Attitudes of Small and Medium-Sized Enterprises towards Energy Efficiency in Wood Procurement: A Case Study of Stora Enso in Finland

Hanna Haavikko, Kalle Kärhä, Miikka Hourula, Teijo Palander

Abstract

Stora Enso Wood Supply Finland (WSF) was certified to the ISO 50001 Energy Efficiency Management System standard in 2015. At Stora Enso WSF, the goal is to improve energy efficiency by 4% by 2020 from 2015. Improving the energy efficiency of wood procurement (i.e. logging and timber trucking) enterprises is currently one of the main focus areas for energy efficiency development at Stora Enso WSF. In order to clarify its state-of-the-art in the business of wood procurement enterprises at Stora Enso WSF, logging and timber-trucking entrepreneurs were interviewed in November and December 2017. The survey data consisted of 25 logging and 25 timber-trucking entrepreneurs. The coverage rate of both entrepreneur groups was 73.5% in the survey. The results indicated that timber-trucking enterprises highlight more energy efficiency and fuel efficiency than logging enterprises. For instance, the timber-trucking entrepreneurs underscored more energy efficiency in their acquisition decisions of new vehicles and the greater role of fuel efficiency in the energy-efficient business than logging entrepreneurs during 2016 and 2017. Furthermore, the survey results revealed that logging and trucking enterprises can improve energy efficiency in their business by organizing more energy efficiency education (i.e. economical and anticipated driving training) for their machine operators and truck drivers. There is a positive attitude towards energy efficiency among both logging and timber-trucking entrepreneurs. This creates a solid background to deepen and continue energy-effective work in the wood supply chain between the enterprises and Stora Enso WSF in the future.

Keywords: SME, ISO 50001, fuel efficiency, economical driving, wood harvesting, long-distance transportation

1. Introduction

At the Paris Climate Conference in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal. In the Paris Climate Agreement, governments agreed the long-term goal of keeping the increase in global average temperature to well below 2 °C above pre-industrial levels and to aim to limit the increase to 1.5 °C, since this would significantly reduce the risks and the impacts of climate change (United Nations 2015). The European Union (EU) has set climate and energy policy targets for 2030, which precedes the Paris Agreement (European Union 2014).

The 2030 EU Climate and Energy Framework (European Union 2014) sets three key targets for the year 2030:

⇒ at least 40% cuts in greenhouse gas emissions from the level of 1990

⇒ at least a 27% share of renewable energy

⇒ at least a 27% improvement in energy efficiency.

The European Commission is further looking at cost-efficient ways to make the European economy

more climate-friendly and less energy-consuming. Its Low-Carbon Economy Roadmap suggests that by 2050, the EU should cut greenhouse gas emissions to 80% below the level of 1990 and the milestones to achieve this are 40% emissions cuts by 2030 and 60% by 2040 (European Union 2011). In addition, a Roadmap for moving to a competitive low-carbon economy in 2050 underlines that all sectors must contribute and that the low-carbon transition is feasible and affordable.

The Energy Efficiency Directive entered into force on 4 December 2012 in Europe (European Union 2012). Its main objective is to implement the energy efficiency target of the 2030 EU Climate and Energy Framework. Energy efficiency agreements guide companies and organizations to improve their energy efficiency (Motiva 2018). For instance, Finland reports to the EU on the progress of its energy saving measures. In Finland, the Energy Efficiency Act requires, among other things, that large companies must carry out an energy audit in which they report energy efficiency targets and development every four years (Energiatehokkuuslaki 2014, Palander et al. 2018).

The energy audit may be released if the company reports on energy efficiency for a certified standard, for example an international ISO 50001 Energy Management System standard. The international ISO 50001 Energy Management System standard is to enable organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use, and consumption. The ISO 50001 standard specifies requirements applicable to energy use and consumption, including measurement, documentation and reporting, and design and procurement practices for equipment, systems, processes and personnel that contribute to energy performance (ISO 2011).

Stora Enso Group is a provider of renewable solutions in packaging, biomaterials, wooden constructions and paper on global markets, which has around 26,000 employees in more than 30 countries. Its sales in 2017 amounted to EUR 10 billion (Stora Enso 2018). Stora Enso has an Energy and Carbon Policy (Stora Enso 2017a). Its ambitions are to drive down fossil fuel use so as to get as close to zero as possible within the decade using technically and commercially feasible means, and to seek to substitute fossil-based and other non-renewable materials with renewable products (Palander et al. 2018). Specific targets for the Energy and Carbon Policy are to:

⇒ reduce specific electricity and heat consumption per saleable tonne of pulp, paper and board production by 15% by the end of 2020 compared to the baseline year of 2010

⇒ reduce fossil CO_2 emissions per saleable tonne of pulp, paper and board by 35% by the end of 2025 from a 2006 baseline (Stora Enso 2017a, Palander et al. 2018).

At the Group level, all 33 production units by Stora Enso were certified to the ISO 50001 Energy Efficiency Management System standard by the end of 2016 (Stora Enso 2017b). Stora Enso Wood Supply Finland (WSF) delivers wood to Stora Enso's Finnish pulp and paper mills, as well as to the company's sawmills. In addition, Stora Enso WSF provides bioenergy to heating and power plants. In 2017, the total volumes supplied by Stora Enso WSF from forests to internal and external mills were about 22 million m^3 solid over the bark (later only: m^3). Stora Enso WSF does not have its own wood harvesting machinery and timber-truck fleet. Currently, there are 34 logging and 34 timber-trucking enterprises, which produce industrial roundwood procurement services from forests to mills for the company. Industrial roundwood procurement services are conducted by more than 300 harvesting chains (i.e. harvesters and forwarders) and more than 200 timber trucks. All logging and timber-trucking companies, which produce wood supply services for Stora Enso WSF, are small and medium-sized enterprises (SMEs), as are all logging and timber-trucking enterprises in Finland (Hope 2017, MetsäTrans tilastot 2018).

Stora Enso WSF was certified to the ISO 50001 Energy Efficiency Management System standard in 2015. The target of the company is to improve energy efficiency by 4% by 2020 from 2015 levels (Stora Enso 2015). In order to achieve this target, several actions at Stora Enso WSF have been conducted to improve energy efficiency during the last three years. In order to accelerate further the energy efficiency work at Stora Enso WSF, more close cooperation throughout the whole wood supply chain with the logging and timber-trucking enterprises contracted to Stora Enso WSF is needed.

Furthermore, when developing deeper cooperation with the enterprises contracted to Stora Enso WSF, a profound understanding of the current situation of energy efficiency in logging and timber-trucking enterprises is required, and knowledge, for example, of what the attitudes of entrepreneurs are towards energy efficiency. This kind of information does not currently exist. Actually, there are very few studies of energy efficiency in the procurement of industrial roundwood (Lindholm and Berg 2005, Palander 2016, 2017, Palander and Kärhä 2018, Palander et al. 2018, Prinz et al. 2018) compared to, for instance, the pulp and paper industries, for which many energy efficiency studies have been done (e.g. Farla et al. 1997, de Beer et al. 1998,

Martin et al. 2000, Kilponen et al. 2001, del Río González 2005, Joelsson and Gustavsson 2008, Thollander and Ottosson 2008, Fleiter et al. 2012, Fracaro at al. 2012, Peng et al. 2015, Hämäläinen and Hilmola 2017).

Nevertheless, the fuel consumption of forest machines and timber trucks in industrial roundwood procurement has been abundantly studied in the 21st century (e.g. Nordfjell et al. 2003, Rieppo and Örn 2003, Brunberg et al. 2004, 2017, Väkevä et al. 2004, Brunberg 2007, Tikkanen et al. 2008, Klvač and Skoupý 2009, Holzleitner et al. 2011a, 2011b, Brunberg 2013, Klvač et al. 2013, Manner et al. 2016, Oyier and Visser 2016, Svenson and Fjeld 2016, Ackerman et al. 2017, Lijewski et al. 2017, Magagnotti et al. 2017, Prinz et al. 2018). In addition, surveys have been conducted focusing on increasing productivity, reducing costs and improving technical and operational efficiency in logging and timber-trucking wood procurement SMEs (e.g. Carter and Cubbage 1995, Mäkinen 1997, LeBel and Stuart 1998, Bonhomme and LeBel 2003, Penttinen et al. 2009, Cacot et al. 2010, Drolet and LeBel 2010, Leon and Benjamin 2012, Soirinsuo 2012, Hourunranta et al. 2013, Conrad IV et al. 2017, Obi and Visser 2017). However, there is currently no energy efficiency research related to logging or timber-trucking enterprises.

Consequently, this study focused on the energy efficiency of logging and timber-trucking SMEs. A case study was conducted, in which the logging and timber-trucking enterprises contracted to Stora Enso WSF were researched. The aims of the study were to:

⇒ clarify state-of-the-art of energy efficiency attitudes in logging and timber-trucking enterprises

⇒ describe the future needs, measures and prospects of entrepreneurs concerning energy efficiency and its improvement.

2. Material and methods

2.1 Data collection

Twenty-five logging and 25 timber-trucking entrepreneurs contracted to Stora Enso WSF were interviewed in person by two interviewers in November and December 2017. The entrepreneurs for the survey were selected evenly from all three wood procurement areas (South, East and North) of Stora Enso WSF, and 8–9 logging and timber-trucking entrepreneurs per procurement area were interviewed. The total number of logging and timber-trucking entrepreneurs was 34 at the time of the survey (the end of 2017), and the coverage rate of both entrepreneur groups in the survey was 73.5%.

There were two structured questionnaires in the survey, one for logging entrepreneurs and the other for timber-trucking entrepreneurs. The questionnaires were mostly identical but there were small differences in questions related to the machinery and truck fleet in the enterprises, as well as the operational environment in logging and timber-trucking business. Before the interviews, the questionnaires were verified by four real interviews (two with logging and two with timber-trucking entrepreneurs). The feedback resulted in useful amendments to the query forms.

The questionnaires had eight sections:

⇒ background information

⇒ discussions about energy efficiency

⇒ energy efficiency education

⇒ role of energy efficiency in the investments of novel machine and truck fleet

⇒ monitoring of energy efficiency and productivity in business

⇒ most important factors affecting energy efficiency

⇒ energy efficiency measures

⇒ future prospects and visions towards energy efficiency.

The answers to the study question one (i.e. state-of-the-art of energy efficiency in the enterprises) were detected in all the sections of the questionnaires. Sections 3, 7 and 8 produced the data for the second study question of the survey (i.e. the future needs, measures and prospects of energy efficiency). To ensure that the interviewees understood the term of energy efficiency similarly, the following was outlined for all entrepreneurs in the beginning of each interview (Palander et al. 2018):

»*Energy efficiency can be increased if overall energy consumption is reduced. Physically and mathematically, the lower value of consumed energy content indicates better energy efficiency. Thus, in wood procurement the energy efficiency is the ratio between the consumed energy content of a conversion process from fuels and indirect energy forms (kW/dm^3, kW/g) as the input of the system and the produced energy content of wood as the output of the system (i.e. kW/m^{3}or kW/kg of cut, hauled, transported wood, or payload of wood or delivered unit of these). Improvement in energy efficiency can be achieved by reducing consumption of energy input with a constant level of energy output but also by enhancing output with constant energy consumption of inputs. It is also possible to develop both measures simultaneously with more complex systems*«.

In Section 1 of the questionnaires, the logging and timber-trucking entrepreneurs' and their firms' background information was investigated with relevant

questions (age and gender of an entrepreneur and the company form at the time of the survey, total logging/long-distance transporting volumes (m^3) by enterprise in 2016 and 2017 (estimate), average logging machinery (i.e. harvesters and forwarders) and timber trucks used in the enterprise in 2016 and 2017, and total number of forestry customers in 2016 and 2017). In addition, in the interviews of logging entrepreneurs, the average size (m^3) of thinning and clear-cutting stands and the average forest machine relocation distance (km) between harvesting stands during the last two years (2016 and 2017) were estimated.

In Section 2 of the questionnaires, it was mapped how often in the enterprises of the survey the energy efficiency has been discussed among own employees (i.e. forest machine operators/timber-truck drivers) and entrepreneur colleagues, and with the wood harvesting and truck transportation officers of Stora Enso WSF during the 2017. The respondents used the following scale: daily, weekly, monthly, less than monthly, or energy efficiency has not been discussed at all in 2017. Section 3 focused on the energy efficiency education and guidance: Have the machine operators and truck drivers of enterprises taken part in energy efficiency education and training, or have they received energy efficiency guidance during the last two years (2016 and 2017)? Furthermore, it was asked to depict more accurately what kind of education and guidance the operators and drivers have been given. It was also established whether the operators and drivers of enterprises would need some energy efficiency training and guidance during the next two years (2018 and 2019).

Section 4 focused on the role of energy efficiency, as well as CO_2 emissions and exhaust emissions (e.g. CO, HC, NO_X, NH_3, PM) in the acquisition decisions of novel logging machinery and timber-truck fleet in the enterprises of the survey during the last two years (2016 and 2017). In addition to the influence of energy efficiency and emissions on machine and truck investments, there were 15 factors listed for logging entrepreneurs and 16 factors for timber-truck entrepreneurs in the questionnaires. Evaluations were conducted with a five-step Likert scale (1 = »Not important at all«, 2 = »Of little importance«, 3 = »Moderately important«, 4 = »Important« and 5 = »Extremely important«). The average importance figure was calculated for each factor as an arithmetical mean of evaluations given by the respondents.

In Section 5 of the questionnaires, the tools and systems used by the respondents' enterprise to monitor energy efficiency in logging operations and timber-trucking business at the time of the survey (the end of 2017) were clarified. Furthermore, the key performance indicators (KPIs) in logging and timber-trucking business used during the year of 2017 were detected. Section 6 aimed to determine the most important factors affecting energy-efficient logging and timber-trucking business in the enterprise by the respondent during the last two years. Overall, there were 36 factors listed for the logging and timber-truck entrepreneurs in the questionnaires. The same five-step Likert scale (1 = »Not important at all« … 5 = »Extremely important«) as in Section 4 of the questionnaires was applied.

Section 7 considered energy efficiency measures in the enterprise by the respondent. First, it established what steps have been taken to improve energy efficiency during the last two years (2016 and 2017), and then what kind of energy efficiency measures the entrepreneur is willing to conduct in order to improve the energy efficiency in his firm in the near future (2018 and 2019).

In Section 8 of the interview, six statements of energy efficiency currently and in the future in the firm were evaluated by the entrepreneur and they were asked to estimate the extent to which they agreed (1 = »Strongly disagree«, 2 = »Disagree«, 3 = »Neither disagree nor agree«, 4 = »Agree«, 5 = »Strongly agree«). The statements were:

- ⇒ energy efficiency related information is sufficiently available
- ⇒ machine operators/truck drivers of my firm work energy efficiently
- ⇒ by improving energy efficiency, it is possible to improve my firm's profitability
- ⇒ I am keen on developing my firm's energy efficiency together with Stora Enso Wood Supply Finland
- ⇒ the role of energy efficiency will be accelerated in the business of my firm during the next few years
- ⇒ in the future, when I invest in new logging machinery/timber-truck fleet in my enterprise, the significance of energy efficiency will increase.

2.2 Survey data

The average age of an entrepreneur was 44.6 years, varying from 25 to 71 years in 2017. All the respondents were men. Of logging enterprises, 92% were limited companies, and of timber-trucking enterprises, 76% were limited companies. Eight percent of logging enterprises and 12% of timber-trucking enterprises were limited partnership companies. The annual total wood harvesting volume of the logging enterprises of the survey was, on average, 297 840 m^3 and the variation ranged between 50 000 and 780 000 m^3/year during

the last two years (2016 and 2017). Correspondingly, the total timber volume transported by timber-trucking enterprises averaged 368 540 m^3/year, ranging from 50 000 to 960 000 m^3/year during the period 2016–2017.

Logging enterprises had from one to five forestry customers and timber-trucking enterprises had from one to four forestry customers. Forty-four percent of logging enterprises and 40% of timber-trucking enterprises had only one forestry customer (i.e. Stora Enso WSF) in 2017. The number of forestry customers was, on average, 2.0 with logging enterprises and 2.1 with timber-trucking enterprises in 2017. There were 2–55 forest machines (i.e. harvesters and forwarders) in logging enterprises and 1–21 timber trucks in timber-trucking enterprises in 2017. The average figures of machine and truck fleets in the survey enterprises were 19.5 and 8.5, respectively.

Logging entrepreneurs estimated that the average size of thinning stands was 445 m^3 (varying from 275 to 700 m^3 by enterprise) and 293 m^3 (varying from 150 to 500 m^3 by enterprise) in clear-cutting sites during the last two years (2016 and 2017). Moreover, the logging entrepreneurs interviewed evaluated that the relocation distance of forest machinery from one harvesting stand to another averaged 27.2 km, ranging from 10 to 55 km by enterprise during the last two years.

2.3 Data analyses

The variables of the questionnaires were analysed using percentage distributions and mean values. We studied the groups of logging and timber-trucking entrepreneurs using nonparametric analysis of variance (the Kruskal-Wallis test) and compared these groups, two at a time, using the Mann-Whitney *U*-test. These tests (both based on ordinals) were used because the variable values (answers) did not show a normal distribution, and with these tests it was possible to assess whether two independent samples (groups) came from the same population. The former test revealed whether the groups being tested were significantly different, after which specific significant differences were identified using the Mann-Whitney *U*-test in paired comparisons. The test level of a significant 0.05 was applied. The statistical analyses were conducted with IBM SPSS Statistics 24 software.

3. Results

3.1 Energy efficiency discussions

The answers by the respondents indicated that energy efficiency or related issues were discussed in logging and timber-trucking enterprises very similarly to all different parties (i.e. own employees, entrepreneur colleagues and wood harvesting and truck transportation officers of Stora Enso WSF) listed in the questionnaires in 2017 (Fig. 1). There were no significant differences between the discussion frequencies of the parties (own employees: U=354.0; p=0.391, entrepreneur colleagues: U=331.0; p=0.707, and officers of Stora Enso WSF: U=392.0; p=0.100) in the logging and timber-trucking enterprises of the survey.

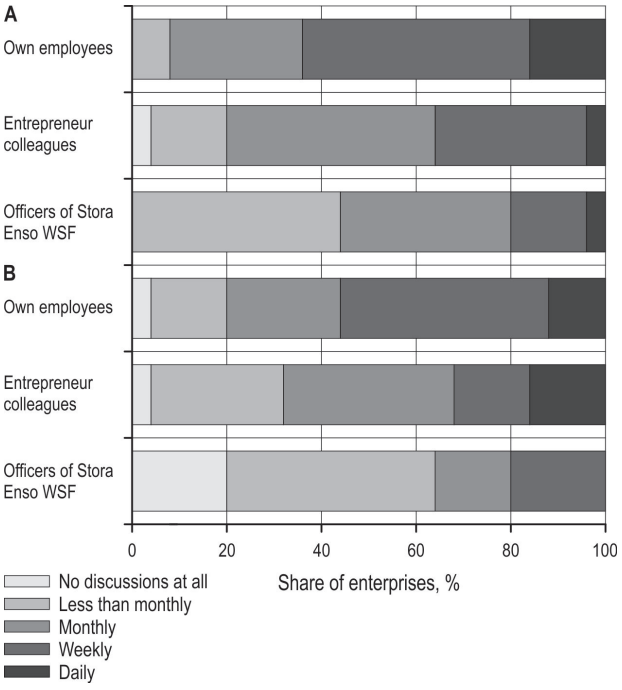

Fig. 1 Frequency distributions of energy efficiency discussions among different parties (own employees, entrepreneur colleagues, and wood harvesting and truck transportation officers of Stora Enso WSF) in logging (A) and timber-trucking (B) enterprises in 2017

Furthermore, the answers displayed most frequently both in the logging and timber-trucking enterprises of the survey that the energy efficiency was discussed among own employees – i.e. machine operators and truck drivers – in 2017 (Fig. 1). The entrepreneurs discussed energy efficiency with each other less frequently than their operators and drivers. The entrepreneurs interviewed had least discussed energy efficiency and related issues with the officers of Stora Enso WSF in 2017 (Fig. 1). There were statistically significant differences between the frequency distributions of the energy efficiency discussions of three conversation parties in both respondent groups (logging: χ^2=12.8; p<0.01 and timber trucking: χ^2=11.6; p<0.01).

3.2 Energy efficiency education

Eighty percent of logging and 96% of timber-trucking entrepreneurs confirmed that they had organized some energy efficiency education for their machine operators and truck drivers during the last two years (2016 and 2017). The most commonly mentioned energy efficiency education (48% of logging and 80% of timber-trucking entrepreneurs) was the user training of machines and trucks provided by forest machine and timber-truck manufacturers for a productive and energy-effective use of logging machinery and timber-truck fleet, and for setting the proper and good adjustments on machines and trucks.

There is a regulation based on a law in Finland that a timber-truck driver must participate in anticipated driving training every five years to keep up his/her driving skill-level (Laki kuorma- ja 2007). This educational requirement reflected the answers by the respondents: Of timber-trucking entrepreneurs, 72% said that their truck drivers had taken part in the anticipated driving schools in 2016 and 2017, and no forest machine operators of the logging enterprises had attended anticipated driving training. Twelve percent of entrepreneurs disclosed that they had themselves requested that their operators and drivers receive economical driving training tailored according to the needs of their enterprise. In addition, 20% of logging and 12% of timber-trucking entrepreneurs revealed that they had organized internal guidance related to energy efficiency for their operators and drivers during the last two years (2016 and 2017).

84% of logging and 92% of timber-trucking entrepreneurs underlined that, during the next two years (2018 and 2019), there is a need for energy efficiency guidance, training and education in their enterprise. Logging entrepreneurs desired most commonly energy efficiency training, especially for energy-efficient working methods in cutting and forwarding (28%) and for setting more optimal adjustments of machinery and its equipment (28%). On the other hand, more than a half (56%) of timber-trucking entrepreneurs stated that in the future their drivers must also actively take part in the obligatory anticipated driving training. Moreover, 16% of trucking entrepreneurs revealed that their firm and its timber-truck drivers will need additional training related to more advanced adjustments of vehicles and better designing of driving plans, including times and routes, during the next two years.

3.3 Role of energy efficiency in investments

All logging entrepreneurs revealed that the reliability of forest machines has been an important or extremely important criterion (average importance: 4.68) in their acquisition decisions of novel wood harvesting machinery for their enterprise during the past two years (2016 and 2017) (Fig. 2). The next most important criteria judged by logging entrepreneurs in their logging machine investments were the coverage

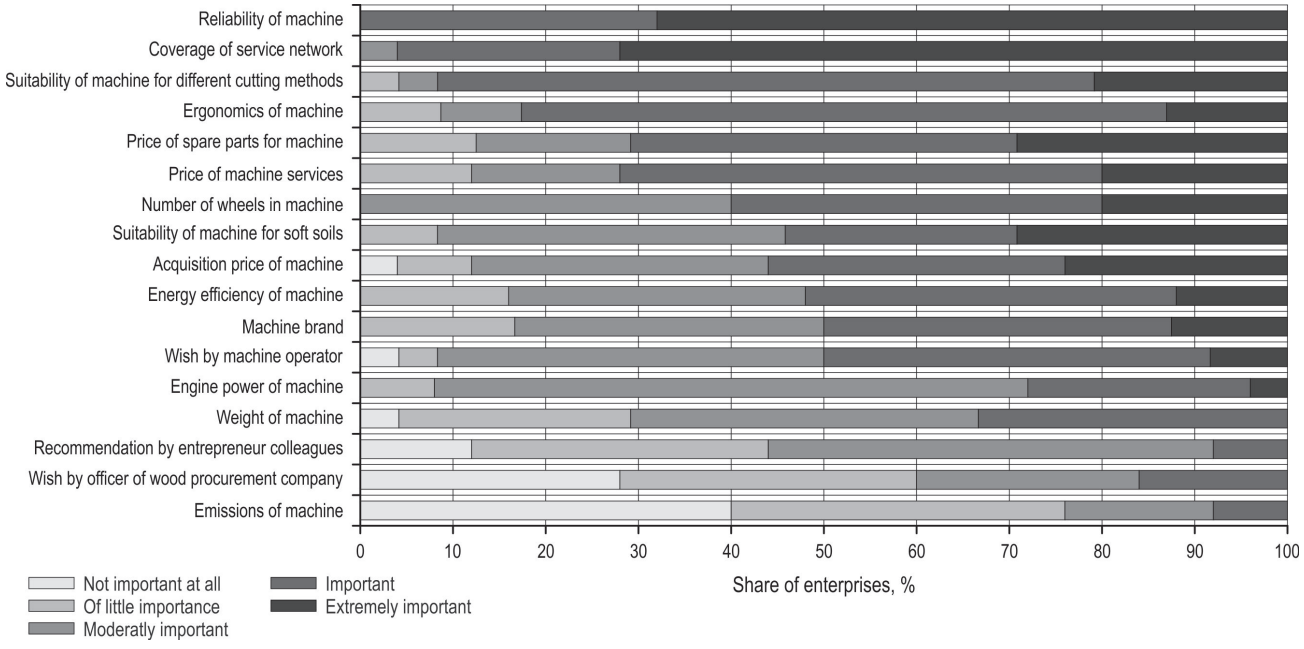

Fig. 2 The most important criteria used by logging entrepreneurs in their acquisition decisions of new wood harvesting machinery during the last two years (2016 and 2017)

of service network of machines (4.68), the suitability of machines for different cutting methods (4.10), ergonomics of machines (3.88), and the price level of spare parts for machines (3.64). The energy efficiency (3.48) was considered the tenth most important criterion for machine acquisitions (Fig. 2). CO_2 and exhaust (e.g. CO, HC, NO_X, NH_3, PM) emissions (1.92) were the last criteria for the forest machine investments by logging entrepreneurs during the last two years.

Timber-trucking entrepreneurs also underlined that reliability (average importance: 4.76) has been one of the most significant criterion for their timber-truck acquisition decisions during the last two years (Fig. 3). The most important criterion of trucking entrepreneurs for their truck investments were the number of axles in a truck (4.80). The following significant factors were the maximum total weight limit (i.e. 76 tonnes) set for timber trucks (4.76), the energy efficiency of trucks (4.24), and the coverage of service network of trucks (4.24). Similarly, emissions (2.92) have been one of the least significant factors for truck investments in the lists of timber-trucking entrepreneurs (Fig. 3).

When comparing the priority lists by the interviewed entrepreneurs (Fig. 2 and 3), it can be noted that the trucking entrepreneurs emphasized more the significance of energy efficiency in their fleet investments than their logging colleagues (U=461.5; p<0.001). Furthermore, the role of emissions (U=459.5; p<0.01) and engine power of vehicles (U=511.0; p<0.001) was also higher in the criterion hierarchy of timber-trucking entrepreneurs when they invested in the novel vehicle fleet in 2016 and 2017. In contrast, logging entrepreneurs stated more than trucking entrepreneurs the coverage of service network in their acquisition decisions of new machine fleet during the last two years (U=206.0; p<0.05) (Fig. 2 and 3).

3.4 Monitoring energy efficiency and business

Mostly, the entrepreneurs interviewed (76% of logging and 80% of trucking entrepreneurs) confirmed that they have some form of fleet management system for monitoring the energy efficiency in their firm. The most commonly used systems in logging enterprises were the fleet management systems provided by the big forest machine manufacturers: John Deere TimberOffice 5, JDLink, Ponsse OptiOffice 2, Ponsse Fleet Management and Komatsu MaxiFleet. In addition, Savotat software produced by Tietohippu Ltd was used to track the energy efficiency in enterprises. On the other hand, timber-trucking entrepreneurs applied the fleet systems from big timber-truck manufacturers: Volvo Dynafleet, Scania Fleet Management and Mercedes-Benz FleetBoard. Some Kiho Fleet Telematics systems (by Mastercom Ltd) were also used for monitoring the energy efficiency in timber-trucking firms at the end of 2017.

The results illustrated that both logging and timber-trucking entrepreneurs had several key perfor-

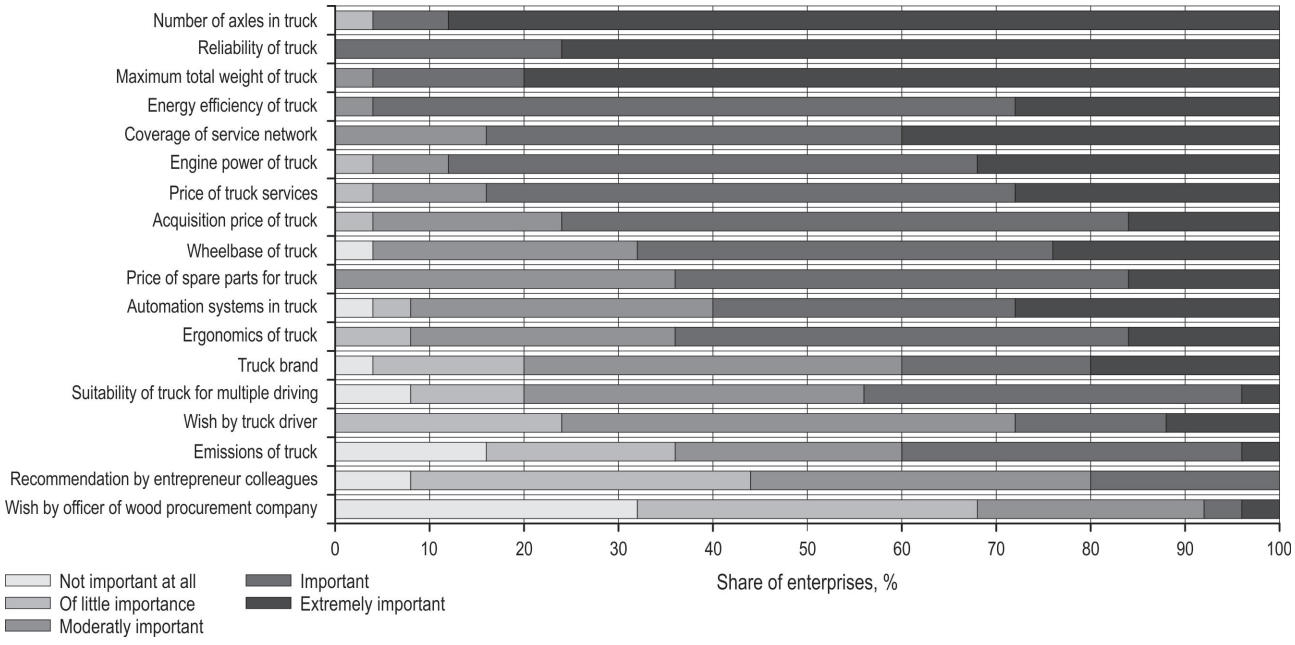

Fig. 3 The most important criteria used by timber-trucking entrepreneurs in their acquisition decisions of new timber-truck fleets during the last two years (2016 and 2017)

Table 1 Key performance indicators (KPIs) used by logging enterprises to manage their business in 2017

Indicator	Monitoring frequency				
	Hour	Day	Week	Month	Year
	Share of enterprises, %				
m^3	20	12	28	52	64
m^3/ha	–	4	4	12	8
m^3/stand	–	4	20	12	–
m^3/machine operator (i.e. work shift)	12	24	20	16	4
m^3/machine	4	12	20	24	16
m^3/cutting method	4	4	8	40	20
Utilization rate (%) of fleet	–	4	8	24	16

Table 2 Key performance indicators (KPIs) used by timber-trucking enterprises to manage their business in 2017

Indicator	Monitoring frequency				
	Hour	Day	Week	Month	Year
	Share of enterprises, %				
m^3	–	4	8	12	60
m^3/truck driver (i.e. work shift)	–	4	–	–	–
m^3/truck	–	12	8	8	4
tonne	–	16	12	8	4
tonne/truck driver (i.e. work shift)	–	16	8	4	–
tonne/truck	–	16	20	12	–
payload	–	24	24	12	–
payload/truck driver (i.e. work shift)	–	32	8	4	–
payload/truck	–	28	12	4	4
Utilization rate (%) of fleet	–	–	8	4	16

mance indicators (KPIs) for managing and controlling their business in 2017 (Table 1 and 2). Logging entrepreneurs favoured the cubic meter-based KPIs. The controlling frequency was typically month, year and week. The most commonly used KPIs in logging enterprises were total harvested timber m^3 per year, per month and per week, as well as total m^3/cutting method/month (Table 1).

Timber-trucking entrepreneurs also controlled their business with cubic meter-based KPIs (Table 2). Moreover, the payload-based KPIs were quite commonly used in trucking firms during 2017. When comparing the controlling frequencies between the logging and trucking enterprises, many timber-trucking entrepreneurs monitored their business daily and weekly (Table 1 and 2). The long-term (year and month) follow-up periods also were applied for monitoring the timber-trucking business (Table 2). The most commonly used KPIs in timber-trucking firms were total transported timber m^3/year, payloads/driver/day and payloads/truck/day in 2017.

3.5 Factors affecting energy efficiency

Logging entrepreneurs pointed out that the most important factors affecting the energy-efficient logging business were the professional skills of the forest machine operator (average importance: 4.76) during the last two years (2016 and 2017) (Fig. 4). Logging entrepreneurs also underlined the role of attitudes and motivation of a machine operator (4.60) to the energy-efficient logging business. The significant factors impacting energy-efficient logging in the entrepreneurs' list were, furthermore, the stand size of harvesting site (4.68), sufficient size of available standing stock (4.68), hindering undergrowth in the stand (4.56), forwarding distance from a stump to roadside landing area (4.48), the number of timber assortments (4.46), technical condition of machinery and its equipment (4.44), carrying capacity of terrain (4.36), and machine relocations between harvesting sites (4.33). The fuel efficiency (dm^3 of heating oil/m^3 of timber harvested) of forest machinery (4.28) was the eleventh important factor in the list of logging entrepreneurs (Fig. 4).

The timber-trucking entrepreneurs interviewed listed fuel efficiency (dm^3 of diesel fuel/tonne of timber transported) of their truck fleet (average importance: 4.76) as the most important factor influencing their business during the last two years (Fig. 5). Trucking entrepreneurs also highlighted significantly the importance of professional skills, as well as attitudes and motivation of truck driver (4.60) for the energy-effective timber-trucking business. Furthermore, trucking entrepreneurs stressed the influence of the following factors on the energy-efficient timber-trucking business: utilization of maximum truck weights (4.76), designing of driving plans (4.60), transport distance from a batch to destination (i.e. mill or buffer storage) (4.56), timber length (4.52), quantity of driving with an unloaded truck (4.50), and quality of road network (4.48) and weather conditions (4.48) (Fig. 5).

When analysing the lists of the most important factors affecting the energy-efficient logging and timber-

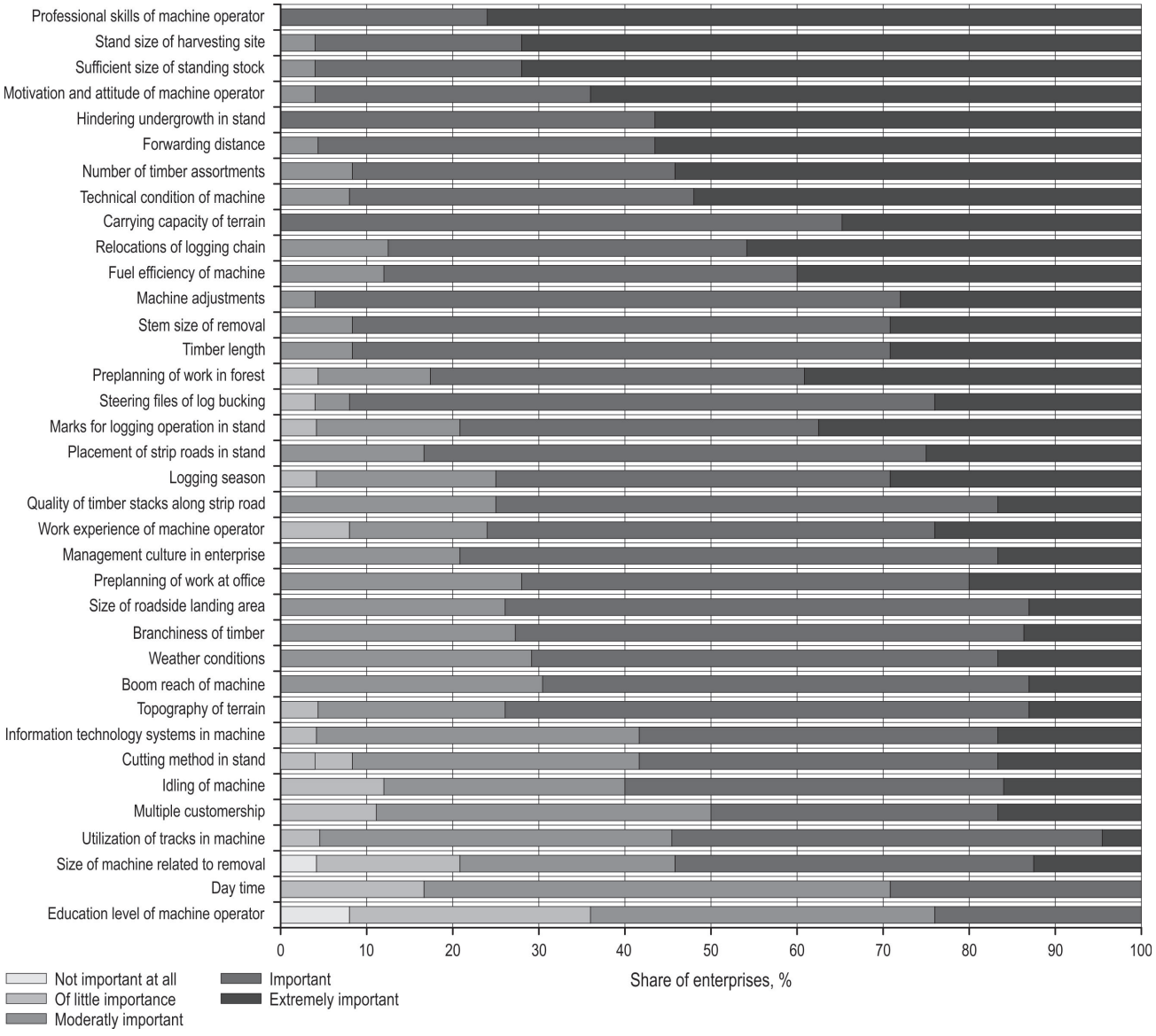

Fig. 4 The most important factors affecting energy-efficient logging business in enterprises according to respondents during the last two years (2016 and 2017)

trucking business, it is clear that a group of respondents emphasized some factors more than the other. Logging entrepreneurs stressed more the importance of timber size (or volume of removal in the stand) (U=166.0; p<0.01) and the number of timber assortments (U=173.5; p<0.01) for energy-efficient business than trucking entrepreneurs. Respectively, timber-trucking entrepreneurs emphasized more the impact of weather conditions (U=464.5; p<0.001), timber length (U=408.5; p<0.05), and fuel efficiency of vehicles (U=434.0; p<0.01) on the energy-effective business than logging entrepreneurs (Fig. 4 and 5).

3.6 Energy efficiency measures

Respondents revealed that several energy efficiency measures have been conducted in their enterprises during the last two years (2016 and 2017). The most commonly implemented energy efficiency measures in the logging enterprises were: transferring the stand planning from a wood procurement company to the logging enterprise (mentioned by 64% of respondents), contracting the new services deals for acquired harvesters and forwarders (60%), more advanced utilization of fleet management systems (20%), and new contracting agreements with novel forestry customers

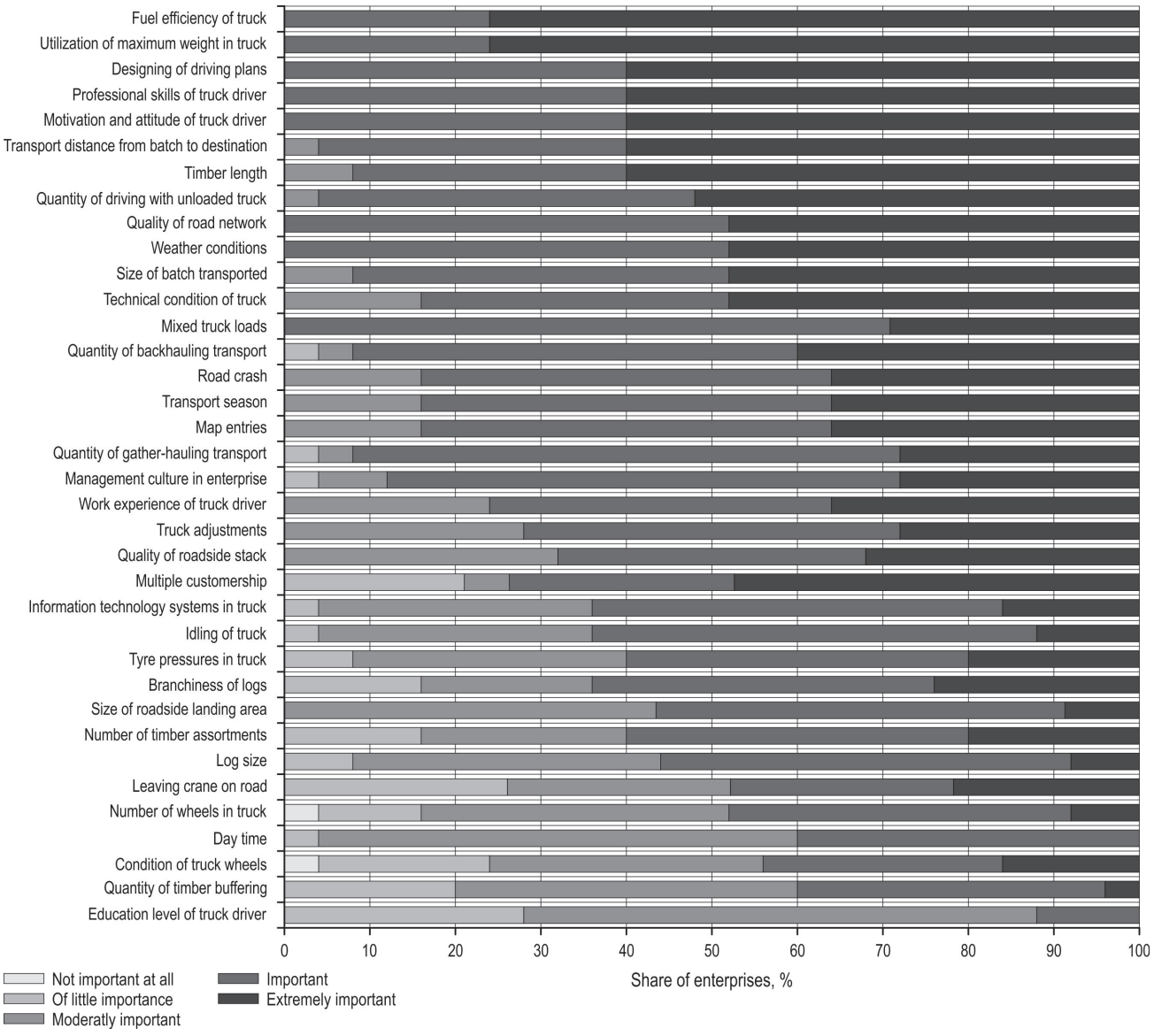

Fig. 5 The most important factors affecting energy-efficient timber-trucking business in enterprises according to respondents during the last two years (2016 and 2017)

(20%). On the other hand, timber-trucking entrepreneurs had mainly focused on conducting the following energy efficiency measures during the last two years: transferring transport planning from a wood procurement company to the trucking enterprise (44%), contracting new services deals for the truck fleet acquired (32%), making new contracting agreements with novel forestry customers (28%), and drawing up a new transportation coalition with other timber-trucking entrepreneurs (20%).

Furthermore, respondents listed many energy efficiency measures, which they are willing to conduct in order to improve the energy efficiency of their enterprise in the near future (2018 and 2019). Logging entrepreneurs introduced the following energy efficiency measures: seeking new clients for their firm (60% of respondents), investing new fleet management systems (24%), as well as making better use of current monitoring systems already acquired (24%). In contrast, timber-trucking entrepreneurs listed the following: increasing multiple customership (64%), developing transport planning based on transportation volumes (44%), hiring own transportation planner for transport planning (24%), and improving collaboration with logging entrepreneurs in wood supply chain (16%).

3.7 Future prospects of energy efficiency

The majority of entrepreneurs said that energy efficiency related information is sufficiently available (52% of logging and 68% of trucking entrepreneurs agreed or strongly agreed with the statement) but there was also a need for further energy efficiency information, because around one tenth of respondents disagreed or strongly disagreed with the statement. The entrepreneurs estimated that their machine operators or truck drivers work mainly energy efficiently (72% of logging and 80% of trucking entrepreneurs agreed or strongly agreed with the statement). In addition, the entrepreneurs interviewed felt significantly that by improving energy efficiency, it is possible to increase the profitability of their enterprise (84% of logging and 100% of trucking entrepreneurs agreed or strongly agreed with the statement). Almost all respondents were keen on developing their firm's energy efficiency together with Stora Enso Wood Supply Finland (92% of logging and 96% of trucking entrepreneurs agreed or strongly agreed with the statement).

Moreover, respondents estimated that energy efficiency will improve in their enterprise business in the next few years (92% of logging and 88% of trucking entrepreneurs agreed or strongly agreed with the statement). Finally, the entrepreneurs forecasted that in the future, when they invest in novel logging machinery or timber-truck fleets for their enterprise, the importance of energy efficiency will increase in their future investments (76% of logging and 84% of trucking entrepreneurs agreed or strongly agreed with the statement). There were no significant differences between the entrepreneur groups in the statements asked.

4. Discussion

This study aimed to illustrate the present state of energy efficiency, as well as the awareness and attitudes towards energy efficiency in logging and timber-trucking enterprises contracted to Stora Enso WSF. All firms selected for the survey were SMEs. Reddy and Shrestha (1998) and Nagesha and Balachandra (2006) emphasized that lack of awareness of energy efficiency is one of the biggest barriers to adopting energy efficiency measures in firms.

Energy efficiency in SMEs is a very topical and significant issue. For instance, Kortelainen et al. (2012) have found that enterprises' attitudes towards energy is related to the size and location (i.e. country) of the enterprise, and they revealed that large enterprises have a more positive attitude towards energy issues than SMEs. Furthermore, Zhang (2016) pointed out that fuel efficiency and energy efficiency have not typically been extended so much in SMEs compared to larger companies. Many studies have underlined the relevance of company characteristics effects on the barriers and drivers of enterprises' implementation of energy efficiency measures (e.g. Schleich 2009, Trianni and Cagno 2012, Hrovatin et al. 2016, Trianni et al. 2016). Hrovatin et al. (2016) concluded that the energy efficiency gap is less likely to exist in large firms, implying that energy efficiency measures should primarily target SMEs. Meanwhile, Schleich (2009) disclosed that energy-intensive firms tend to put a higher priority on energy efficiency than less energy-intensive firms, as well as the fact that larger firms tend to adopt more energy efficiency measures than smaller firms.

For the study, in total 50 entrepreneurs were interviewed in person. The coverage rate (>70%) in the survey was relatively high, as the total population was 68 SMEs. It can be concluded that the results present very well the state of energy efficiency among logging and timber-trucking entrepreneurs at Stora Enso WSF. However, the results do not necessarily display the energy efficiency in the other logging and timber-trucking enterprises in Finland, neither do they do so for other countries. Therefore, our study was a case study at Stora Enso in Finland.

The results indicated that timber-trucking enterprises highlight more energy efficiency and fuel efficiency than logging enterprises. For instance, timber-trucking entrepreneurs underscored more energy efficiency in their acquisition decisions of new vehicles and the role of fuel efficiency has impacted more the energy-efficient timber-trucking business during the last two years (Fig. 3 and 5). The main reason for this result is the fact that in timber-trucking business, the weight of energy and its costs are much higher than in logging business. According to the index of forest machine and timber-trucking costs (Statistics Finland 2017), the proportion of fuel costs is around 12% in logging and more than double (30%) in timber-trucking business. Nowadays (October 2018), the price of Brent crude oil is approximately $75–85/barrel (Oilprice.com 2018). If the oil price rises higher than its current level, it can be forecasted that there will be a bigger stimulation or inducement for both logging and timber-trucking firms to improve their energy efficiency (Rohdin and Thollander 2006, Rohdin et al. 2007, Trollander and Ottosson 2008, Thollander et al. 2013, Brunke et al. 2014).

Moreover, the survey results revealed that the logging and trucking enterprises could improve the energy efficiency in their business by organizing more energy efficiency training and education for their

machine operators and truck drivers (Kojima and Ryan 2010, Trianni et al. 2016). Only a few entrepreneurs explained in the interviews that they had arranged for their operators and drivers the economical driving training, which had been tailored according to their needs by the enterprise. In Finland, there is a regulation that a timber-truck driver must participate in anticipated driving training every five years to keep up his/her driving skill-level (Laki kuorma- ja 2007), but nonetheless there is no similar requirement for forest machine operators. In addition, professional qualifications in the education of forest machine operators do not currently consist of any requirements regarding the economical and anticipated driving training (EDU-FI 2012, 2013). Therefore, the economical and anticipated driving training could be included in the novel professional qualifications of forest machine operators in the future.

The energy efficiency education of machine operators and truck drivers also plays an essential role because of the significance of professional skills, attitude and motivation of a driver and operator for the energy-efficient logging and trucking business (Fig. 4 and 5). Thollander et al. (2007), Sardianou (2008), Ren (2009) and Trianni et al. (2013a, 2013b) have estimated that the lack of experience and skills significantly inhibits the improvement of the company's energy efficiency. Several forest work studies have been carried out to analyse the effect of the harvester operator on his/her performance, and many studies have underlined that there is a significant correlation between the work experience and skills of an operator and his/her productivity in forest machine work (e.g. Sirén 1998, Kärhä et al. 2004, Ovaskainen et al. 2004, Dvořák et al. 2008, Ovaskainen 2009, Purfürst 2010, Purfürst and Erler 2011, Palander et al. 2012a, Malinen et al. 2018). For instance, Purfürst and Erler (2011) found out that the stem size and the operator account together for 84% of the total overall variation in cutting productivity, and the operator alone accounts for 37% of the variance. Hence, fuel consumption studies, including the effect of a machine operator and truck driver on fuel consumption and energy efficiency, are needed in the future.

The logging and timber-trucking enterprises of the study implemented many energy efficiency measures during the last two years (2016 and 2017). There is, however, huge potential related to new innovative energy efficiency measures in enterprises. For instance, Devlin et al. (2008) highlighted the enormous possibilities by intensifying the planning and optimizing of transportation routes and further heightening the energy efficiency in transportation. In this respect, new trends of outsourcing are increasing the company size of service providers (i.e. logging and timber-trucking enterprises), which provides better options for backhauling optimization for reducing truck driving with empty loads (Palander and Väätäinen 2005, Palander et al. 2012b, Malinen et al. 2014, Palander and Kärhä 2018). However, entrepreneurs do not have enough information and knowledge on how to fully utilize the measurements with new technology in the changing digitized working environment of Stora Enso WSF. A fairly easy and inexpensive means of improving energy efficiency in logging and timber-trucking enterprises is to focus on productive and right adjustments in machines and trucks. For instance, Prinz et al. (2018) reported that in cut-to-length wood harvesting, the adjustments of engine settings has a significant impact on fuel consumption and CO_2 emissions. The other easy means to save fuel and to further improve energy efficiency is to avoid and minimize the idling of forest machines and timber trucks in firms.

The entrepreneurs monitor the energy efficiency of their business with several key performance indicators (Table 1 and 2). The fleet management systems currently used in logging and timber-trucking enterprises enable an effective platform to control better the future business. Nevertheless, the development of fleet management systems is necessary for taking into account more flexibility in energy issues in monitoring the energy efficiency of the firm. For instance, it is crucial that harvesting (e.g. stem size of removal, forest haulage distance, cutting method) and transportation (e.g. gradient, curvature, road surface roughness and functional road class) conditions are considered as independent variables in reporting energy efficiency. For instance, Svenson and Fjeld (2012) reported that the impact of gradient and road surface roughness on fuel consumption of timber trucks is as high as 77%. Furthermore, Palander (2016, 2017) revealed that the environmental emissions of timber transportation (g/tkm) for fuel consumption (dm^3 of diesel/tkm) cannot only be determined by the technical efficiency of a vehicle, but are also closely related to vehicle operators, highway driving versus forest road driving, and flow conditions on a transport network. Forest machine and timber-truck manufacturers in cooperation can develop the fleet management systems, as well as optimize adjustments in machines and trucks, and provide training of effective working methods for operators and drivers.

The results illustrated that there is a positive attitude towards energy efficiency among the logging and timber-trucking entrepreneurs. This creates a solid

background to deepen and continue energy-effective work between the enterprises and Stora Enso WSF in the coming years. Most of the entrepreneurs interviewed believe that there is a positive connection between the energy efficiency and profitability of the firm. This entrepreneurs' statement is in line with the earlier energy efficiency studies. For example, Rao and Holt (2005), Green Jr et al. (2012) and Trianni et al. (2016) have recognized energy efficiency, as well as green supply chains, as one of the primary means to increase the competitiveness of the firm, and in particular, for SMEs.

It must be noted that, to satisfy the requirements of the Energy Efficiency Act in Finland, the main drivers for energy efficiency at Stora Enso WSF are long-term strategy, top management with a real commitment, and of course cost reduction from lower energy use (Rohdin and Thollander 2006, Rohdin et al. 2007, Thollander et al. 2007, 2013, Trollander and Ottosson 2008, Brunke et al. 2014). Promoting energy efficiency work has been done for three years at Stora Enso WSF, and the energy efficiency work in logging and timber-trucking enterprises has been conducted for less than three years. Therefore, there is a considerable amount of work with energy efficiency among logging and timber-trucking enterprises contracted to Stora Enso WSF to be done in the near future. For instance, energy efficiency should be further discussed with entrepreneurs as part of normal annual development conversations. Currently, the energy efficiency debates with wood harvesting and truck transportation officers of Stora Enso WSF are fairly rare (Fig. 1). To promote such discussions and to satisfy the requirements of the Energy Efficiency Act, the energy efficiency measures per harvested cubic meter in logging and transported tonne of wood in timber trucking will be developed and used in debates instead of the measures of per saleable tonne of pulp, paper and board (Palander et al. 2018).

5. Conclusions

Energy efficiency provides a new option of wood procurement systems for logging and timber-trucking entrepreneurs in the Finnish forest industry. So far, it has not been utilized effectively, which was demonstrated by the answers to the questions of this study. In our survey, all firms were SMEs. The influence of firm size on energy efficiency in wood procurement must be clarified more deeply in future studies. During the interview, the entrepreneurs' awareness of energy efficiency terms was clarified and they understood that by focusing on energy efficiency, it is possible to improve firms' profitability. Altogether, the entrepreneurs' attitudes towards energy efficiency was good, but there is a need for knowledge, education and advanced technology. Education and knowledge play key roles when it comes to attitudes, motivation and working methods. In particular, there is a need for energy efficiency education and advanced working methods among logging entrepreneurs. In the timber-trucking business, energy efficiency is most likely at a better level because they have already begun education, e.g. in anticipated driving training. In this respect, manufacturers and institutions but also entrepreneurs should develop their future cooperation.

The results also revealed that there is a need for further investigation relating to energy efficiency measurements. Currently, most of the entrepreneurs have different fleet management systems, which provide information that can be used for monitoring energy efficiency, cost efficiency and productivity for their business purpose. However, it seems that entrepreneurs do not have enough information and knowledge on how to fully utilize the measurements with new technology in changing the digitized working environment of Stora Enso WSF. Therefore, it is necessary to develop the automated systems further to improve the energy efficiency in the entire wood supply system and to meet the aims of the Energy Efficiency Act in Finland and the EU Energy Efficiency Directive.

6. References

Ackerman, P., Williams, C., Ackerman, S., Nati, C., 2017: Diesel consumption and carbon balance in South African pine clear-felling CTL operations: A preliminary case study. Croatian Journal of Forest Engineering 38(1): 65–72.

Bonhomme, B., LeBel, L., 2003: Harvesting contractors in Northern Quebec: A financial and technical performance evaluation. In: 2003 Council on Forest Engineering (COFE) Conference Proceedings: Forest Operations Among Competing Forest Uses, 7–10 September, Bar Harbor, Maine, USA.

Brunberg, T., 2007: Bränsleförbrukningen hos skördare och skotare vecka 13 och 39, 2006 (Fuel consumption of harvesters and forwarders during weeks 13 and 39, 2006). Arbetsrapport Från Skogforsk 629.

Brunberg, T., 2013: Fuel consumption in forest machines 2012. Arbetsrapport Från Skogforsk 789.

Brunberg, T., Granlund, P., Nordén, B., 2004: Bränslemätningar på skotare och skördare (Measuring fuel consumption of forwarders and harvesters). Arbetsrapport Från Skogforsk 585.

Brunberg, T., Johansson, F., Löfroth, C., 2017: Diesel consumption in forest trucks, 2016. Arbetsrapport Från Skogforsk 941.

Brunke, J.C., Johansson, M., Thollander, P., 2014: Empirical investigation of barriers and drivers to the adoption of energy conservation measures, energy management practices and energy services in the Swedish iron and steel industry. Journal of Cleaner Production 84: 509–525.

Cacot, E., Emeyriat, R., Bouvet, A., Helou, T.E., 2010: Tools and analysis of key success factors for mechanized forest contractors specializing in mechanized harvesting in the Aquitaine region. In: FORMEC, Forest Engineering: Meeting the Needs of the Society and the Environment, 11–14 July, Padova, Italy.

Carter, D.R., Cubbage, F.W., 1995: Stochastic frontier estimation and sources of technical efficiency in southern timber harvesting. Forest Science 41(3): 576–593.

Conrad IV, J.L., Vokoun, M.M., Prisley, S.P., Bolding, M.C., 2017: Barriers to logging production and efficiency in Wisconsin. International Journal of Forest Engineering 28(1): 57–65.

de Beer, J., Worrell, E., Blok, K., 1998: Long-term energy-efficiency improvements in the paper and board industry. Energy 23(1): 21–42.

del Río González, P., 2005: Analysing the factors influencing clean technology adoption: a study of the Spanish pulp and paper industry. Business Strategy and the Environment 14(1): 20–37.

Devlin, G., McDonnell, K., Ward, S., 2008: Development of a spatial decision support system (SDSS) for route costing calculations within the Irish timber haulage sector. Transactions of the ASABE 51(2): 763–773.

Drolet, S., Lebel, L., 2010: Forest harvesting entrepreneurs, perception of their business status and its influence on performance evaluation. Forest Policy and Economics 12(4): 287–298.

Dvořák, J., Malkovský, Z., Macků, J., 2008: Influence of human factor on the time of work stages of harvesters and crane-equipped forwarders. Journal of Forest Science 54(1): 24–30.

EDUFI (Finnish National Agency for Education), 2012: Metsäkoneenkuljettajan ammattitutkinto 2012. Näyttötutkinnon perusteet (Qualification of forest machine operator, 2012. Basics for qualification), Decree 43/011/2012.

EDUFI (Finnish National Agency for Education), 2013: Puunkorjuun erikoisammattitutkinto 2013. Näyttötutkinnon perusteet (Qualification of wood harvesting operations, 2013. Basics for qualification), Decree 8/011/2013.

Energiatehokkuuslaki (Energy Efficiency Act in Finland) 1429/2014, 2014.

European Union, 2011: Comminication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Roadmap for moving to a competitive low carbon economy in 2050.

European Union, 2012: Directive 2012/27/EU of the European Parliament and of the Council of 25 October on Energy Efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

European Union, 2014: Comminication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A policy framework for climate and energy in the period from 2020 to 2030, COM/2014/015 final.

Farla, J., Blok, K., Schipper, L., 1997: Energy efficiency developments in the paper and pulp industry: A cross-country comparison using physical production data. Energy Policy 25(7–9): 745–758.

Fleiter, T., Fehrenbach, D., Worrell, E., Eichhammer, W., 2012: Energy efficiency in the German pulp and paper industry – a model-based assessment of saving potentials. Energy 40(1): 84–99.

Fracaro, G., Vakkilainen, E., Hamaguchi, M., de Souza, S.N.M., 2012: Energy efficiency in the Brazilian pulp and paper industry. Energies 5(9): 3550–3572.

Green Jr, K.W., Zelbst, P.J., Meacham, J., Bhadauria, V.S., 2012: Green supply chain management practices: Impact on performance. Supply Chain Management 17(3): 290–305.

Hämäläinen, E., Hilmola, O.P., 2017: Energy efficiency at the paper mill – dilemma of improvement. Energy Efficiency 10(4): 809–821.

Holzleitner, F., Kanzian, C., Stampfer, K., 2011a: Analyzing time and fuel consumption in road transport of round wood with an onboard fleet manager. European Journal of Forest Research 130(2): 293–301.

Holzleitner, F., Stampfer, K., Visser, R., 2011b: Utilization rates and cost factors in timber harvesting based on long-term machine data. Croatian Journal of Forest Engineering 32(2): 501–508.

Hope, K. (Ed.), 2017: Annual report on European SMEs 2016/2017, Focus on self-employment. SME performance review 2016/2017, Final report. European Commission, Internal Market, Industry, Entrepreneurship and SMEs.

Hourunranta, P., Kettunen, A., Partala, S., 2013: Metsäkoneyritysten suorituskyvyn johtaminen (Management of performance of forest machine companies). TTS:n tiedote Metsätyö, -energia ja yrittäjyys 770.

Hrovatin, N., Dolšak, N., Zorić, J., 2016: Factors impacting investments in energy efficiency and clean technologies: empirical evidence from Slovenian manufacturing firms. Journal of Cleaner Production 127: 475–486.

ISO (International Organization for Standardization), 2011: ISO 50001 Energy Management System Standard.

Joelsson, J.M., Gustavsson, L., 2008: CO_2 emission and oil use reduction through black liquor gasification and energy efficiency in pulp and paper industry. Resources, Conservation and Recycling 52(5): 747–763.

Kärhä, K., Rönkkö, E., Gumse, S.I., 2004: Productivity and cutting costs of thinning harvesters. International Journal of Forest Engineering 15(2) 43–56.

Kilponen, L., Ahtila, P., Parpala, J., Pihko, M., 2001: Improvement of pulp mill energy efficiency in an integrated pulp and paper mill. In: Proceedings of 2001 ACEEE Summer Study on Energy Efficiency in Industry – Increasing Productivity through Energy Efficiency, 24–27 July, Tarrytown, NY, USA, 363–374.

Klvač, R., Skoupý, A., 2009: Characteristic fuel consumption and exhaust emissions in fully mechanized logging operations. Journal of Forest Research 14(6): 328–334.

Klvač, R., Kolařík, J., Voloná, M., Drápela, K., 2013: Fuel consumption in timber haulage. Croatian Journal of Forest Engineering 34(2): 229–240.

Kojima, K., Ryan, L., 2010: Transport energy efficiency. Implementation of IEA Recommendations since 2009 and next steps. International Energy Agency (IEA), Information Paper.

Kortelainen, J.T., Ratinen, M., Linnanen, L., 2012: Attitudes towards energy efficiency and renewable energy in European small and medium-sized enterprises. In: Vazquez-Brust, D., Sarkis, J. (Eds), Green Growth: Managing the Transition to a Sustainable Economy. Greening of Industry Networks Studies 1: 229–243.

Laki kuorma- ja linja-auton kuljettajien ammattipätevyydestä (Act on the Professional Qualifications of Truck and Bus Drivers) 273/2007, 2007.

LeBel, L., Stuart, W.B., 1998: Technical efficiency evaluation of logging entrepreneurs using a nonparametric model. Journal of Forest Engineering 9(2): 15–24.

Leon, B.H., Benjamin, J.G., 2012: A survey of business attributes, harvest capacity and equipment infrastucture of logging businesses in the Northern Forest. The University of Maine, School of Forest Resources.

Lijewski, P., Merkisz, J., Fuć, P., Ziółkowski, A., Rymaniak, Ł., Kusiak, W., 2017: Fuel consumption and exhaust emissions in the process of mechanized timber extraction and transport. European Journal of Forest Research 136(1): 153–160.

Lindholm, E.L., Berg, S., 2005: Energy requirement and environmental impact in timber transport. Scandinavian Journal of Forest Research 20(2):184–191.

Magagnotti, N., Pari, L., Spinelli, R., 2017: Use, utilization, productivity and fuel consumption of purpose-built and excavator-based harvesters and processors in Italy. Forests 8(12): 485, 12 p.

Mäkinen, P., 1997: Success factors for forest machine entrepreneurs. Journal of Forest Engineering 8(2): 27–35.

Malinen, J., Nousiainen, V., Palojärvi, K., Palander, T., 2014: Prospects and challenges of timber trucking in a changing operational environment in Finland. Croatian Journal of Forest Engineering 35(1): 91–100.

Malinen, J., Taskinen, J., Tolppa, T., 2018: Productivity of cut-to-length harvesting by operators' age and experience. Croatian Journal of Forest Engineering 39(1): 15–22.

Manner, J., Nordfjell, T., Lindroos, O., 2016: Automatic load level follow-up of forwarders' fuel and time consumption. International Journal of Forest Engineering 27(3): 151–160.

Martin, N., Angliani, N., Einstein, D., Khrushch, M., Worrell, E., Price, L.K., 2000: Opportunities to improve energy efficiency and reduce greenhouse gas emissions in the U.S. Pulp and Paper Industry. Ernest Orlando Lawrence Berkeley National Laboratory LBNL 46141.

MetsäTrans tilastot 2018 (MetsäTrans Statistics 2018), 2018: MetsäTrans 21(1): 6–27.

Motiva, 2018: Energy efficiency agreements in Finland. Available at: http://www.energiatehokkuussopimukset2017-2025.fi/en/energy-efficiency-agreements/

Nagesha, N., Balachandra, P., 2006: Barriers to energy efficiency in small industry clusters: Multi-criteria-based prioritization using the analytic hierarchy process. Energy 31(12): 1969–1983.

Nordfjell, T., Athanassiadis, D., Talbot, B., 2003: Fuel consumption in forwarders. International Journal of Forest Engineering 14(2): 11–20.

Obi, O.F., Visser, R., 2017: Operational efficiency analysis of New Zealand timber harvesting contractors using data envelopment analysis. International Journal of Forest Engineering 28(2): 85–93.

Oilprice.com, 2018. Available at: https://oilprice.com

Ovaskainen, H., 2009: Timber harvester operators' working technique in first thinning and the importance of cognitive abilities on work productivity. Academic Dissertation. Dissertationes Forestales 79 p.

Ovaskainen, H., Uusitalo, J., Väätäinen, K., 2004: Characteristics and significance of harvester operators' working technique in thinnings. International Journal of Forest Engineering 15(2): 67–77.

Oyier, P., Visser, R., 2016: Fuel consumption of timber harvesting systems in New Zealand. European Journal of Forest Engineering 2(2): 67–73.

Palander, T., 2016: Environmental benefits from improving transportation efficiency in wood procurement systems. Transportation Research Part D: Transport and Environment 44: 211–218.

Palander, T., 2017: The environmental emission efficiency of larger and heavier vehicles – A case study of road transportation in Finnish forest industry. Journal of Cleaner Production 155(1): 57–62.

Palander, T., Väätäinen, J., 2005: Impacts of interenterprise collaboration and backhauling on wood procurement in Finland. Scandinavian Journal of Forest Research 20(2): 177–183.

Palander, T., Kärhä, K., 2018: Characteristics of energy performance measures for 100% carbon-neutral wood procure-

ment of forest industry. In: Zhu, J., Jin, A., Zhu, D. (Eds), New trends in nanotechnology, material and environmental sciences. AV AkademikerVerlag, 304–332.

Palander, T., Ovaskainen, H., Tikkanen, L., 2012a: An adaptive work study method for identifying the human factors that influence the performance of a human-machine system. Forest Science 58(4): 377–389.

Palander, T., Vainikka, M., Yletyinen, A., 2012b: Potential mechanisms for co-operation between transportation entrepreneurs and customers: A case study of regional entrepreneurship in Finland. Croatian Journal of Forest Engineering 33(1): 89–103.

Palander, T., Haavikko, H., Kärhä, K., 2018: Towards sustainable wood procurement in forest industry – The energy efficiency of larger and heavier vehicles in Finland. Renewable and Sustainable Energy Reviews 96: 100–118.

Peng, L., Zeng, X., Wang, Y., Hong, G.B., 2015: Analysis of energy efficiency and carbon dioxide reduction in the Chinese pulp and paper industry. Energy Policy 80: 65–75.

Penttinen, M., Mikkola, J., Rummukainen, A., 2009: Profitability of wood harvesting enterprises. Working Papers of the Finnish Forest Research Institute 126.

Prinz, R., Spinelli, R., Magagnotti, N., Routa, J., Asikainen, A., 2018: Modifying the settings of CTL timber harvesting machines to reduce fuel consumption and CO_2 emissions. Journal of Cleaner Production 197: 208–217.

Purfürst, F.T., 2010: Learning curves of harvester operators. Croatian Journal of Forest Engineering 31(2): 89–97.

Purfürst, F.T., Erler, J., 2011: The human influence on productivity in harvester operations. International Journal of Forest Engineering 22(2): 15–22.

Rao, P., Holt, D., 2005: Do green supply chains lead to competitiveness and economic performance? International Journal of Operations & Production Management 25(9): 898–916.

Reddy, B.S., Shrestha, R.M., 1998: Barriers to the adoption of efficient electricity technologies: a case study of India. International Journal of Energy Research 22(3): 257–270.

Ren, T., 2009: Barriers and drivers for process innovation in the petrochemical industry – A case study. Journal of Engineering Technology Management 26(4): 285–304.

Rieppo, K., Örn, J., 2003: Metsäkoneiden polttoaineen kulutuksen mittaaminen (Measuring fuel consumption of forest machines). Metsätehon raportti 148.

Rohdin, P., Thollander, P., 2006: Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden. Energy 31(12): 1836–1844.

Rohdin, P., Thollander, P., Solding, P., 2007: Barriers to and drivers for energy efficiency in the Swedish foundry industry. Energy Policy 35(1): 672–677.

Sardianou, E., 2008: Barriers to industrial energy efficiency investments in Greece. Journal of Cleaner Production 16(13): 1416–1423.

Schleich, J., 2009: Barriers to energy efficiency: A comparison across the German commercial and services sector. Ecological Economics 68(7): 2150–2159.

Sirén, M., 1998: One-grip harvester operation, it's silvicultural result and possibilities to predict tree damage. Academic Dissertation. Finnish Forest Research Institute, Research Papers 694.

Soirinsuo, J., 2012: Growth and profitability of logging and transportation in wood procurement companies in Finland: What strategies and entrepreneurs are needed for profitable growth? Academic Dissertation. University of Helsinki, Department of Economics and Management Publications 54.

Statistics Finland, 2017: Metsäalan kone- ja autokustannusindeksi 2015 = 100, Käsikirja (Index of logging machine and timber-trucking costs in 2015 = 100, Handbook).

Stora Enso, 2017a: Stora Enso's Policy for Energy and Carbon.

Stora Enso, 2017b: Stora Enso Sustainability Report 2016.

Stora Enso, 2018: Progress Book. Part of Stora Enso's Annual Report 2017.

Stora Enso Wood Supply Finland, 2015: Energiatehokkuuden johtamisjärjestelmä ISO 50001. Stora Enso Metsä, Tavoitteet ja toimenpiteet (ISO 50001 Energy efficiency management system. Stora Enso Wood Supply Finland, Targets and measures).

Svenson, G., Fjeld, D., 2012: The influence of road characteristics on fuel consumption for logging trucks. In: Setting future standards: International symposium on heavy vehicle transport technology - HVTT12, 16–19 September, Stockholm, Sweden.

Svenson, G., Fjeld, D., 2016: The impact of road geometry and surface roughness on fuel consumption of logging trucks. Scandinavian Journal of Forest Research 31(5): 526–536.

Thollander, P., Ottosson, M., 2008: An energy efficient Swedish pulp and paper industry – exploring barriers to and driving forces for cost-effective energy efficiency investment. Energy Efficiency 1(1): 21–34.

Thollander, P., Danestig, M., Rohdin, P., 2007: Energy policies for increased industrial energy efficiency: Evaluation of a local energy programme for manufacturing SMEs. Energy Policy 35(11): 5774–5783.

Thollander, P., Backlund, S., Trianni, A., Cagno, E., 2013: Beyond barriers – A case study on driving forces for improved energy efficiency in the foundry industries in Finland, France, Germany, Italy, Poland, Spain, and Sweden. Applied Energy 111: 636–643.

Tikkanen, L., Ovaskainen, H., Palander, T., Vesa, L., 2008: TimberLink as a tool for measuring the fuel consumption of a harvester. In: Suadicani, K., Talbot, B. (Eds), The Nordic-Baltic Conference on Forest Operations, 23–25 September, Copenhagen, Denmark. Forest & Landscape Working Papers 30: 70–71.

Trianni, A., Cagno, E., 2012: Dealing with barriers to energy efficiency and SMEs: Some empirical evidences. Energy 37(1): 494–504.

Trianni, A., Cagno, E., Thollander, P., Backlund, S., 2013a: Barriers to industrial energy efficiency in foundries: a European comparison. Journal of Cleaner Production 40: 161–176.

Trianni, A., Cagno, E., Worrell, E., Pugliese, G., 2013b: Empirical investigation of energy efficiency barriers in Italian manufacturing SMEs. Energy 49(1): 444–458.

Trianni, A., Gagno, E., Farné, S., 2016: Barriers, drivers and decision-making process for industrial energy efficiency: A broad study among manufacturing small and medium-sized enterprises. Applied Energy 162: 1537–1551.

United Nations, 2015: Paris Agreement. Available at: http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

Väkevä, J., Pennanen, O., Örn, J., 2004: Puutavara-autojen polttoaineen kulutus (Fuel consumption of timber trucks). Metsätehon raportti 166.

Zhang, S., 2016: Energy efficiency and firm performance – Evidence from Swedish industry. Academic Dissertation. Swedish University of Agricultural Sciences, Acta Universitatis agriculturae Sueciae 2016: 49.

Authors' addresses:

Hanna Haavikko *
e-mail: hanna.haavikko@gmail.com
Kalle Kärhä, PhD
e-mail: kalle.karha@storaenso.com
Miikka Hourula
e-mail: miikka.hourula@storaenso.com
Stora Enso Wood Supply Finland
P.O. Box 309
00101 Helsinki
FINLAND

Prof. Teijo Palander, PhD
e-mail: teijo.s.palander@uef.fi
University of Eastern Finland
Faculty of Science and Forestry
P.O. Box 111
80101 Joensuu
FINLAND

* Corresponding author

Received: April 20, 2018
Accepted: November 3, 2018