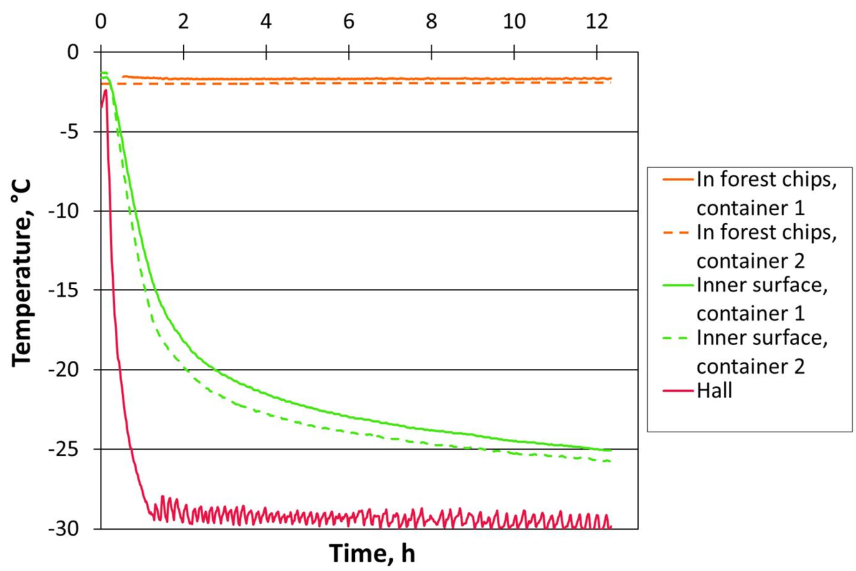


Figure 14 The freezing test of the metal containers.

Figure 14 shows that the temperature results were similar in both of the metal containers. The temperature was below zero on the container inner surfaces both in the beginning and in the end of the freezing test. All the containers were loaded in the open air where the temperature was below zero two days before the tests began. The temperature decreased from −2 °C to −25 °C on the inner surfaces, but stayed stable at −2 °C in the 1 m depth of the forest chips.

The forest chips were unloaded after the freezing test. The outside walls of the metal containers were beaten with forge hammers. Many tipping attempts were needed to dump all the chips that could be unloaded. The chip content was throughout frozen in such a way that the chips were frozen to each other within a 20 cm layer from the content surface in both of the metal containers. The chips were also frozen below the totally frozen layer, but the chips were not frozen to each other. Both of these metal containers were emptied for the most part, but a layer of the frozen forest chips with a thickness of approximately 50 cm–60 cm was stuck onto the floors and did not come out despite the efforts of tipping. Figure 15 shows the situation of one metal container before and after the unloading. The situation was the same with both of the metal containers. The residual frozen forest chips weighed 2.09 t (17% of the total weight) in the first metal container and 1.59 t (14% of the total weight) in the second metal container.

Figure 15 The metal container before the unloading on the left and after on the right.

The freezing test with the composite container

Based on the oven drying measurement, the average moisture content of the forest chips was 48.7% and the weight of the forest chips was 13.12 t in the composite container. The composite container was transferred to the laboratory hall after the test of the metal containers. Figure 16 shows the results of temperature measurements of forest chips and composite container inside surfaces during the 12-hour freezing test. There was a measurement interruption of 7 hours from 4 h to 11 h. The broken temperature curves were connected with a straight line in the graph.

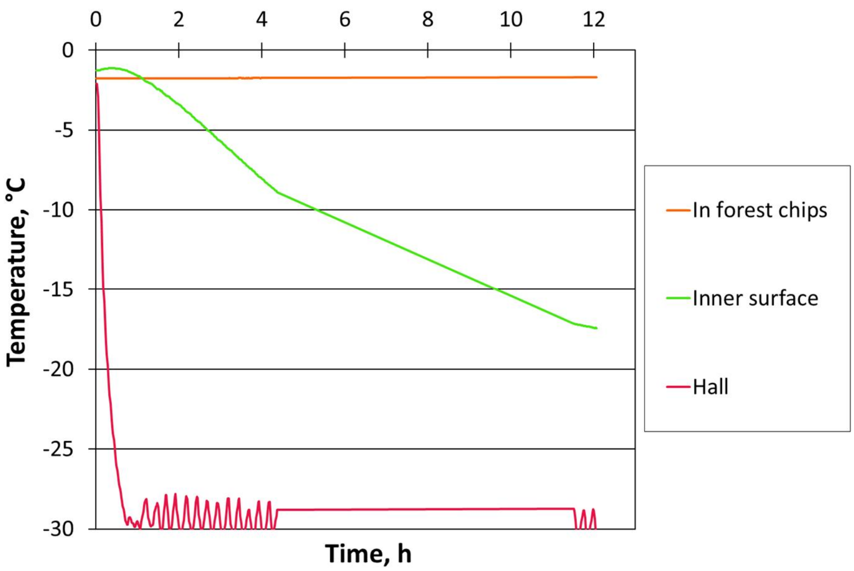


Figure 16 The freezing test of the composite container.

During the freezing, in the composite container, the temperature results were similar to those of the metal containers. Only the end temperature (−17 °C) of the inner surface was higher than in the metal containers, and the same temperature curve dropped less sharply.

The forest chips were unloaded after the freezing test. The chip content was throughout frozen in such a way that the chips were frozen to each other within a 20 cm layer from the content surface. The chips were also frozen below the totally frozen layer, but the chips were not frozen to each other. Nevertheless, the whole composite container was emptied of the chips. Figure 17 shows the situation of the composite container before and after the unloading.

Figure 17 The composite container before the unloading on the left and after on the right.

The unloaded forest chip heap contained a lump of frozen chips like the unloaded forest chips from the metal containers in the previous test. Due to the slippery inner surface, the unloaded chip mat was shorter in length than the unloaded chip mat from the metal containers.

4.1.5 Conclusions

The chip content was throughout frozen in such a way that the chips were frozen to each other within a 20 cm layer from the content surface in all of the containers. The chips were also frozen below the totally frozen layer, but the chips were not frozen to each other. A frozen chip layer with the thickness of approximately 50 cm–60 cm was stuck on the floors of the metal containers, in which case it was impossible to unload about 14%–17 % of the total weight. The other metal container was treated with a special coolant, EC1, but that did not seem to affect either the freezing of the chips onto the inner surfaces or the unloading problems. The composite container was emptied easily of the chips after the freezing test.

Based on this study, long-lasting deliveries, lasting for example 2–3 days, are not suitable for biomass when metal containers are being used in cold weather. It was impossible to unload the metal containers of the chips perfectly after the freezing test because the problem was the freezing of the chips onto the floor. The major problems do not occur after the deliveries, the duration of which is only a few hours, but biomass starts to freeze onto the inner surfaces when the delivery time is extended.

The problem with the freezing did not occur at any stage when the composite container was used during the freezing tests. Therefore, it can be stated that the composite container is more cold-resistant than the metal containers. On the other hand, the chips were normally frozen into lumps, but the frozen chips were unloaded completely because of the slippery plastic composite material. The temperature of the chips within the heap was below zero, being about −2 °C, in all freezing tests.

The composite container is suitable for the deliveries of the bulk produces in the Nordic conditions wherein there is a risk of freezing. The intermodal logistics of the truck and the train are promising for the composite containers because of the frost-proof material, in which the biomass does not freeze onto the inner surfaces. These containers made of plastic composite have entered the interchangeable container market, and their functionality has now been confirmed in the unloading situations when operating in extreme cold temperature conditions.

4.2 RFID tracking in roadside chipping chain and efficiency analysis of biomass logistics

4.2.1 Introduction

Although Radio Frequency Identification (RFID) technology is widely used in industry, so far it has almost no applications for energy biomass logistics. Logistics, especially interchangeable container logistics, offers an interesting target for this kind of applications. RFID technology enables the online tracking of biomass load information keeping transaction logs and locating the load during the reading actions. (Ranta et al., 2014)

RFID is a remote identification method that uses radio frequencies. A typical RFID system consists of a tag and reader, their antennas and electronics controlling their operations (Violino, 2005). The reader device uses a magnetic or electromagnetic field to communicate with the tag, which is a small electronic device that consists of a small antenna, control electronics and a small amount of memory. The tag is attached to the object that is being tracked. The reader device is observing the around tags and reads theirs information wirelessly. Typically, the tags are passive and getting the energy required for communication from the magnetic or electromagnetic field of the reader device. An active tag has an internal power source for continued operation, but it needs to be replaced at regular intervals. The advantages of passive tags are a long lifetime and maintenance freedom.

In the study, truck-specific transportation monitoring was carried out with the help of Resource Control (RECO), which is a asset management system. Trucks delivered the forest chips from the forest roadside storages to the power plant, while the chipping of solid biomass was carried out by a mobile chipper on the spot by the roadside. The drivers had smartphones, wherein BioHake phone application was installed. The application enables the enterinf of the load information in real-time to the message-based RECO system with an online wireless Internet connection. Additionally, the application collects the time information of each delivery operation. The fixed reader gates were fitted at the weighbridge of the power plant, which read the RFID tags that were affixed to the container outside walls. The truck vehicles were identified when driving through the weighbridge and their time stamps were stored to the system at the same time. The moisture samples were taken from each load during the unloading. The samples were analysed using the oven drying method, and the energy content of the load was defined based on the strength of the moisture.

The main purpose of the study was to determine the efficiency of energy biomass logistics when using the real-time web-based tracking system. Three traditional solid-frame trucks and one truck with interchangeable containers were included in the study. The energy contents of the loads and the delivery performance ratios of the deliveries were analysed. Additionally, the functionality and the reliability of the real-time monitoring system was examined as part of the roadside chipping chain when the vehicles were operated in extremely demanding conditions.

4.2.2 Material and methods

The study was carried out as field monitoring during the period from December 2013 to April 2014 (5 months). In the study, one cooperation partner was Santa Margarita Oy, which produces IT services in Lappeenranta. The company was responsible for procurements and installations of the research equipment and their software. Another cooperation partner in the researchwas Protacon Group, which enabled the real-time availability of the load weights of the transportations from the Once system to the RECO system. The power plant weighbridge used the Once system.

Forestry society Metsä-Savo offered the location and storage information of the roadside storage places for the research. The forest chips delivered in the study were made of a whole tree or a forest residue. The roadside storage places (14 pieces) located between Mikkeli and Juva (Figure 14). The end delivery place of the forest chips was the power plant of Etelä-Savon Energia Oy (ESE) in the city of Mikkeli (Fig. 1). ESE took part to the co-operation by collecting the moisture samples for the research and providing the load information data for post-inspections.

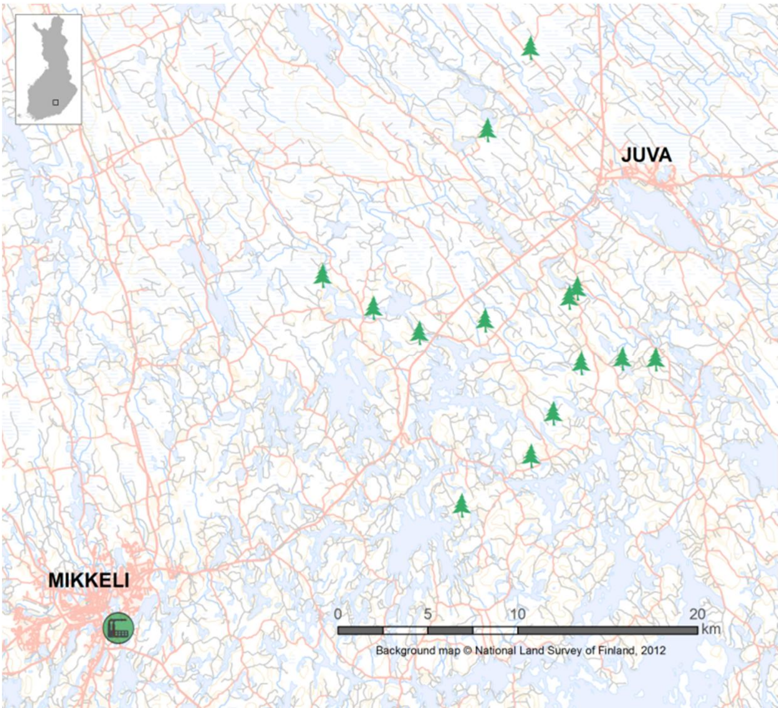


Figure 14 **Locations of the storage places in relation to the power plant location (made by Olli-Jussi Korpinen).**

The truck vehicles that participated in the study are owned by Kotimaiset Energiat Oy, which offers chipping and delivery services. A container truck is a combination of three containers, it has a hook system, and the unloading is carried out by dumping. Traditional solid-frame trucks were the chain unloading systems. On the whole, the total number of deliveries was 68 pieces during the study: 20 pieces of the deliveries were only head truck deliveries and the rest was truck and trailer combination deliveries. The truck vehicles are specified below:

- A container truck, 8 axles (truck 40 m^3 + trailer 80 m^3 = 120 m^3)
- A solid-frame truck, 6 axles (truck 47 m^3 + trailer 68 m^3 = 115 m^3)
- A solid-frame truck, 7 axles (truck 45 m^3 + trailer 68 m^3 = 113 m^3)
- A solid-frame truck, 8 axles (truck 50 m^3 + trailer 70 m^3 = 120 m^3)

The tracking of the deliveries was performed with the help of smartphones, and the drivers were able to enter their load information and time mark of delivery phase to the RECO system in real time. The drivers used the phone model Nokia Lumia 900 in which the BioHake phone application was installed. In addition, the time breaks were tagged to the system by the driver. Because the load information was entered container-specificly on the roadside, it was possible to deliver the biomass of the different sellers volume-specificly.

The RFID tags were installed to each outer surface of the delivery container before the start of the study. Hence, it was possible to identify the truck vehicles automatically on the weighbridge of the power plant at the reading time. The tags were protected with a separate RFID identifier box made of plastic. The box was planned and produced by a student of Mikkeli University of applied sciences as a thesis. The RFID tags were stuck to the inner surface of the box and the box was glued with instant glue to the side of the container (Figure 15).

Figure 15 **The RFID identifier box on the left and the truck vehicle on the weighbridge of the power plant on the right.**

Both RFID tags were kind of paper stickers. The oblong tag (SMARTRAC DogBone) was based on UHF technology and the circular tag on NFC technology. The UHF tags were for the reader gate and the NFC tags for smartphone. However, the NFC tags were not used in this study because the phone made it possible to enter all information to the RECO system. The reading distance was several metres for the UHF tag and a few centimetres for the NFC tag. The antenna of the reading gate was a fixed equipment installed at both ends of the weighbridge and connected to the reader unit, which was inside the condensed and heated cabinet. The reading distance between the antenna and the passing vehicle was approximately 1 m. The cabinet was installed on the outside wall of the hut into the vicinity of the weighbridge (Figure 16). The reader unit had an wireless Internet connection to the RECO system.

Figure 16 The reader unit was inside the cabinet.

4.2.3 Results

RECO system and BioHake phone application

The whole monitoring system was based on the RECO system, to which the information and the transactions relative to the material and vehicle types were entered and reported. RECO was basically a ready logistics tracking system, but it was remodelled for the needs of the container logistics. The actual system worked excellently and was completely reliable for recording the information and transactions of the deliveries during the follow-up period (Figure 17). The drivers used Lumia smartphones, wherein the BioHake phone application was installed for the entering and recording of logistics information (Figure 18).

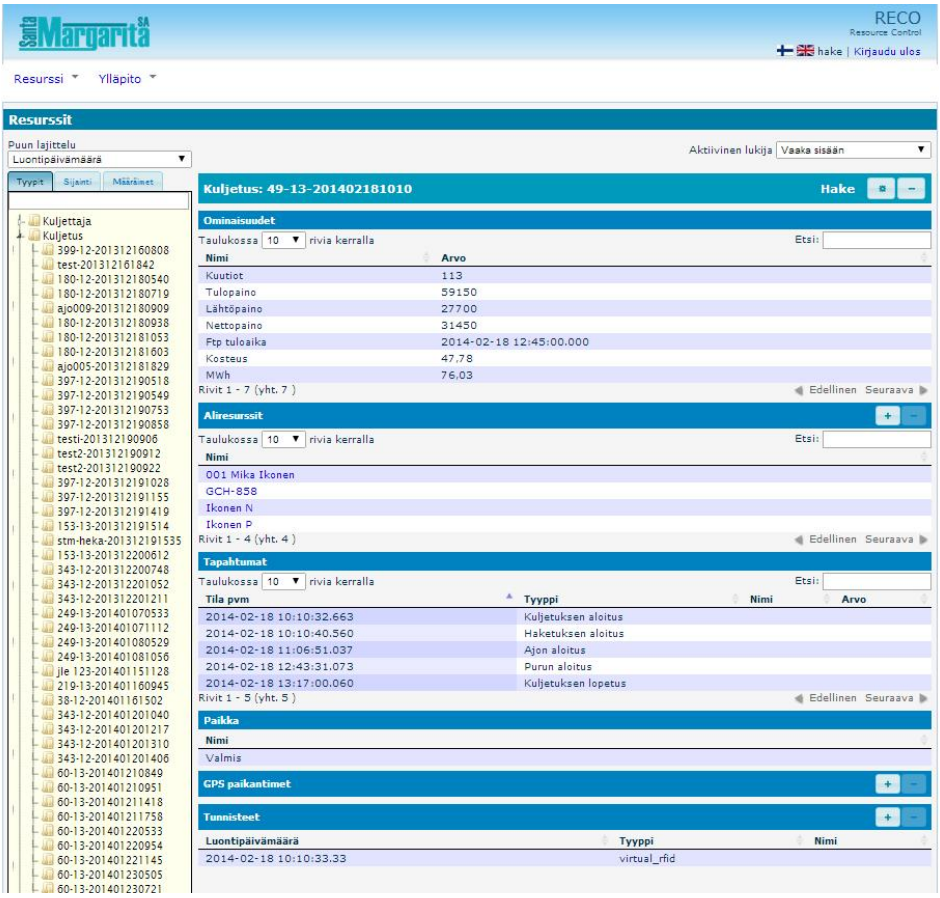


Figure 17 View of the RECO system.

Figure 18 View of the BioHake phone application.

The building and development of the phone application were a time-consuming task during the entire study. The phone application was tested carefully before the follow-up period, but it was improved nevertheless according to the wishes of the drivers to be more user-friendly during a couple of months. Finally, the phone application was developed into a functional and reliable entity that is easy to use. If the Internet connection of the application failed at a blind spot, the messages were buffered to the line and sent automatically to the RECO system when the connection was restored.

Efficiency of deliveries

In the study, forest chips deliveries were observed, which were performed using two truck combination types. The forest chips were chipped logging residues or size tree (Table 11). The total number of the loads was 68 pieces. The loads were separated according to the truck combinations as follows: 46 loads by the solid-frame trucks and 22 loads by the container truck. The grouping according to the forest chips was: 49 logging residues loads and 19 size tree loads.

Table 11 Total loads.

		Forest chips type		**Total**
		Logging_residues	Size tree	
Truck / Trailer	Solid-frame	35	11	**46**
	Container	14	8	**22**
	Total loads	**49**	**19**	**68**

The net weight, energy content, delivery time, distance to storage and the delivery performance ratio of the load were used to describe the deliveries (Table 12). The large variation in the net weight and the energy content can be explained by the using of the full and half truck combinations.

Table 12 Descriptions of the deliveries.

	Min	Max	Mean	Std. dev.
Net weight [t]	10.60	40.80	26.8	9.7
Energy content [MWh]	23.1	133.8	70.6	29.5
Delivery time[b] [min]	86	519	261	93
Distance to storage[a] [km]	30.0	50.5	39.8	7.1
Delivery performance ratio	0.53	3.01	1.36	0.62

[a]) One-way distance from storage to power plant
[b]) Delivery time incl. driving time start - storage - power plant, chipping time and interruptions time

The delivery performance ratio was used to describe the efficiency of the deliveries (Equation 1), which made it possible to compare the efficiencies of the deliveries of different types of truck vehicles and forest chips. In the equation, the distance to storage multiplied by two was used as an estimation of the driving kilometres and the energy content (MWh) was measured from the load.

Equation 1 The delivery performance ratio

$$Delivery\ performance\ ratio = \frac{2 \times Distance\ to\ storage}{Energy\ content}$$

The deliveries of the sample were analysed by the group comparison of means which directed to test potential differences in logistics performance between vehicle types and delivered biomass type (Figure 19). Non-parametric methods were used for the statistical tests due to the small sample size. The deliveries were divided into groups as follows:

- Type of forest chips (logging residues / whole tree)
- Type of truck vehicle (fixed / transfer container)

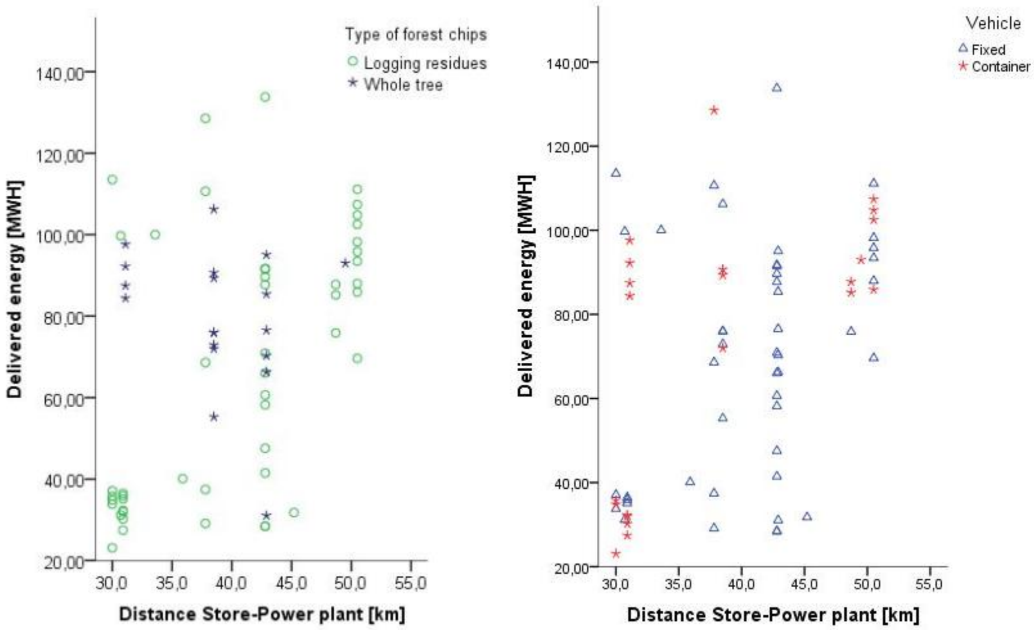


Figure 19 **The dispersion of the driving distance and the delivered energy with the type of forest chips and vehicle.**

At the beginning, the existence of a systematic error was eliminated by making pair comparisons to the variables of Equation 1 (Table 13 and Table 14). Mann-Whitney U-test was used as the test. Statistically significant differences were not found in the distance to storage or the delivered energy content when the significance rate (p-value) was 0.05. The changes in the efficiency were caused by the effects of the bioenergy amount and the distance. However, the result of the test should be regarded critically because of the small sample size and the difference of group sizes.

Table 13 **Comparison: vehicle types.**

	Mean (fixed)	Mean (container)	Std. test statistics	p-value
Energy content [MWh]	69.1224	73.8414	0.511	0.609[n]
Distance to storage[a] [km]	40.609	38.191	−1.202	0.229[n]
Delivery performance ratio	1.4036	1.2569	−1.049	0.294[n]

n) No statistically significant differences between groups
***) Statistically significant difference between groups at p<0.01**

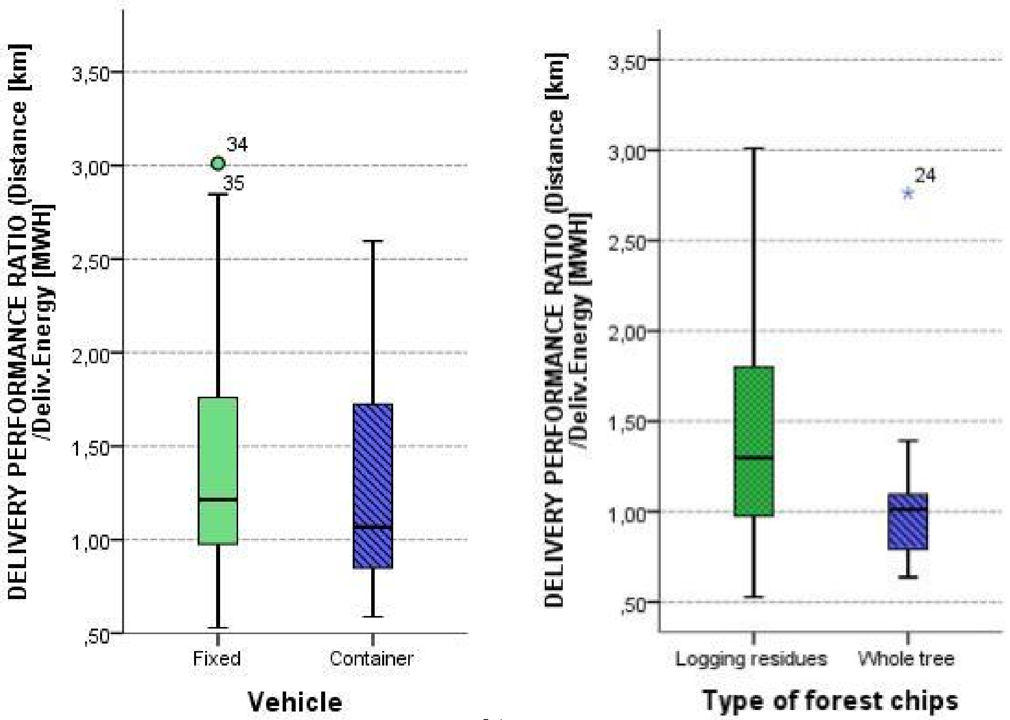
Table 14 Comparison: forest chip types.

	Mean (whole tree)	Mean (logging residues)	Std. test statistics	p-value
Energy content [MWh]	79.8837	67.0684	1.278	0.201 [n]
Distance to storage[a] [km]	38.911	40.182	0.269	0.788 [n]
Delivery performance ratio	1.0585	1.4715	−2.658	0.008*

[n)] No statistically significant differences between groups

***) Statistically significant difference between groups at p<0.01**

The vehicle type does not seem to be of any relevance according to the delivery performance ratio (U-test −1.049 (p=0.294)). It also shows with a similar variation in the tested efficiency numbers (Figure 20a). The significant difference of efficiency was found between the types of the forest chips on the basis of the statistical test (U-test −2.658 (p=0.008)). It also shows with the small mean and the dispersion of the efficiency number (Figure 20b). Therefore, it can be said that the loads of whole tree were more predictable than the loads of logging residues.



a) b)

Figure 20 Delivery performance ratios.

4.2.4 Conclusions about RFID tracking

The aim of this study was to determine the efficiency of energy biomass logistics when using a real-time web-based tracking system. By means of the asset management system RECO, it was possible to track the trucks moving in the supply chain via the Internet portal in which all tracking data were stored on a virtual cloud server. The RFID identification and GPS position functions were built into the RECO system. Both smart phones and gate readers equipped with the wireless Internet connection were used for data transfer into the message-based RECO system. The experiments were carried out along the supply chain from the forest roadside storages to the power plant by using the traditional solid-frame trucks and the trucks with interchangeable containers mounted with RFID tags.

The whole tracking system worked excellently and was completely reliable for recording the information and transactions of the deliveries during the follow-up period. Statistically significant differences were not found in the distance to storage or the delivered energy content between the vehicles. The type of vehicle did not seem to be of any relevance. The significant difference of efficiency was found between the types of the forest chips on the basis of the statistical test.

This study pointed out that RFID identification enables the tracking of the trucks on a real-time basis through the delivery chain, and that the information data can be used to analyze the vehicle-specific time usage and the efficiency of deliveries to fulfil the needs of customers. The information stream can be divided into parts such as single containers according to the owner, origin, destination, content and quality of biomass. This can be used to prove the efficiency and sustainability for the exact individual transportation path of forest-based biomass as a part of the whole supply chain.

4.3 Simulation modelling of the costs

Three cost modelling study cases of forest based biomass resources and logistics are presented in the following.

- Case study 1 is based on the results of the cost simulation within the article "Cost-efficiency of intermodal container supply chain for forest chips" (Karttunen et al., 2013) from the project "Container logistical innovations" (Lappeenranta University of Technology).
- Case study 2 is based on the same project using RFID demonstration data and cost modelling of alternative truck systems in the conference article manuscript (Föhr et al., 2014).
- Case study 3 is based on the combined methodology of forest management simulation and logistic cost modelling in the ECOSUS project (University of Helsinki) in the article manuscript (Karttunen & Laitila, vuosi?).

The case examples give a description of opportunities for cost modelling of forest-based biomass resources and logistics. The principle idea is to describe the cost reduction potential of forest-based biomass resources and logistics for energy purposes by comparing traditional options to innovative ones in order to create value. It is significant to understand the value creation process of forest-based biomass and to show how a perfect competitive market situation should work in theory and how an imperfect market situation with market failures works in practice. It can be applied for the knowledge how market of forest-based biomass for energy purposes may behave in each situation.

4.3.1 Long-distance transportation for forest biomass

For shorter distances (< 60 km), truck transportation of loose residues and end-facility comminution has hitherto been the most cost-competitive method (Tahvanainen and Anttila, 2011), but over longer distances, roadside chipping with chip truck transport has been shown to be more cost-efficient (Ranta and Rinne, 2006). For even longer distances (135 km–165 km), depending on the biomass source, train transportation of forest chips can offer the lowest costs when used in conjunction with roadside chipping systems (Tahvanainen and Anttila, 2011). Inland barge transportation has also been studied, and the results indicate that barge transportation of roadside-chipped chips is more cost-efficient than truck transportation for distances greater than 100 km–150 km (Karttunen et al., 2012). The optimum method of transporting forest-based biomass as the most cost-efficient way faces the continuous change all the time.

Within the Finnish national context, especially the use of small-diameter energy wood could be increased to reach energy targets. More dense forest management of young stands, including energy wood thinning, can be used to produce small-diameter trees more economically (Heikkilä et al., 2009). Logging is the most expensive part of the supply chain for small-diameter energy wood (Laitila, 2008), and the costs are significantly higher than those of logging residues (Hakkila, 2004). Innovations leading to more efficient logging have been developed in recent years, such as single-grip harvester heads equipped with multi-tree handling equipment for cutting whole trees and multi-stem delimbed energy wood (Laitila et al., 2010; Belbo, 2011; Kärhä, 2011). Other costs of the supply chain, such as chipping and transportation of chips, are quite similar for both small-diameter trees and logging residues (Laitila, 2008; Hakkila, 2004).

Efficient supply chains for biomass are clearly of considerable significance for greater use of energy wood and thus form an interesting area of study. Specific issues that need addressing include: cost-efficient solutions for long-distance transportation of chips, small-diameter delimbed trees or other uncomminuted biomass material—road, rail or waterway and combined approaches; cost structures of small-diameter energy wood, which unlike logging residues and stumps are not dependent on final cutting and possible effects of technical innovations to create cost reductions such as intermodal container concepts (Case study 1), cost tracking of alternative truck systems by using the RFID technology (Case study 2) or denser forest management regime combined to innovative harvesting technology and whole supply chain (Case study 3).

4.3.2 Market balance

Market balance refers to the situation, in which demand and supply are equal for the exact market quantity and price of product. The price adapts to each situation in relation to the market demand and supply. The market balance can be determined theoretically in the situation, where other factors, such as prices or technology, are kept constant. It is important to separate the change in prices and the change in other influence factors. The price change can be determined by moving through the demand or supply curves, whereas the change in other influence factors can be determined by transferring the demand or supply curves from one place to another. Usually one change is made at a time to study the market influences theoretically.

Market balance exists for the price and quantity of forest chips where demand and supply are equal. If the price is higher, there would be a situation of excess supply in the market. If the price is lower, there would be too much demand. If the demand and supply functions are known, it is possible to measure the market balance. As an example, supplied quantity of forest chips should be 16 TWh when the average price is 20.7 €/MWh in 2013 according to the statistical data (Statistics Finland) (Figure 21). In a perfect competitive market situation, the demand curve refers to a price of product as an inelastic demand. Price elasticity of demand measures how the demand reacts to a change in prices. Price elasticity of supply describes how the supply reacts to a change in prices.

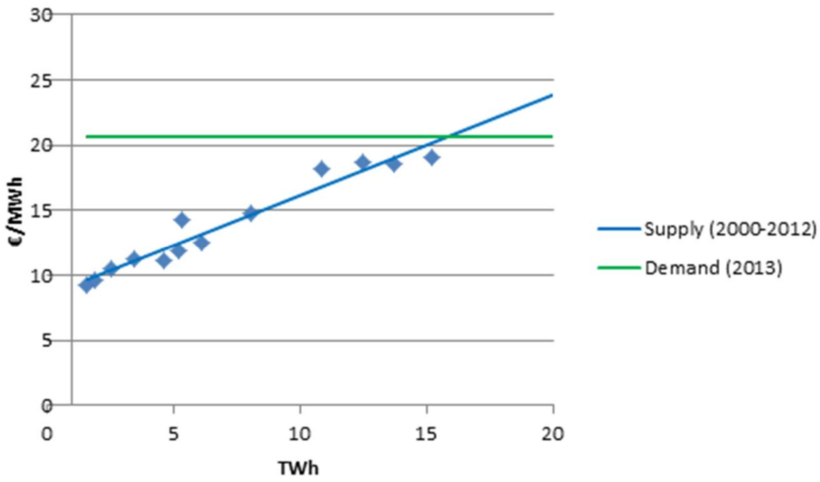
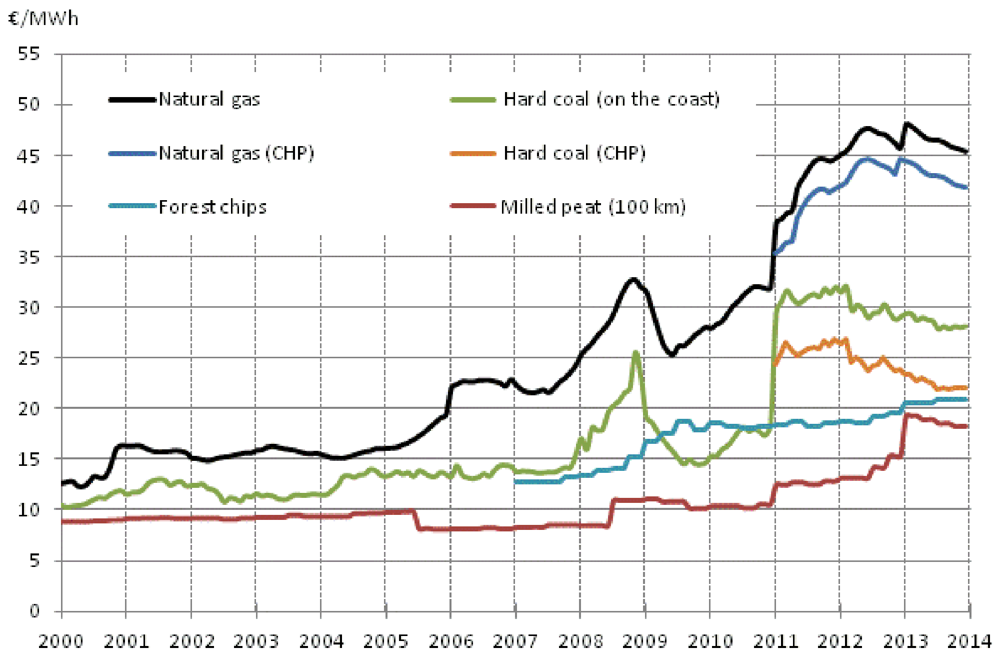


Figure 21 Market balance of forest chips can be met at the point, where demand and supply curves meet due to price and quantity (Statistics Finland). Demand = average price of forest chips in year 2013. Supply = the real prices and quantities of forest chips, years 2000–2012 (corrected by consumer price index).

The market demand curve can be determined by calculating the demand in relation to the price of each production amount. The market demand curve of forest chips describes the willingness to pay for forest chips by fuel buyers. The following factors may have influence on market prices of forest chips: the number of users, the volume of users, final product prices and the prices of substitute products or production cost structures. In addition, subsidies for renewable energy or taxes for nonrenewable energy have strong impacts on market prices.

Products can be consider as either normal, inferior, substitute or complementary commodities. The demand of a normal commodity increases in relation to income, whereas the demand decreases for inferior commodity. When the product is a substitute commodity, it functions to replace some other product or it can be replaced by another product in relation to a change in price (Figure 22). Forest chips can replace, for instance, coal in heat production, or be replaced itself. Complementary commodities are goods, the demand of which will increase when the price of another good is increased. Forest chips can be a complementary commodity, for instance when complementing peat in heat production.



Sources: Finnish Customs/Foreign Trade Statistics, Energy Market Authority/Gasum Oy, The Bioenergy Association of Finland/Association of Finnish Peat Industries, Finnish Petroleum Federation

Source: Statistics Finland, Energy prices

Figure 22 Fuel prices in heat production in Finland (Statistics Finland).

Forest biomass used for energy purposes is produced relatively evenly throughout the year, but differences in the supply and demand do occur, especially in district heat production (Jirjis, 1995). Forest biomass supply should be based on customer demand, which means that it is in greater demand during the winter (Nurmi, 1999). In boreal areas where the demand of forest chips is primarily for heat, the demand curve strongly correlates with seasonal temperature changes. The supply of biomass can be geographically patchy, making it more difficult to secure raw material supplies (Ranta et al., 2005).

The market supply curve tells how much the product is supplied at each price level. It is possible to estimate for forest chips, for instance, whether statistics are available about quantities and prices of forest chips during time period. To estimate the supply curve, information is needed for the factors which explain the supply. Theory is needed to read the information and factors included in the supply curves. The supply curve of forest chips is the result of all firm quantities to provide forest chips at each price level. In theory, a firm will choose its quantity of supply so that the marginal cost is equal to the price of forest chips. The smaller the marginal costs by given amount, the larger the supplied quantity potential of a firm.

4.3.3 Production costs and profits

Firms function to maximize profit, which is the result of the total revenue minus total costs (Figure 23). In competitive markets an individual firm cannot influence the prices. Instead, the production amount can be influenced and cost reduction can be attempted. Production costs are the cost of the inputs: labor, capital, energy and materials. Production costs depend on the technology used in production and technological advances. Cost reductions can be achieved by choosing an optimal amount of production or by innovating production technology. The marginal cost describes the cost of producing one more unit of a good. Marginal revenue is the additional revenue that will be generated by increasing product sales by one unit. It refers to the price of product in competitive market. Profit is maximized at the point where marginal revenue is equal to marginal cost (Figure 24).

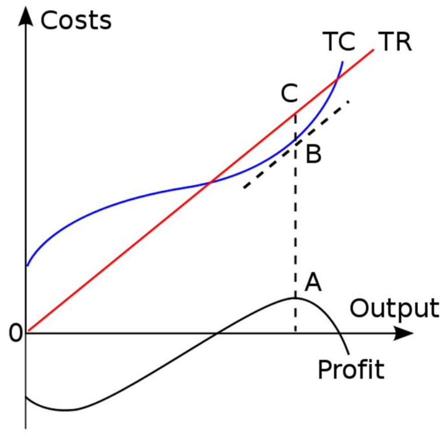


Figure 23 Profit maximization problem by figure. TC = Total cost, TR = Total revenue, A = Profit (C–B).

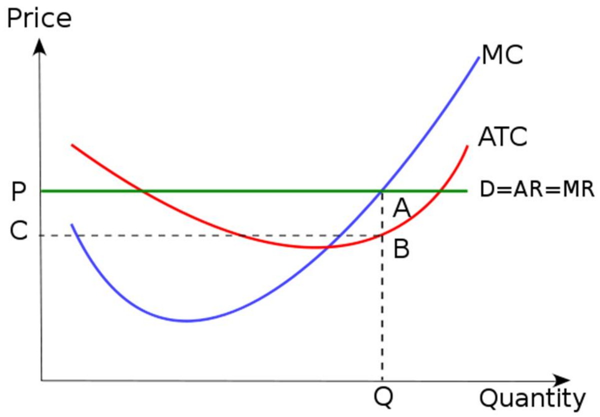


Figure 24 Profit maximization problem by figure. MC = Marginal cost, ATC = Average total cost, Q = Optimum quantity, P = Price of product, D = Demand curve is equal to marginal revenue curve (MR) and price (P). Q = Optimal quantity. Total economic profit is represented by the area of the rectangle PABC.

Procurement costs remain the major impediment for large-scale biomass when competing with fossil fuels (Gan & Smith, 2006). In wood-based energy production it is difficult to achieve the same economics of scale as fossil fuels because of the disadvantages of transporting widely distributed biomass to a central location (Ikonen & Asikainen, 2013). This weakens the economic sustainability of wood-based energy production (Ranta, 2005).

The greater the output of an energy-producing plant, the higher the annual consumption and the higher the procurement costs of biomass will be, resulting in higher total operating costs per unit of energy produced (Ikonen & Asikainen, 2013). When the annual consumption of forest chips in a single plant increases from 10 000 m^3 to 100 000 m^3, the mean procurement costs increases by 8%–15% (Asikainen et al., 2001).

The price of forest based biomass is highly variable due to the low energy-intensity and transport economy (Ikonen & Asikainen, 2013). Improvements in the productivity of biomass production, harvesting and transport systems are clearly the key to enhance the bioenergy share of total energy production (Gan & Smith, 2006). The overall cost reduction potential is estimated to be up to 25%, mainly due to better technology, improved harvesting techniques and optimized long-distance transportation (Hogan et al., 2010). There are ample indications that factors such as technological progress and upscaling have led to significant reductions in production costs of forest biomass production in the past few decades (Junginger et al., 2005).

In principle, the cost of competing fuel defines the maximum acceptable cost of forest based biomass (Ikonen & Asikainen, 2013). When the marginal cost of forest based biomass use exceeds the mean cost of alternative fuels, using biomass for energy is not economically sustainable. Decreased procurement costs will increase the optimum scale of operations and make new volumes of resources available (Andersson et al., 2002). By integrating the biomass supply chain within the roundwood supply chain by forest companies or by using cooperative structures in biomass feedstock supply, forest management, operational management and long-distance transportation cost savings can be achieved and overall profitability in the supply chain increases (Ikonen & Asikainen, 2013).

4.3.4 Productivity and cost structures

Case study 1:

The productivity times and the operating hour productivity coefficients were based both on the estimates of the author and earlier follow-up or pre-test studies (Karttunen et al., 2013, Karttunen et al., 2010; Föhr & Karttunen, 2012). The new approach and large number of alternatives means that exact productivity information was not always available. Productivity estimates (unit/time) were converted into efficiency figures (time/unit) within minimum to maximum value ranges in the simulation timetable, where the delays and idle times were taken into account. Those are reported more exactly in the study of Karttunen et al. (2013).

Case study 2:

Productivity is an average measure of the efficiency of production. In this case study, it was determined how effectively forest chips can be transported to energy purposes from roadside storage to power plant and back by using alternative truck systems. Data was collected by using automatic RFID technology. The time of each operation was collected from the start of the operation to the end of the operation either by the driver using a mobile phone or automatically from a reader at the gate of the power plant terminal. The transportation operation started from chipping, “1:terminal time, loading”, at the roadside terminal straight to the truck and ended when the next operation,“2:driving full”, started. The delay times were collected during the transportation operations, but they were not separated in this study. Driving operation ended at the gate of the power plant automatically, where the net weight was measured as a difference between full and empty load. Payload as energy content (MWh) was converted from net weight of load (tonne) by taking moisture samples of every load and analyzing them in a laboratory. The unloading of the truck, “3:terminal time, unloading”, was the time wasted inside the power plant terminal area between the full and empty weight measurement of the truck system. In this study, the final operation of driving back to the same storage as empty, “4:driving time, empty”, was assumed to take 5% less time than driving full.

Case study 3:

The productivity of cutting industrial roundwood and delimbed energy wood using the multi-tree processing technique was based on the study of Laitila and Väätäinen (2013). The forwarding productivity of industrial roundwood and multi-stem delimbed energy wood was calculated using the model of Kärhä et al. (2006). The effective time (E_0) productivities of cutting and forwarding were converted into gross effective time (E_{15}) productivities with the coefficients 1.393 and 1.302 (Jylhä et al., 2010; Laitila and Väätäinen, 2012).

Multi-stem delimbed energy wood and pulpwood were transported using a conventional timber truck with a trailer, with the maximum payload of 44 tonnes (Korpilahti, 2013). The road transportation times were composed of driving with an empty load, driving loaded and terminal times (incl. loading, unloading, waiting and auxiliary time). Time consumption of driving, with full load and empty load, was calculated as a function of transportation distance according to the speed functions of Nurminen and Heinonen (2007).

Cost structures:

The cost of forest chips made of logging residues and small-diameter whole trees were analysed for the vehicles and machines throughout the supply chain and supplied either from roadside to the power plant including the whole supply chain costs (Case study 1) or including separated transportation costs (Case study 2). Forest management and whole supply chain costs for delimbed energy wood from first thinning harvesting stands were included (Case study 3). The supply chain must include all operations for the sake of comparability. The operating costs (excluding VAT) of the alternative vehicles and machines were calculated with the aid of machine cost structure analysis. The cost structure analysis included annual fixed costs (e.g. capital depreciation, interest expenses, insurance fees and administration expenses) and variable operating costs (e.g. labour costs, fuel, repairs and service) which were set for the input values of the cost modelling. There were differences in the cost structure analyses between case study articles. In the simulation case study 1, the whole annual fixed costs were used for all vehicles and machines, whereas driving cost was analyzed in relation to variable costs as changing tons and distances (€/tnkm changed to MWh) with the unloading machine costing 11.07 €/container in the simulation model. In the transportation cost analysis (2 and 3) terminal (labour and fixed cost) and driving (fixed and variable cost) costs were separated.

4.3.5 Forest based biomass resources

Case study 1

The source data consisted of municipal estimates of forest fuel availability and land-use data (Korpinen et al., 2012). The datasets were imported to a geographical information system (GIS) environment and was processed using ArcGIS software (ESRI, 2013).

The points of origin for forest-fuel supply were generated via a 4 km × 4 km grid. The midpoints on the grid were extracted for further use in the transport analysis. This raster-to-vector conversion was required to connect the estimates of biomass availability to the transport network in vector format.

In practice, there may be several roadside sites in a 16 km² area, and places of forest operations change from one year to the next as new cuttings appear. The biomass volumes in points closer than 4 km from one another were aggregated. Describing the information for several roadside sites as the attributes of one origin point decreases the computational load of route calculation.

The results of the availability analysis are given as average amounts of forest chips, including logging residues and small-diameter trees. Stumps were excluded from the study because they are normally chipped at terminal sites. The competitive demand for forest fuels was taken into account as market share analyses (Korpinen et al., 2012).

Case study 2:

The real forest biomass from roadside storages was used in this case study. The forest biomass was either logging residues or small-diameter whole trees. The biomass supply chain was followed as each truck loads from roadside storage to the final plant, where the amount of payload as energy (MWh) was determined according the net weight of truck load and moisture content of forest chips. Totally 14 roadside storages and 61 loads were followed in this truck specific analysis.

Case study 3:

This case study focused on 30 stands representing pure Scots pine (Pinus sylvestris L.) stands in Finland. All stands based on average regional stand data. Stands represented three temperature sum regions: 900 (Northern), 1100 (Central) and 1300 (Southern) day-degrees (d.d.) and two soil types: the less fertile VT (Vaccinium) or the fertile MT (Myrtillus) site (Cajander, 1909). The density of stand before first thinning varied between 1500 and 4000 trees per hectare.

For each stand, the tree growth was produced using the Motti stand simulator (Hynynen et al., 2005). Motti has been designed to simulate and analyze stand development for alternative forest management regimes in different growth conditions with all major tree species in Finland (Hynynen et al., 2005). The growth of pure pine young stands with alternative growth and density conditions were modelled for the whole rotation, but in this case study, the first thinning stands were of the main interest.

4.3.6 Modelling

Models are typically used when it is either impossible or impractical to create experimental conditions in which scientists can directly measure outcomes. A simulation is the implementation of a model. A steady state simulation provides information about the system at a specific instant in time. A dynamic simulation provides information over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave.

The most used approaches of simulations are Discrete-Event Simulation (DES), system dynamics and hybrid models, like Agent-Based Modelling (ABM) (Lättilä, 2012). In this section, discrete-event simulation approaches are presented more closely for logistics study methodology. ABM could be regarded as an application of discrete-event simulation or as hybrid simulation model.

4.3.7 Logistics simulation

Discrete-event simulation (DES) is the process of codifying the behavior of a complex system as an ordered sequence of well-defined events. In this context, an event comprises a specific change in the system's state at a specific point in time. A clock time is an important part during the simulation. Events occur in simulation based on a calendar schedule. The simulation follows the calendar schedule, and the system will activate the event as soon as the clock time reaches the next active event in the calendar. Usually, queuing theory with mathematical models is used in DES (Banks et al., 2005). The entity is the object of interest in the system. Entity seizes a resource, which can have several units of capacity, which can be changed during a simulation. Variable is a piece of information that reflects some characteristic of the whole system, whereas a collection of variables is called the state that contains all the necessary information to describe the system at any time. Events change the state of the system.

Agent-Based Modelling (ABM) is the newest approach of simulation made possible by increasingly powerful computers (Macal and North, 2005). Macal and North (2006) have listed some reasons for the growing interest of ABM. Observed systems are becoming more complex in terms of interdependence. Some systems have been too complex to be modelled with other approaches. ABM makes it possible to multiply the created agents, which operate as individuals in the model structure. Transportation and warehousing modelling can benefit from ABM principles, when they are getting too complex to be analyzed with traditional approaches (Lättilä, 2012). There are not many studies containing a simulation of an empirical case. Studies are still on the conceptual level. ABM principles have been used in container terminal systems (Henesey et al., 2009), seaport container terminals (Vidal and Huynh, 2010; Sun et al., 2012) and within the field of study of the forest product industry (Frayret et al., 2007).

Case study 1:

The simulation was conducted with AnyLogic 6 software, which is suitable for discrete-event and process-centric modelling (XJ Technologies, 2013). The simulation model was constructed through a combination of discrete-event simulation and agent-based modelling as a hybrid simulation system. The model consists of a fixed number of truck agents and a final user-site and follows a discrete-event structure (Lättilä, 2012). The train scenario was additionally created as an agent model, but it followed the more complex discrete-event structure, including loading and unloading terminals.

The trucks have five distinct states: out of service, waiting, moving, being loaded and emptying. The trucks are out of service as their schedules indicate between maximum 00:00 and minimum 07:00. on every weekday and are unused on weekends. The trucks operate in two shifts from November until April and have one shift in May–June and September–October. The trucks do not operate during July–August. The trucks wait at the main terminal of the power plant until they have potential cargo. The state chart for the truck agents presented in Figure 25 shows the logic of the trucks in the simulation model.

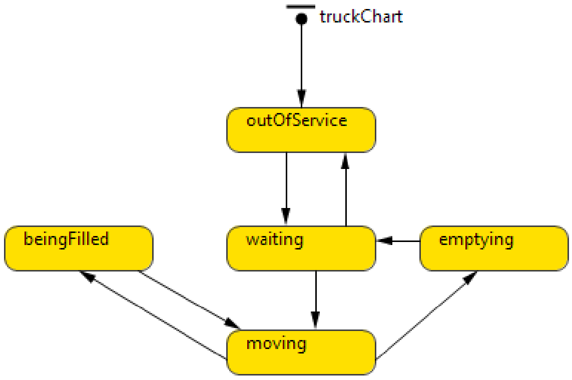


Figure 25 State chart for the truck agents.

The cargo is generated according to the availability analysis. GIS data are used to estimate how long it takes a truck to drive to a potential load. There are 20 potential loads in the model at all times. The model checks beforehand if there is time to pick up and return any of the cargo loads according to the day schedule. When appropriate cargo is found, a truck moves to the location. The delay required for the move depends on the distance and the type of road between the terminal and the cargo location. When the truck reaches the location, it is loaded. The weight of load depends on the moisture content of the forest chips, which ranges between 30% and 60%. On completion of loading, the truck moves back to the terminal to be emptied. Next, the truck is commanded to seek for potential cargo, and the route cycles are continued. At the end of the day, the truck returns to the 'Out of Service' state.

The simulation model keeps track of the costs of the systems (Figure 26). The model runs for a virtual amount of one year and calculates the total costs, which consist of the yearly fixed costs plus variable costs dependent on the production amount of forest chips. The total costs are then divided by the total amount of energy transported to the final user site, to yield the unit cost of energy as Euros per megawatt hours. It is possible to stop the model during the year to analyse the total unit costs of other utilization rates.

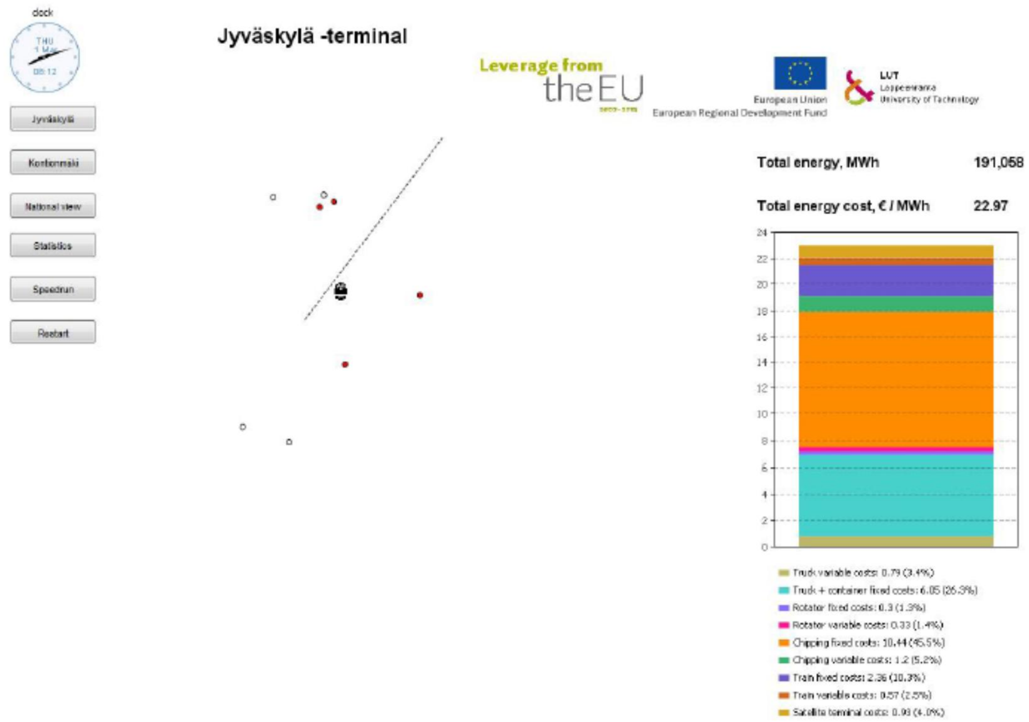


Figure 26 **Screen shot from the display of the simulation model used in the study.**

In the simulation model, the train operates only in the wintertime when the trucks are operating two shifts because of high demand for forest chips. The train leaves the loading terminal (satellite terminal) in the early evening and the unloading terminal (main terminal of power plant) in the early morning. Thus, the train conducts four round-trips per week. A one-way trip takes approximately six hours, so there are six hours to load and another six hours to unload the train during a day. The state chart of the train is similar to the truck: the train is idle, moving between locations or being loaded or unloaded.

Case study 2:

The cost structures of trucks were assumed and updated by using a special chip truck calculator (Föhr & Karttunen, 2012) (Equation 2). The truck systems were separated into either truck and trailer combination or only truck transportation system. The costs were separated for driving (fixed and variable costs) and terminal costs (fixed and salary costs). Driving costs varied between 62 €/h and 77 €/h and terminal costs varied between 38 €/h and 45 €/h depending on the truck system. The aim of the cost modelling was to introduce the idea of the cloud service concept for analyzing the cost-efficiency potential of alternative truck systems.

Equation 2 The following formula was used for logistics (Laitila & Väätäinen, 2012)

$$\frac{(Dc * Dh) + (Tc * Lh)}{P}$$

D_c = Driving cost, 62–77 €/h
D_h = Full driving + Empty driving, h
T_c = Terminal cost, 38–45 €/h
L_h = Loading + unloading, h
P = Payload, MWh (28–113 MWh)

Case study 3:

The cost of forest management regimes was examined through the comparison of the discounted net value revenue and costs as regards different alternatives over time horizon. The discount interest was 3%. Trend prices for 2013, which were achieved by using real stem prices for an intermediate time period (1995–2012) with an index increase, were used in the study. The costs and roadside prices were expressed in real terms (2013).

In total, 30 simulations were followed through in this case study. The basic density of Scots pine first thinning trees was set at 400 kg/m^3 (Lindblad and Verkasalo, 2001). The average moisture content for small-diameter delimbed energy wood was set to 35% (to be 615 kg/m^3). The moisture content affects the energy content of wood, so that a solid-m^3 of wood includes 2.0 MWh of energy when the moisture content is 35% (3.25 MWh/tonne).

The minimum top diameter of delimbed energy wood was 4 cm and the minimum diameter of saw log was 15 cm. The minimum length of wood trunks was 3 meters. The overall length of long-distance transportation was limited to 100 kilometres.

In this case study, a cost analysis was done for energy purposes. Chipping cost at the terminal next to the plant was included. Chipping productivity of delimbed shortwood at the terminal was 54 $m^3/E_{15}h$ (Laitila and Väätäinen, 2012), which denoted the chipping cost of 1.6 €/MWh. The hourly cost of the mobile drum chipper was

167.0 €/E_{15}h when operating at the terminal next to the plant. The same formula was used as in Case study 2, but the truck and trailer cost was kept constant: 86.4 €/h (driving cost) and 60.7 €/h (terminal cost) (Laitila & Väätäinen, 2012). Forest management and harvesting formulas were presented in the article of Karttunen and Laitila (vuosi?).

4.3.8 Results

Study case:

Scenarios are the following for either traditional or container transportation concepts (Figure 27):

1. Current use of forest chips supplied by truck transportation (540 GWh).
2. Additional use of forest chips supplied by truck transportation (540 GWh + 200 GWh).
3. Additional use of forest chips supplied by train transportation (540 GWh + 200 GWh).

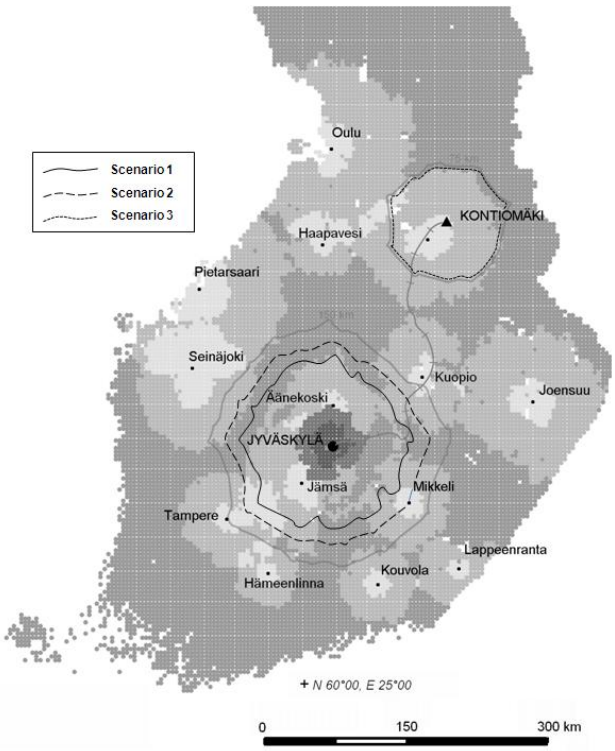


Figure 27 Study area around the city of Jyväskylä (Scenario 1 & Scenario 2) and around the satellite terminal of Kontiomäki (Scenario 3).

Container supply chains were the most cost-efficient alternatives for current maximum truck dimensions (15.3 €/MWh–16.9 €/MWh) (Figure 28). The unit costs of traditional supply chains varied between 16.1 €/MWh and 18.2 €/MWh, the precise amount depending on the scenario used. The total costs of the traditional supply chain were 5%–11 % greater than those of the corresponding container supply chain for the current dimensions, depending on the scenario. The unit costs of truck and railway supply chains are presented separately (Figure 29).

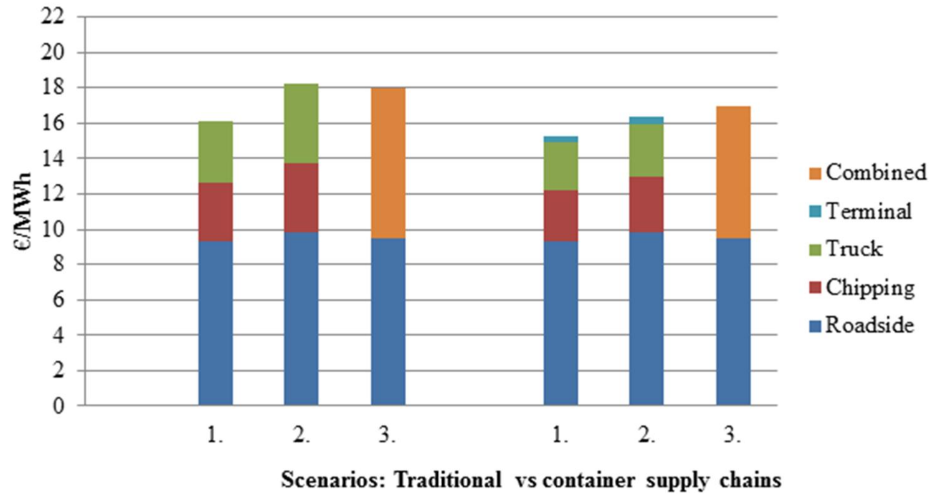


Figure 28 Unit cost of forest chips (€/MWh) transported by traditional supply chain (left) and container supply chain (right). Combined system includes both truck and railway supply chains. (Scenarios: Fig. 7.)

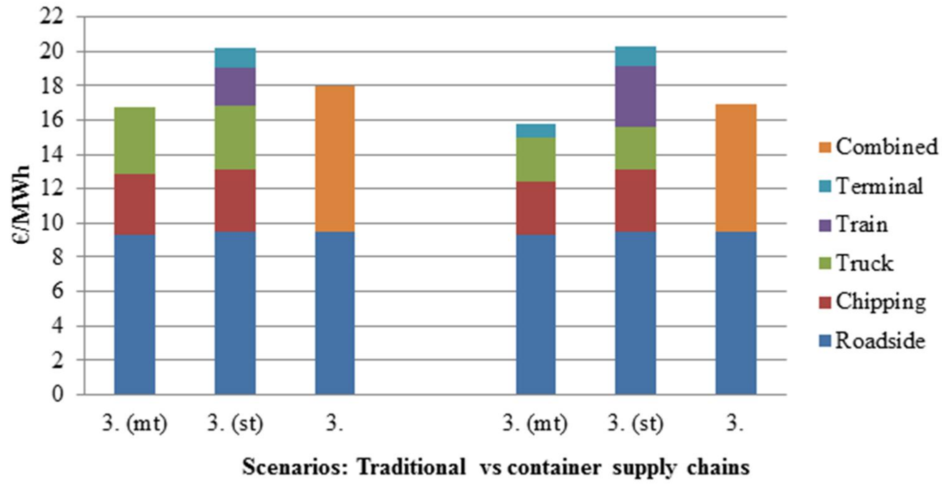


Figure 29 Unit cost of forest chips (€/MWh) transported by traditional supply chain (left) and container supply chain (right) as calculated separately for the truck and railway supply chain. Main terminal (around power plant) = mt; satellite terminal (around railway terminal) = st. (Scenarios: Fig. 7.)

Total costs for current dimension scenarios varied between 7.4 and 14.7 million Euros depending on the amount of forest chips (482 GWh–834 GWh) and logistical alternative (traditional or container supply chain). Total unit cost varied between 15.3 €/MWh and 20.0 €/MWh depending on the simulated amount of forest chips and logistical alternative. The unit cost of the railway supply chain varied between 20.3 €/MWh and 26.5 €/MWh.

As an example, if deliveries of forest chips are increased from 600 GWh to 800 GWh, the unit costs of the traditional supply chain by trucks increase from 17.2 €/MWh to 19.2 €/MWh, whereas container supply chain costs by trucks increase from 14.7 €/MWh to 15.8 €/MWh (Figure 30). The annual fixed costs of trucks (totally 10–16 trucks in the simulation model) increased the total unit costs when the procurement was lower than the aim of the first scenario, 540 GWh.

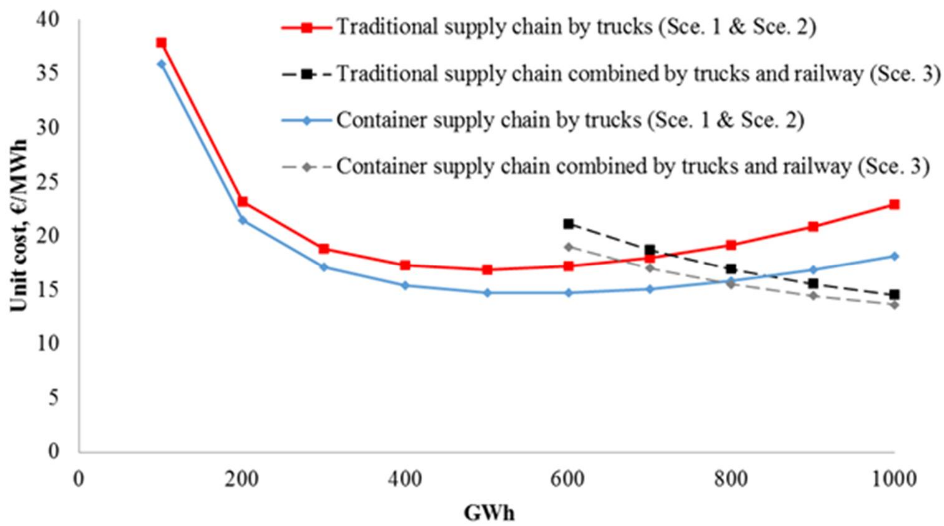


Figure 30 Unit cost (€/MWh) of traditional and container supply chain scenarios for truck transportation (Scen. 1 & Scen. 2) and multimodal transportation (Scen. 3) for forest chips (current dimensions). The delivery amount of forest chips by trucks was kept constant (500 GWh) for multimodal supply chains (Scen. 3).

Combined multimodal truck and railway transportation (Scen. 3) can be used to decrease the unit costs for longer distances (Fig. x). For example, if the total deliveries of forest chips are increased from 600 GWh to 800 GWh, so that the share of railway transportation is increased from 100 GWh to 300 GWh, the unit costs of the traditional multimodal supply chain decrease from 21.2 €/MWh to 16.9 €/MWh, whereas intermodal container supply chain costs decrease from 19.1 €/MWh to 15.5 €/MWh. This savings potential cannot be achieved until the delivery amount of the railway supply chain approaches 300 GWh, when the unit cost savings vary between 0.3 €/MWh (container) and 2.3 €/MWh (traditional) (annual savings from 0.2–2.3 million Euros) as a result of using railway systems instead of trucks for long-distances.

Study case:

The total unit cost of transportation varied between 3.0 €/MWh–3.6 €/MWh depending on the truck system at an average distance of 40 km. The truck and trailer combination was the most cost-efficient way of transporting forest chips (Figure 31). Significant cost differences between container and solid-frame truck systems were not observed. The truck only systems were on average 7%–20% more expensive than the corresponding full truck and trailer combination. Absolute time usage varied between the truck systems mainly in chipping time (terminal time, loading), but the relative time usage stayed quite similar (Figure 32).

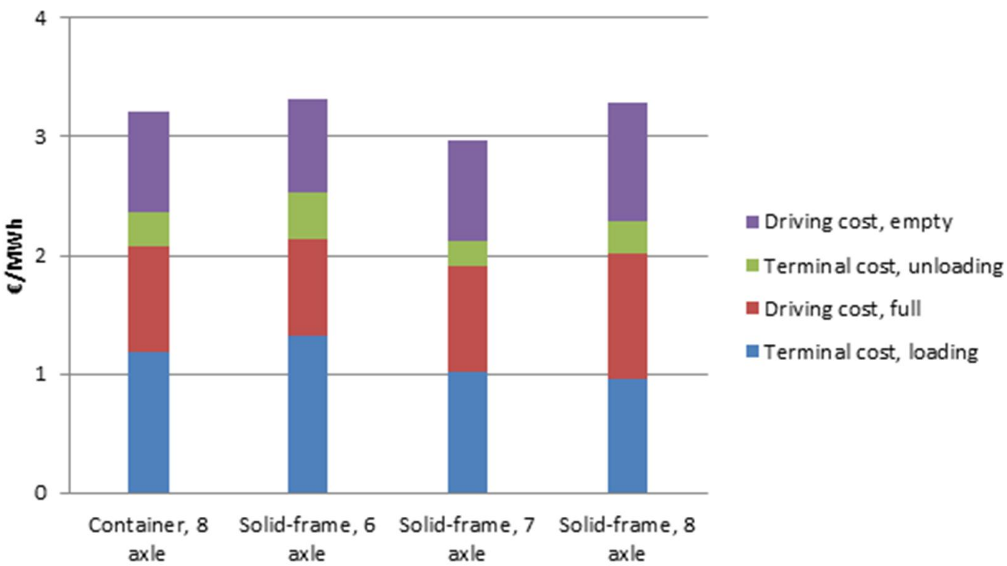


Figure 31 Total unit cost of transportation for vehicle combinations (n=41).

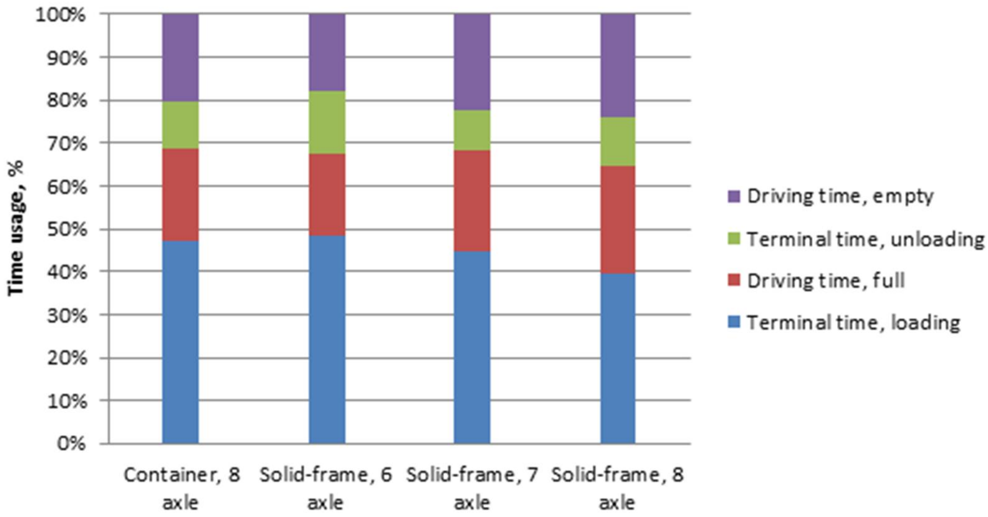


Figure 32 Time usage of transportation for truck and trailer combinations (n=41).

In this study, the unit cost of specific truck transportation concepts stayed similar. The container truck system was found to be as cost-efficient as the solid-frame truck systems. The transport distance from roadside terminal to power plant was quite short in this study (40 km). Container truck combination may improve the cost-efficiency in longer distances compared to the solid-frame truck systems, especially when using light structured composite containers. Shorter distances, container truck only system was found to be very efficient to operate in difficult roadside storages, and the cost difference was not remarkably higher (10%) compared to the full container truck and trailer combination. Truck transportation with interchangeable containers could be cost-effective either in long-distance or short-distance supply of forest chips.

Study case:

The main interest of this case study was to combine forest management simulations with harvesting and logistics analysis to find out the cost reduction potential of small-diameter wood supply chains. The study showed that the density of a stand before the first thinning influenced the cost of small-diameter wood supply chains. In this case study, the largest cost reduction was achieved for denser forest management of 3100 trees per hectare for unfertile stands (VT) in the scenario where all biomass was assumed to be transported for energy purposes (Figure 33). Profitable supply chain of small-diameter delimbed trees from first thinning for energy use without subsidies was achieved from well-managed denser forest management before cutting due to the current price level of forest chips, 20.7 €/MWh in 2013 (Statistics Finland). The results of the study confirm the forest recommendations for denser forest management aiming for energy wood harvesting and may impact on the practical forest management, especially for companies operating own forest resources and supply chains.

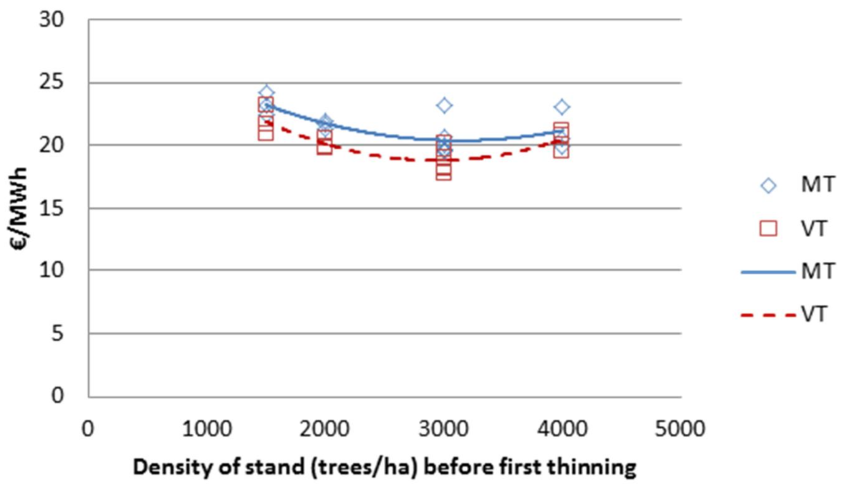


Figure 33 Cost of supply chain for delimbed energy wood according to the density of stand before the first thinning for fertile (MT) and unfertile stands (VT) without subsidies.

5 DISCUSSION AND RECOMMENDATIONS

5.1 Discussion

The biomass volumes increase in Europe due to the EU targets which lead to intensive wood fuel mobilization applying for example container logistics. The wood chip transportation focuses around Germany and the Central Europe due to the wood product industry. The Eastern Europe is the net exporter. The competing concept Innofreight already operates in these regions, but there might be new market areas in the Western Europe. Still, we found market potential for new container logistic concepts in the energy industry and wood processing industry as well in areas where material streams seem to be more complementary in the future. However, regions with high demand but low supply volumes require new logistics solutions than conventional supply methods. This development will bring rail and waterway transport modes into supply logistics. Therefore, a need has emerged to find efficient solutions for integrating separate transport modes. Interchangeable containers have proved to be a promising option.

5.1.1 Concept perspective to the container logistic services

The container logistic service concept forms three major categories of separate business models which provide value regarding customers amongst energy producers, logistic operators and transportation entrepreneurs. The overall container logistic environment seems to be dependent on information system providers and cloud service, which combine different parts of the concept. Particularly, the actors that gather big data from processes are supposed to have power to determine standards for the service process and lead the service provision network. The main service packages are container rental and RFID, while other services are formed around these main activities. Simulation is supporting other functions, but its relative importance in customer value creation is fairly low, when customers are in transportation business. On the other hand, RFID cloud service brings usable information for cost control and tracking for truck entrepreneurs or logistics companies. Information can be used, for instance in contract negotiations or supply chain developing. The largest benefit of simulation can be found in developing the full figure of supply chains working more cost-efficient way. The operational and developing information could be divided in different business possibilities.

5.1.2 Technical advantages in container logistics and composite containers

The advantage of container logistics lies in the possibilities for intermodal transport and efficient terminal operations. Interchangeable containers have many advantages in the supply chain, but they will also cause idle times for containers in terminals and long-lasting deliveries. Idle times may cause freezing problems for containers that are full of biomass, especially during winter time in the Nordic conditions. Freezing problems occur typically when metal containers are used. Freezing tests for composite and metal containers reveal several advantages for new materials. The chips were normally frozen into lumps, but the frozen chips were unloaded completely because of the slippery plastic composite material. A frozen chip layer with the thickness of approximately 50 cm–60 cm was stuck on the floors of the metal containers, in which case it was impossible to unload about 14%–17% of the total weight. The composite container was emptied easily of the chips after the freezing test. The problem with the freezing did not occur at any stage when the composite container was used during the freezing tests. Therefore, it can be stated that the composite container is more cold-resistant than the metal containers.

The research aims also to study the potential of RFID identification and tracking of the trucks on a real-time basis to provide data that can be used to analyse the vehicle-specific time usage and the efficiency of deliveries to fulfil the needs of customers. The study evaluates also the reliability of a system where a cloud service based system and a smart phone application are integrated. The tracking system worked reliably for recording the information and transactions of the deliveries during the follow-up period. The container truck system was found to be as cost-efficient as the solid-frame truck systems. Moreover, containers may improve performance in longer distances compared to the solid-frame truck systems, especially when using light structured composite containers. Container truck system was also found to be efficient in truck only transportation from short-distances. Interchangeable containers can give flexibility in many operations during forest chip supply chains. RFID system made it possible to follow the productivity of single container or truck transportation system and bring usable comparisons for cost control in alternative systems. When the theoretical cost of truck transportation system can be increased with the real operational productivity information, either it brings more reliable results through the cost simulations or gives more usable knowledge to analyse other market influences and failures in the price of product. Also driver can be motivated and encouraged to work optimally.

5.1.3 Markets and customers for the container logistic concept

Finnish transportation companies are micro or small-sized businesses the economic status of which economic differs significantly from a segment to another. In this study, we based the market analysis on the segmentation of the Finnish transportation companies using turnover, ROI, QR and Equity ratio, which revealed three major customer groups. The biggest customer segment is Low performance companies (60.0 % of samples) (Table 3), which has acceptable profitability but rather weak financing in terms of liquidity and depth ratio. The Good and High performance companies represents the second group (23.1% of samples), which have very good profitability and financing situation. The smallest segment is the Crisis companies (9.8% of samples), which are unprofitable and have very weak financing situation indicating high business risks for external funding. Overall, many small transportation companies are in debt, and their buffers against any losses are low. The companies are faced with high investments due to higher vehicle weights and dimensions. The risk is going out of business if the companies are unable to make the necessary equipment purchases. Since the general costs have risen, the profitability in the transportation sector is under severe strain.

The European rail freight operators are large-sized businesses with high equity ratios and mostly poor (less than 5%) return on assets. This means the companies are not using their assets efficiently to generate earnings, and the profitability is low. Similar situations can be recognized also in the logistic operator sector. Logistic companies need high and constant transportation volumes to keep their business profitable. Practically, the transportation equipment should be used all year round, which requires either findings ways to stabilize monthly revenues or the flexibility of system. The flexibility of the system and assets are most relevant for the current situation. Because the transportation volumes change periodically, the equipment should flex as well.

The Finnish energy companies have mainly good financial buffers, but the profitability is fairly low. The most important customer need for energy companies is smooth, reliable fuel supply. Another important factor is flexible transportation, which adapts to seasonal variation and eases storage management.

5.2 Recommendations for business development

The actor in the container logistics concept is not necessarily an operating entity, but a network of co-operating companies. Furthermore, the composite container manufacturing, the container maintenance and the RFID and the simulation business concepts would be beneficial to stay separated due to different customer base and dynamics of the markets. Composite container rental would be suitable for a company already operating in container or trailer rental business. The large logistic operators have integrated customer positions in the Container Logistic Service network, which makes them powerful to define standards and provide a gatekeeper position for acceptable solutions. The logistic service concept is still lacking a “common language” for the platform, which would enable information sharing between the parties in the ecosystem. The major customers amongst logistic service companies and energy sector should also be involved in the integration process because the new service concept will be established through the central actors in the network.

Based on this study, long-lasting deliveries, lasting for example 2–3 days, are not suitable for biomass when metal containers are being used in cold weather. The problem with the freezing did not occur at any stage when the composite container was used during the freezing tests. As a conclusion, the intermodal logistics of the truck and the train is a promising market for the composite containers because of the frost-proof material, in which the biomass does not freeze onto the inner surfaces.

The needs of transportation entrepreneurs could be satisfied with an offering of container rental and RFID. Container rental would provide an alternative way to increase the capacity without high investment costs. RFID would lead to time savings and well-designed driving arrangements, improving profitability. A suitable offering for logistic operators would include RFID and container rental. RFID offers driving arrangements to avoid traffic congestion, actor-specific quality control and integrated devices and interfaces. Container rental would satisfy the need of flexible equipment supply. The needs of energy companies could be satisfied with an offering of simulation and RFID. The RFID tracking revealed significant differences of efficiency between the types of the forest chips. In general, the loads of whole tree were more predictable than the loads of logging residues, and whole tree loads have also a slightly higher average energy content. Simulation would fulfil the need for fuel supply optimization, lower transportation costs, use of different transportation modes and supply chain lead time reduction. The most important RFID feature would be driving arrangements to avoid traffic congestion. All in all, business concepts of RFID cloud service was found promising opportunities for container or truck specific supply chains.

In forest biomass logistics, the information of truck weight measurement was able to be connected automatically to the cloud service concept but measurement of moisture content was not yet automatic in power-plant. This slows down the practical usability of RFID cloud service in the logistics for the older plants. On the other hand, RFID cloud service could be taken use in the other logistics systems, such as container tracking in harbors, truck transportation of round wood etc. In any case, that could bring enormous business opportunities in logistics sector. The biggest potential was however found in sustainability tracking of forest-based biomass supply chains. Sustainability benefits gained by RFID cloud service can be seen as economical (cost control), ecological (traceability) and social (local employment) way.

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APPENDIX 1 - Wood-based chip and particle flows in European region

Source country	Target Country	Cubic-meters
Albania	Italy	2888
Austria	Germany	4958
Austria	Hungary	4041
Austria	Italy	236041
Austria	Slovenia	1578
Belarus	Latvia	7779
Belarus	Lithuania	169409
Belarus	Poland	151125
Belarus	Russian Federation	1700
Belgium	France	41036
Belgium	Germany	23700
Belgium	Luxembourg	26789
Belgium	Netherlands	7606
Bosnia and Herzegovina	Croatia	1230
Bosnia and Herzegovina	Germany	1476
Bosnia and Herzegovina	Italy	1321
Bosnia and Herzegovina	Slovenia	2193
Bulgaria	Greece	19646
Croatia	Austria	64673
Croatia	Hungary	78885
Croatia	Italy	2349
Croatia	Slovenia	96448
Cyprus	Latvia	3427
Czech Republic	Austria	107040
Czech Republic	Germany	131653
Czech Republic	Italy	3730
Czech Republic	Poland	2938
Czech Republic	Slovakia	1678
Denmark	Germany	8616
Denmark	Norway	34819
Denmark	Sweden	32059
Estonia	Finland	245388
Estonia	Latvia	18675
Estonia	Sweden	62155
Finland	Sweden	238488
France	Belgium	56000
France	Denmark	7000
France	Germany	176000
France	Italy	137000
France	Japan	1000
France	Luxembourg	5902
France	Portugal	1000
France	Spain	4000

APPENDIX 1 - Wood-based chip and particle flows in European region

Source country	Target Country	Cubic-meters
France	Switzerland	126000
Germany	Austria	1256000
Germany	Belgium	75000
Germany	Czech Republic	85000
Germany	Denmark	164000
Germany	Finland	4000
Germany	France	304000
Germany	Italy	1000
Germany	Luxembourg	23961
Germany	Netherlands	58053
Germany	Norway	184000
Germany	Poland	14000
Germany	Russian Federation	2267
Germany	Switzerland	158000
Germany	United Kingdom	1505
Greece	Bulgaria	1323
Hungary	Austria	79315
Hungary	Slovakia	5903
Hungary	Slovenia	7961
Ireland	Germany	13467
Ireland	Norway	42329
Ireland	United Kingdom	13437
Italy	Austria	35383
Latvia	Austria	1000
Latvia	Belgium	2000
Latvia	Denmark	85000
Latvia	Estonia	155576
Latvia	Finland	867000
Latvia	Germany	67000
Latvia	Lithuania	290000
Latvia	Norway	28000
Latvia	Poland	16000
Latvia	Sweden	1006000
Latvia	United Kingdom	2408
Lithuania	Denmark	2753
Lithuania	France	1321
Lithuania	Germany	6012
Lithuania	Poland	81100
Lithuania	Sweden	34303
Luxembourg	Belgium	42283
Luxembourg	France	38319
Luxembourg	Germany	4102
Luxembourg	Netherlands	5010

APPENDIX 1 - Wood-based chip and particle flows in European region

Source country	Target Country	Cubic-meters
Netherlands	Belgium	76896
Netherlands	Denmark	5183
Netherlands	Germany	58433
Norway	Estonia	1372
Norway	Sweden	83003
Poland	Germany	37324
Poland	Netherlands	1020
Poland	Slovakia	1027
Portugal	Netherlands	1515
Romania	Austria	50105
Romania	Bulgaria	8843
Romania	Italy	1834
Romania	Turkey	21938
Russian Federation	China	154000
Russian Federation	Denmark	4000
Russian Federation	Estonia	1504
Russian Federation	Finland	2312000
Russian Federation	Germany	8000
Russian Federation	Japan	35000
Russian Federation	Kazakhstan	1965
Russian Federation	Netherlands	1046
Russian Federation	Sweden	36000
Russian Federation	Turkey	1000
Slovakia	Austria	36822
Slovakia	Czech Republic	2233
Slovakia	Poland	5201
Slovenia	Austria	49890
Slovenia	Italy	74869
Spain	France	1745
Spain	Portugal	17815
Sweden	Denmark	70888
Sweden	Germany	51436
Sweden	Norway	202346
Sweden	Poland	1801
Switzerland	Austria	9185
Switzerland	France	13734
Switzerland	Germany	4212
Switzerland	Italy	38449
Ukraine	Greece	3825
Ukraine	Italy	4900
Ukraine	Romania	1047
Ukraine	Turkey	330005
United Kingdom	Germany	104840

APPENDIX 1 - Wood-based chip and particle flows in European region

Source country	Target Country	Cubic-meters
United Kingdom	Ireland	5456
United Kingdom	Norway	84907
United Kingdom	Portugal	9825
United Kingdom	Singapore	1099
United Kingdom	Sweden	41136

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