Forests **2013**, *4*, 945-967; doi:10.3390/f4040945

OPEN ACCESS

forests

ISSN 1999-4907

www.mdpi.com/journal/forests

Article

Nordic Forest Energy Solutions in the Republic of Karelia

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Received: 27 June 2013; in revised form: 21 September 2013 / Accepted: 8 October 2013 / Published: 13 November 2013

Abstract: The situation in Karelia, a region in Northwest Russia, is analyzed in the context of forest energy. The annual potential energy available from wood harvesting is about 7 tera watt hours (TWh) (3.6 million m^3), which is equal to the total need of Karelia in energy for municipal heating. We point out that the contribution to the municipal economy, the moderate heating cost, the enhanced energy security in the cold Russian climate, the environmental friendliness, the better access to the forests and the utilization of the proven Nordic forest energy solutions (NFES) might have important consequences for strategy-making processes in forest energy development. For this purpose, connecting Analytic Hierarchy Process (AHP) with SWOT (internal strengths (S) or weaknesses (W) and external opportunities (O) or threats (T)) analysis is proposed to identify local operational strategies and assign priorities. Major threats include lack of government support, an insufficient road network, the dominance of extensive forest management, gasification and financial indiscipline. Analysis indicates that NFES are viewed positively for the Russian conditions. The forest biomass market has virtually unlimited opportunities for growth. Together, with the transition to intensive forest management, favorable policy in terms of forestry development programs can support bioenergy development. The advantageous location of existing power plants next to forests, increasing fossil fuel prices, the improvement of the road network and the availability of new technology are seen as potential opportunities for NFES. However, the results also indicate that there is substantial uncertainty and skepticism concerning how such markets benefit forest leaseholders who would like to adopt forest energy. The lack of bioenergy technology development, high transportation cost, low awareness of NFES, high demands for roads, the requirement for skilled specialists and wood fuel quality are the main weaknesses regarding the transfer of NFES to Karelia.

Keywords: analytic hierarchy process; wood chips; forest energy; forest sector; Russia; SWOT; energy wood harvesting

1. Introduction

Woody biomass is considered one of the main sources for bioenergy globally [1]. Biomass-based energy accounted for roughly 10% of world total primary energy supply in 2009. Most of this is consumed in developing countries for cooking and heating, using very inefficient conversion technologies and with significant impact on deforestation. The modern bioenergy supply is relatively small, but is growing steadily [2]. In 27 member countries of the United Nations Economic Commission for Europe (UNECE), wood energy accounted for 3.4% of the total primary energy supply and 38.9% of the renewable energy supply in 2011 [3], confirming its role as the leading source of renewable energy. Russian forests produce over 1 billion m^3 of woody biomass annually [4]. However, the use of wood in energy production does not correspond to the resource potential. Consumption of wood biofuels was in 2009 about 6.4 million tons of oil equivalent (Mtoe), which corresponds to 1% of the total energy supply or 30% of the renewable energy supply for the Russian Federation [2].

The total forest area of the Republic of Karelia, a region in Northwest Russia, is 15 million ha, with a growing stock of about 1 billion m^3. Forest land covers approximately 53% of Karelia [5]. Based on the Karelia region's total actual harvest of 6 million m^3, the potential for wood energy production from wood harvesting operations would be equal to 2.3 million m^3 (4.7 TWh). Mechanical wood processing provides altogether 1 million m^3 by-products, which represents approximately 30% of Karelia's total potential energy wood resources [6]. The total need in Karelia for energy sources in municipal heating is about 3.4 million m^3 of energy wood. However, only 10% of this amount is used by municipal heating plants at the moment [7]. In reality, most of the energy wood is left in the forests; only non-industrial round wood is used by the local population as firewood.

At the moment, despite the high biomass potential for energy purposes in Karelia, almost all logging residues and a significant amount of low quality round wood are left in the forest [8]. This creates favorable pre-conditions for forest fires, which destroy up to nine thousand ha (0.4 million m^3) of the Karelian forests annually [9].

The availability of relatively cheap natural gas and other fossil fuels is a key challenge that prevents the development of forest energy [10]. Most existing heating plants in the rural area of Karelia, however, have no access to a gas tube. Typically used fuels are light or heavy oil and coal. Fossil fuel boilers could be converted to wood chips, as has been done already in Finland [11] and other countries, such as Latvia. Heating plants are often located next to forests with quite reasonable transportation distances from harvesting sites to villages. Transportation cost represents a significant part of woody biomass fuel cost [12], because the state of forest roads is poor and the average density of forest roads in Karelia is really low, only 20% of those in the Nordic countries (in terms of km of road per squared km of surface).

Lack of domestic bioenergy technology should be taken into account when analyzing the prospects of forest energy in Karelia. The availability of modern machinery on the global market can significantly reduce the above challenge. However, on the other hand, this might lead to another challenge, to high demand for skilled specialists for export technology [12,13]. It is also important to note that low awareness of forest energy among all segments of society is common in forest regions in Russia, such as Karelia. Even in Finland, where the share of energy from forest biomass is as high as 20%, it is not commonly recognized [14].

Karelian forests have a great need for thinning. Extensive forest management focusing on final harvesting practices still dominates, but implementation of more intensive maintenance is often discussed [15]. One of the most common concerns over the transition to intensive forestry in Karelia is the lack of a market for low quality wood in the wood processing industry. The implementation of intensive forest management should enhance the amount of forest biomass, in particular, from young and middle-aged forests, which could be used for energy purpose [16]. The next concern is forest ownership. There is no private forest ownership in Russia, and forestry is based on forest leasing [17]. Leasing of forests (instead of forest ownership) does not support long-term forestry-related business activities [18]. Forest regeneration, the tending of young forests and thinning are vested by leaseholders who often neglect or poorly understand those activities [19].

The development of forest energy in Karelia is constrained by a number of legal, scientific, technical, economic and social barriers. In spite of the high risks and negative factors, the Karelian forest business could attract investments in bioenergy development. Investments in the forest sector have grown 20 times since 2001 [20]. Versatile use of forest biomass may become one of the most useful and sustainable sectors in the economy of the country [21]. Firstly, this is reflected in the support of the municipal economy, contributing to employment generation in rural areas [22–24]. Secondly, rural areas are dependent on imported energy, and electricity and heat tariffs are constantly increasing, meaning that the implementation of forest energy may improve energy security and minimize costs [25,26]. Moreover, it is worth noting that the use of woody biomass for energy purposes contributes to the mitigation of climate change by reducing the emissions of greenhouse gases into the atmosphere [27].

Despite the identified barriers, there are perspectives for the development of forest energy in Karelia. The experience of the Nordic countries, in particular Finland and Sweden, could be used for supporting the implementation of the high bioenergy potential of the neighboring regions of Russia. Lately, some pilot projects have been realized, both with public and private sector participation. However, compared to many industrialized countries, the scale and growth rates of renewable energy in Russia are still very low. A systematic and analytical approach could help to make those solutions already proven in the Nordic countries and, to some extent, piloted in Russia/Karelia possible. Such an approach should utilize different decision support applications and methods. In order to obtain a systematic approach and support for decision making, SWOT (internal strengths (S) or weaknesses (W) and external opportunities (O) or threats (T)) analysis was selected to be used for analyzing the environment influencing the transfer of the Nordic forest energy solutions (NFES) considered to

Karelia. NFES refer to different kinds of practical and proven solutions implemented in the Nordic countries, in particular, in Finland and Sweden, in the forest energy value chain. These solutions are related to technology, business, policy and knowledge base [28,29]. Biomass is a major source of renewable energy in the Nordic countries. The domination of biomass energy sources is not only the result of available natural resources, but can also be explained by policy measures, advanced technology and business models. In Finland and Sweden, the development of district heating is less dependent on regulation and more directly related to its competitiveness on the heating market. The use of woody biomass in energy is increasing. Biomass already dominates in the Swedish district-heating production with about 35 TWh in 2009 [30]. Large shares of the heat are produced in co-generation plants. In Finland, 75% of all district heating comes from co-generation. This is considered to be one of the most important success factors of district heating, as the high overall efficiency leads to the low cost of heat generation [30].

SWOT analysis was chosen because of the complexity of the problem, the strong influence of subjective views and the lack of reliable experimental or regulatory instruments. SWOT analysis was developed in the 1960s by Leraned *et al*. [31]. The SWOT approach is based on the aggregation of internal strengths (S) or weaknesses (W) and external opportunities (O) or threats (T) for adopting strategies. The SWOT matrix as a tool for analyzing situations was introduced in the 1980s by Weihrich [32]. SWOT has been demonstrated in many references of strategic planning in many fields, including also forestry and bioenergy applications [33–39]. The usual approach for solving SWOT problems is to use prioritization methods. In particular, the Analytic Hierarchy Process (AHP) by Saaty [40] has been used [37,41,42]. The method, which is called A'WOT (AHP SWOT) [43,44], is in fact obtained by connecting the AHP with SWOT analysis. In this paper, we analyze the development of forest energy in Russia/Karelia, consider the best practices from Nordic countries using the A'WOT approach, and formulate possible alternatives for transferring NFES to Karelia.

2. Material and Methods

In order to conduct the SWOT analysis, various materials relevant to NFES and applicable in Karelia were collected from various sources, for example, forest statistics, academic journals, professional magazines, conference proceedings, forest road manuals, governmental programs and meetings with experts. The information was summarized, and the key issues, already highlighted in the Introduction, are listed in Table 1 for better coverage of the problem and future analytical analysis. Extracted strategies from the SWOT matrix consist of the above four categories of factor combinations.

Despite its wide applications, the SWOT method has also a number of limitations [45,46]. The most important limitations are that: (a) usually only qualitative examination of environmental factors is considered; (b) it does not consider any priority for various factors and strategies; (c) if the number of factors increase, the number of adopted strategies will be increased exponentially (for example, if the number of each set of SWOT factors is equal to five, the resulting number of the combined strategies will be around one hundred, which would make selection of the appropriate strategy very difficult); (d) it does not consider the vagueness of factors. In order to avoid the above disadvantages, an A'WOT analysis was applied to identify critical issues that enable or hinder the implementation of the NFES transfer to Karelia. We carried out the analysis by first interviewing representatives of two stakeholder groups in the Republic of Karelia in late 2012 to early 2013. They represented logging industry (two companies) and R&D organizations (a state university and two research institutes). Karelia was chosen because a few Karelian logging companies have had experience with NFES for years. The total number of respondents was eleven. The interviews were undertaken during visits to the respondents.

Table 1. Selected factors for the SWOT (internal strengths (S) or weaknesses (W) and external opportunities (O) or threats (T)) analysis of the Nordic forest energy solutions (NFES) transfer to Karelia.

Strengths	**Weaknesses**
Proven solutions	Lack of development in domestic bioenergy technology
Contribution to municipal economy	High demands for skilled specialists
Enhanced energy security	Site productivity
Environmental friendliness	Low awareness of Nordic solutions
Fire control	High demands for density and quality of forest roads
Improvement young forest thinning	High quality demands for wood fuel
Moderate heating cost	High transportation cost
Opportunities	**Threats**
Unlimited source and market potentials	High investment cost
Increasing fossil fuel prices	Lack of government support
Improvement of forest road network	Dominance of extensive forest management
Authority programs for forest sector development	Gasification
Advantageous location the existing boilers	Financial indiscipline
Transition to intensive forest management	Insufficient forest road network
Availability of new technology	

Based on the methods outlined in previous A'WOT analyses [37,41,47], we followed three main steps: SWOT, AHP and A'WOT procedures.

In the first step, SWOT factors related to the transfer of NFES to Karelia were identified through a literature review and consultation with a few key stakeholders. Identification of the most important factors and parameters of the NFES transfer involved the following activities:

- Investigation of the NFES environment in Karelia. This step enabled detection of major trends and challenges that could affect the future of the NFES in Russia. Woody biomass resources and the technological, economic, environmental, political and socio-demographic indicators should be analyzed. Indicators of regional disparities and benchmarks are particularly useful in revealing O and T. This step should not be exhaustive, since the aim is to obtain an overall picture and to illustrate the key issues.
- External parameters analysis. This step consisted of listing the parameters of the environment that are not under direct control of a decision-maker, but which are assumed to strongly influence development.
- Internal factors analysis. This step involved an inventory of the factors that are at least partly under direct control of a decision-maker and that may either promote or hinder development.

- Mapping of external parameters and internal factors. Parameters are usually illustrated in a quadrangle (Table 1): internal feasibility regarding S and W and external environment regarding O and T.

In the second step, a standard AHP was applied. Relevant factors of the external and internal environment were identified and included in the analysis. When standard AHP is applied, it is recommended that the number of factors within a SWOT group should not exceed ten (e.g., Saaty recommended seven [40]), because the number of pairwise comparisons needed in the analysis increases rapidly. We developed a questionnaire based on the most important factors and held meetings with individual organizations, representing the stakeholder groups, to conduct the pairwise factor comparisons. A series of meetings was held with industrial and R&D organizations. In each meeting, factors were first explained to the organization, and participants were asked to reach a group consensus in assigning relative weights of factors for each pairwise comparison within a given SWOT category. In each pairwise comparison, the more important factor was assigned a weight based on its relative importance. A score of one indicated that the two factors were weighted equally. Information delivered from a pairwise comparison is represented in a comparison matrix, ***A***:

$$A = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \cdots & 1 \end{bmatrix} \quad (1)$$

where *a* is entries and *n* is a number of factors.

A factor priority score was then calculated for each comparison using the eigenvector/eigenvalue method, and means were calculated for each SWOT group (see [37] for details). The priority vector $\boldsymbol{W} = (w_1, \ldots, w_n)$ is obtained by solving the equation $\boldsymbol{AW} = \lambda\text{max}\boldsymbol{W}$, where λmax is the largest eigenvalue of the matrix ***A***.

Regarding the consistency, the matrix, ***A***, is acceptably consistent if:

$$CR = CI/R < 0.1 \quad (2)$$

where *CR* is a consistency ratio, $CI = (\lambda\text{max} - n)/(1 - n)$ is the consistency index and *R* is the average random consistency index.

If $CR > 0.1$, serious inconsistency exists, and AHP may not yield meaningful results. In this case, the experts should reconsider their judgments.

The priority vectors, ***W***, and consistency ratios *CR* of the SWOT group comparison matrices, ***A***, were calculated with MPRIORITY 1.0 [48] decision support software for all factors in the SWOT groups, and the results are tabulated in Table 1. The choice of this software among many similar software applications, e.g., the Hierarchical Preference (HIPRE) software family by Hämäläinen and Kettunen [49], Logical Decisions [50], was due to its Russian interface, which was more convenient when dealing with the experts in Russia.

In the next step, the pairwise comparisons were made between the four SWOT groups. The factor with the highest priority value under each SWOT group was taken forward for future comparison. These four factors were then compared and their relative priorities calculated. These were the scaling factors of the four SWOT groups, and they were used to calculate the overall priorities of the independent factors within them. This was achieved by multiplying the factors' local priorities by the value of the corresponding scaling factor of the SWOT group. The overall priority scores of all factors across the SWOT groups sum to one, and each score indicates the relative importance of each factor in the decision.

The different elicitations were aggregated using basic statistics (mean, median, standard deviation). Finally, the Perth-formula, $(s + 4m + l)/6$, was used, where s is the smallest value, m the median and l the largest value of the observations. In this way, the bias of the extreme elicitations for a and c in the calculations is mitigated [51].

In the final step, the results of the hybrid A'WOT procedure were utilized in structuring the problem, for the strategy of the NFES transfer formulation and evaluation process. The contribution to the strategic planning process came in the form of numerical values for the factors. New goals may be set, strategies defined and such implementations planned, taking into close consideration the foremost factors. Taking into account the identified O and T, the main group of interdependent "O-S/W" and "T-S/W" were selected. This step allows the drawing of strategic conclusions from this analysis, merely for structuring the problems and challenges and for finding solutions within the existing and prospective resources. It is at this stage of the A'WOT analysis that the strategic objectives of the NFES transfer are defined. The formulation of the main strategic directions is based on their importance. The strategy is formulated on the basis of the matrix of T and O and mutual influences. Strategic O and T that require the concentration of all the necessary resources for their implementation and related T are the parts with the highest priority. They must be under constant supervision. The O, which releases required resources, and T, which demands control, are given medium priority. The other possible O and T have the lowest priority.

3. Results and Discussion

3.1. SWOT Results

Results of the SWOT analysis (the list of key factors) are shown in Table 2. Based on internal audit and the survey of experts, S, W, O and T of the NFES transfer to Karelia were identified and described as follows.

Table 2. Results of the Analytic Hierarchy Process (AHP) SWOT (A'WOT) analysis of the NFES transfer to Karelia (*CR* is consistency index per SWOT group; *w* is weight obtained with the APH procedure per SWOT factor).

Strengths (*CR* = 0.060)	***w***	**Weaknesses (*CR* = 0.069)**	***w***
Contribution to municipal economy	0.32	Lack of development in domestic bioenergy technology	0.33
Proven solutions	0.16	High transportation cost	0.17
Moderate heating cost	0.16	High demands for skilled specialists	0.14
Improvement young forest thinning	0.11	Low awareness of Nordic solutions	0.13
Enhanced energy security	0.11	High demands for density and quality of forest roads	0.10
Environmental friendliness	0.08	High quality demands for wood fuel	0.08
Fire control	0.07	Site productivity	0.05

Table 2. *Cont.*

Opportunities (*CR* = 0.056)	*w*	**Threats** (*CR* = 0.059)	*w*
Unlimited source and market potentials	0.28	Lack of government support	0.32
Transition to intensive forest management	0.26	Insufficient forest road network	0.17
Authority programs for forest sector development	0.13	Gasification	0.17
Increasing fossil fuel prices	0.11	Financial indiscipline	0.13
Advantageous location the existing boilers	0.09	Dominance of extensive forest management	0.12
Improvement of forest road network	0.08	High investment cost	0.09
Availability of new technology	0.05		

3.1.1. Strengths

- *Contribution to municipal economy*. Firstly, forest energy positively effects employment by creating new jobs. According to experts', forecasting bioenergy production in Russia may provide new working places and better living conditions for as many as 30 million rural habitants [52]. Secondly, almost all the capital investment stays within the municipality; cash flows circulate within the municipality. For example, a small settlement in Finland saves about 2 million euros within the local economy annually and increases annual employment, equivalent to 7–10 man years, due to forest energy production [53,54].
- *Proven Nordic solutions*. Nordic countries, such as Finland and Sweden, have a long and successful experience of using energy biomass. This has led to increasing share of wood energy in total primary energy supply to about 22% and 20% in 2011 accordingly [3]. Nordic countries are at the forefront in the use of technologies for the extraction and utilization of woody biomass. Some Russian regions have good experience from the implementation of NFES [55].
- *Local energy source brings safety and independence* in case of a possible energy crisis. The basic power plants in Russia are thermal power plants, covering 66% of the total value of the energy produced. Power plants use coal, natural gas and fuel oil, and therefore, the price of energy is influenced by long transport delivery and fossil fuel prices. In turn, wood-based energy is less exposed to such dependence, and energy supply based on local wood-based sources *enhances energy security* [56–60].
- *Environmental friendliness*. Global warming and pollution of the atmosphere are extremely topical at the moment. Combustion of wood does not result in a net increase in carbon dioxide emissions. On the contrary, the combustion of any fossil fuel increases the emission of greenhouse gases. CO_2 emission in heat and electricity production using heavy fuel oil is 350 kg/MW, and in the case of natural gas, 270 kg/MW. In contrast CO_2 emission in biomass-based energy production is less than 58 kg/MW. In addition, the use of biomass for energy production purposes saves 5840 and 4240 kg of CO_2 emissions annually in comparison to heavy fuel oil and natural gas, accordingly [61,62]. For example, one small settlement in Finland saves/replaces approximately 1.9 million liters of oil annually and reduces carbon dioxide emissions by about five million kg annually, due to forest energy production [55].

- As a result of wood harvesting process, logging residues are left in the forest. The risk for forest fire increases due to abandoned logging residues, especially during the first two years of material decay [63]. That is why the utilization forest biomass contributes to *fire safety*.
- *Young forest improvement*. Young forests (the first and second age classes) dominate in the Republic of Karelia, covering about 37% of the total forest area. According to the Forest Plan in Karelia, pre-commercial thinning in young forests should be implemented annually on 14,000 ha, mostly by leaseholders [64]. In order to stimulate pre-commercial thinning, harvesting operations in young forests should be less expensive and provide merchantable energy wood. Forest energy can contribute to the formation of local markets for woody biomass from pre-commercial thinning and provides positive effects on the local forestry and landscape. In addition, ash and nutrients can be returned back to the forest. The best practice from NFES shows that up to 70% of resources may come from pre-commercial thinning in a municipal heating system [55].
- *Moderate heating prices*. Forest energy may provide cheaper heat for consumers compared to fossil fuel, in particular in the case of light fuel oil. In Nordic countries, consumer prices of heating for wood-based energy are significantly lower than for fossil fuel-based energy. For instance, energy prices (with zero value added tax, VAT 0%) in heat production in December, 2012, in Finland were for hard coal, 29 €/MWh, for natural gas, 46 €/MWh, and for forest chips, 19 €/MWh [65]. The experience of a Russian company in Siberia, using Finnish and Austrian boilers, shows that the production cost of heat energy based on wood chips can be two times lower in comparison to natural gas [52]. As a result, the heating bills of the local people are almost reduced by half, as the selling price of heat (with VAT) decreased from 25 €/MWh to 14 €/MWh in 2011 [66].

3.1.2. Weaknesses

- *Lack of development in domestic bioenergy technology*. There is no serial production of equipment for forest energy in Russia. A few pilot projects by Russian research institutes were unrealized, because there are no responsible sides for its industrial implementation [67,68]. As a result, Russian engineering service and training staff is poorly prepared to participate in the development of forest energy [69].
- *High demands for skilled specialists*. Forest energy development requires skilled personnel in design, implementation and maintenance [53,70]. For example, the operator qualification has a significant impact on the machine productivity for the extraction of woody biomass for energy purposes. Ultimately, this impacts on the quality and cost of wood fuel [13]. According to the Ministry of Energy [53], about 10–12 thousand specialists should be trained for renewable energy development until 2010, but only 300–400 specialists graduate annually. It is also necessary to take into account the poor quality of training. The number of academic staff is at least 10–15 times less than required. Thus, currently, both the quantity and quality of the specialists for bioenergy field in Russia do not satisfy the needs [53].
- *Low awareness of Nordic solutions*. The low awareness of the best solutions is a reason for the slow progress in the forest energy and may lead to higher investment costs, financing problems

(problems regarding the investor/user dilemma), increasing competition from fossil fuels, lack of information about access to state-of-the art technology, *etc*. [70].

- *Site productivity*. Increased removal of biomass from forest stands based on whole-tree harvesting has raised concerns of the operations on the sustainability of site productivity. Recent review of nearly 90 studies show that the risk of negative impacts on site productivity, often clear-cutting with whole-tree harvesting, might be high enough to justify the need for mitigation measures. Following thinning with whole-tree harvesting at the end of the rotation, the probability of the occurrence of negative effects and the risk levels were lower in comparison to clear-cutting with only final harvest at the end. Therefore, mitigation measures for thinning may not be needed [71].
- *High demand for the density and quality of forest roads*. A set of chipper and chip truck is the main system for wood chip production and delivery. Road conditions in Russia significantly complicate the delivery systems. Heavy chip trucks have quite low passing ability and mobility within the existing road conditions of Russia. These factors significantly complicate forest chip transportation and increase delivery time, influencing the productivity and production costs negatively [12,72].
- *High quality demand for wood fuel*. The most important quality parameters for wood fuel are moisture and ash contents. Wood chip is the most common type of wood fuel. Fresh wood chips have approximately a 50% moisture content [73]. Excessive moisture effects the heating value, where high or uneven moisture content complicates the combustion process. The ash content of stem wood is lower than logging residues. Contamination of logging residues by dirt, sand and stones should be considered for lowering ash content and problems in the fuel supply and boilers in the power plant. In addition, low wood fuel quality reduces its price. However, harvesting operations in Russia, in particular with traditional full tree systems, should be improved to get the maximum dry and clean biomass [12,74,75].
- *High transportation cost*. Woody biomass for energy purposes (logging residues, small-sized trees) is a raw material with low bulk density. A full load of a truck compartment with a maximum allowable load of the delivered material should have a minimum bulk density of about 250–280 kg/m^3, while woody biomass fuel has about 120–150 kg/m^3 [76,77]. In order to increase bulk density, the material should be compacted before loading. High moisture content also vastly reduces the load volume of wood fuels. Low bulk density and moisture content significantly influence transportation cost and can bring additional costs and increase delivery time if not addressed properly, e.g., drying at the roadside [13,78].

3.1.3. Opportunities

- *Unlimited source and market potentials*. Two theoretical scenarios were analyzed to show the potential energy wood that could be available if certain forest management measures were implemented in Karelia. If the entire annual allowable cut were to be utilized, the annual potential energy wood available from roundwood harvesting could be as high as 7 TWh. The regional total potential could be nearly 11 TWh, if, in addition to the full utilization of the allowable cut, thinnings were also done according to their full technical potential [6]. In addition, wood damage during harvesting operations [74,75] and forests damaged by fires and wind storms can provide raw material for energy production.

- *Increasing fossil fuel prices*. According to the Federal Statistics Service of Russia, prices for fossil fuels have increased continuously. Since 2002, the price of coal has increased from 9.7 to 33.2 €/ton (+242%), oil from 48.9 to 259.6 €/ton (+431%) and natural gas from 5.9 to 2 8.8 €/1000 m^3 (+388%). At the same time, the price of firewood has just increased from 3.4 to 10.5 €/m^3 (+209%) [25]. These changes impact customer costs for heat and electricity in all Russian regions, including Karelia. In order to counter balance uncontrolled increases in energy prices, Karelian municipalities should pay more attention to creating local independent energy supply systems based on locally available woody biomass [59].
- *Improvement of forest road network* plays a key role in the success of a woody biomass supply. First of all, this is determined by the availability of forest resources and by the transportation network and costs. Optimal delivery time and distance to forest sources provide efficient and effective supply of woody biomass feedstock for energy production [59,60]. According to the "Forestry development in the Republic of Karelia" program, about 2,000 km of all seasonal forest roads should be constructed and reconstructed in 2013–2015. This would increase forest road density from current 2.3 up to 2.4 m/ha and would also improve the quality of roads [59].
- *Authority programs for forest sector development*. The regional strategy on energy production based on local energy resources in 2011–2020 is in the implementation phase in Karelia [7]. The primary aims of the strategy are to use local energy sources, to reduce the dependence of Karelia on imported fossil fuels, to reduce the cost for heat energy production and to control increasing heat energy tariffs, to create new work places and to reduce CO_2 emissions. According to the strategy, about 80 from 400 existing small and medium-sized heat plants in Karelia should be transferred onto local energy sources (wood chips and peat) [7].
- *Advantageous location of heating plants*. Most of the existing heating plants in Karelian municipal districts have sufficient potential and availability of woody biomass [7]. The plants are within an average transportation distance of about 50–70 km, which makes woody biomass energy costs competitive, at least in terms of light fuel oil [79,80].
- *Transition to intensive forest management*. Thinning is a key element of intensive forest management. Thinnings, both pre-commercial and commercial, should be applied regularly in forestry. This would mean that woody biomass for energy purposes is available in the form of small-sized trees, logging residues and low-quality wood during the whole period of the growth of the forest.
- *Availability of new technology*. A market for forest energy technology is developing rapidly. Nordic countries are global leaders, and solutions are also available for the Russian markets [81,82].

3.1.4. Threats

- *High investment cost*. Typical investment costs for bioenergy systems are higher in comparison to fossil fuels systems. In Finland, the investment costs for the oil-fired boilers are 133 €/kW_{heat} and 200 €/kW_{heat} for boilers using biofuel [83]. A set of mobile chippers with two chip trucks for forest chip supply costs about one million € without VAT [84]. Thus, high investment costs can make bioenergy production an unattractive business in Russia, due to high interest rates (>10%) on bank loans.

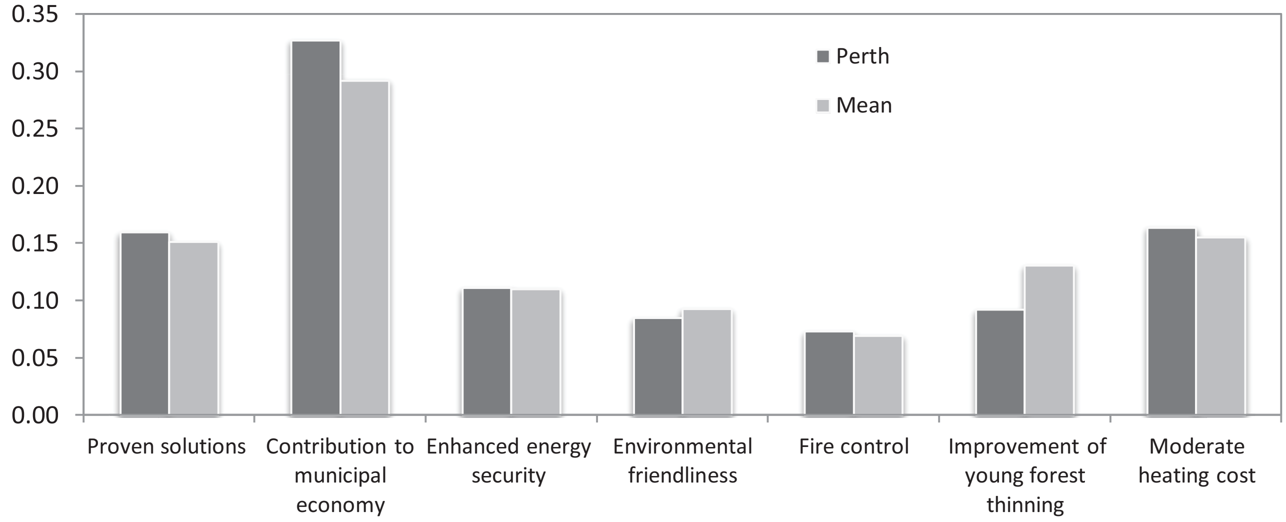
- *Lack of government support*. The development of wood-based energy in Russia is supported to some extent by the national energy policy. According to the Energy Strategy of Russia until 2030 [53], the use of local fuels in the regional power balance is insufficient at present. The Strategy prioritizes intensification of energy generation mostly from other renewable sources other than wood, mainly hydropower. The Russian government does not provide any subsidy for forest energy production. On the contrary, the state supports transport of fossil fuels to the forest regions of Russia. Ultimately, this makes forest energy development very challenging [10,85].
- *Dominance of extensive forest management*. In Russia, wood is mainly from final felling, and therefore, a significant amount of small-sized trees from thinning are not available for bioenergy. In Finland, about 40% of forest chips consumed in heating and power plants are from small-sized trees, mainly from pre-commercial and commercial thinnings [86].
- *Gasification*. The Russian energy sector is directed toward fossil fuel sources development, and gasification of rural settlements [87] plays an important role here. According to the plan for the gasification of Karelia [88], the existing gas pipeline system will be extended, and new power plants were designed to burn natural gas instead of biofuels in the south part of Karelia. This plan is in conflict with the previously scheduled development of bio-energy in Karelia [7].
- *Financial indiscipline* and a strong dependence on the financial situation in the wood processing industry. Wood biomass availability depends on wood harvesting activity. In turn, logging companies are dependent on the wood processing industry. The process of the transition to a market economy in Russia is still suffering from a severe payment crisis. Due to more recent economic and political stabilization, there is now normalization of public finances and a more or less favorable situation of Russia on the world commodity markets. However, in particular, the wood processing industry is still dependent on delays within payment system. This is evidenced by the last posts about the bankruptcy of a few of the largest sawmills and pulp and paper mills in Karelia and other north-western regions in Russia [89,90].
- *Insufficient forest road network*. After the collapse of the Soviet Union, the building of forest roads has significantly decreased [91]. According to the Forest Plan of Karelia [64], the total length of roads in Karelian forest is about 27,000 km, of which 7000 km (~26%) are public roads. In addition to low forest road density (about 2 m/ha), half of the roads are in need of major repairs. Ninety-six percent of public roads were built under an axial load of six tons [64], which prevents the use of heavy modern wood and chip trucks and increases wood fuel procurement costs.

3.2. AHP Results

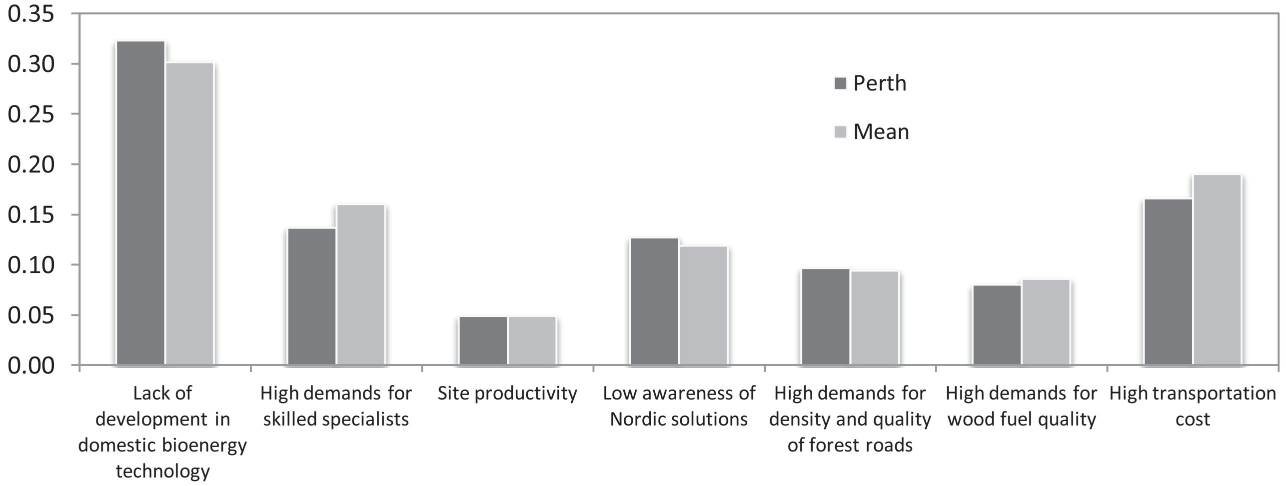
The overall results of the AHP procedure are shown in Table 2, including the priority vectors, ***W***, and consistency ratios, *CR*, for all factors in the SWOT groups. More detailed statistics for the results by stakeholder group, such as the Perth-formula estimations, are presented in Figure 1. According to the results of the AHP analysis, four factors with the highest priority were selected representing the

SWOT groups. Ss were represented by the factor "Contribution to municipal economy", Ws by "Lack of domestic bioenergy technology development", Os by "Unlimited sources and market potentials", and Ts by "Lack of government support". Priority vectors, $\boldsymbol{W}_{\text{swot}}$, and consistency ratio, CR_{swot}, for the SWOT groups are shown in Table 3. The development of scaling factors among the four SWOT categories shows the relative importance of the most dominant in each category. This means that Ts ($w_{\text{swot}} = 0.31$) are the most important group of factors for further policy development of NFES in Karelia, Os ($w_{\text{swot}} = 0.26$) are just as important as Ss ($w_{\text{swot}} = 0.27$) and Ws are the least important ($w_{\text{swot}} = 0.16$).

Figure 1. Descriptive statistics for weights (*w*) obtained with the APH procedure for (**a**) strengths; (**b**) weaknesses; (**c**) opportunities; (**d**) threats; and (**e**) the SWOT groups.

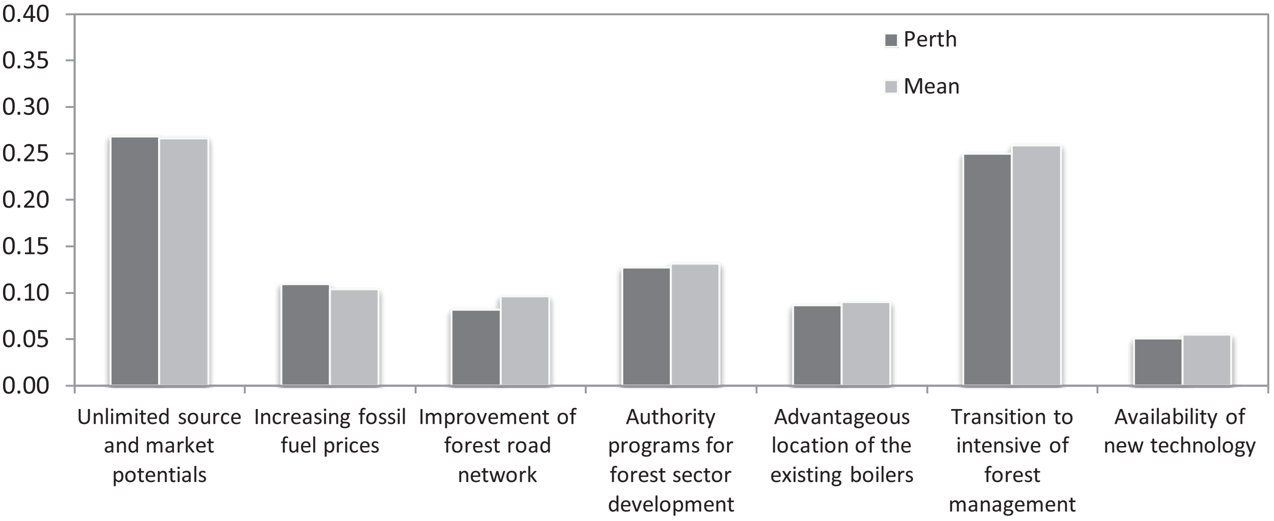


(**a**)

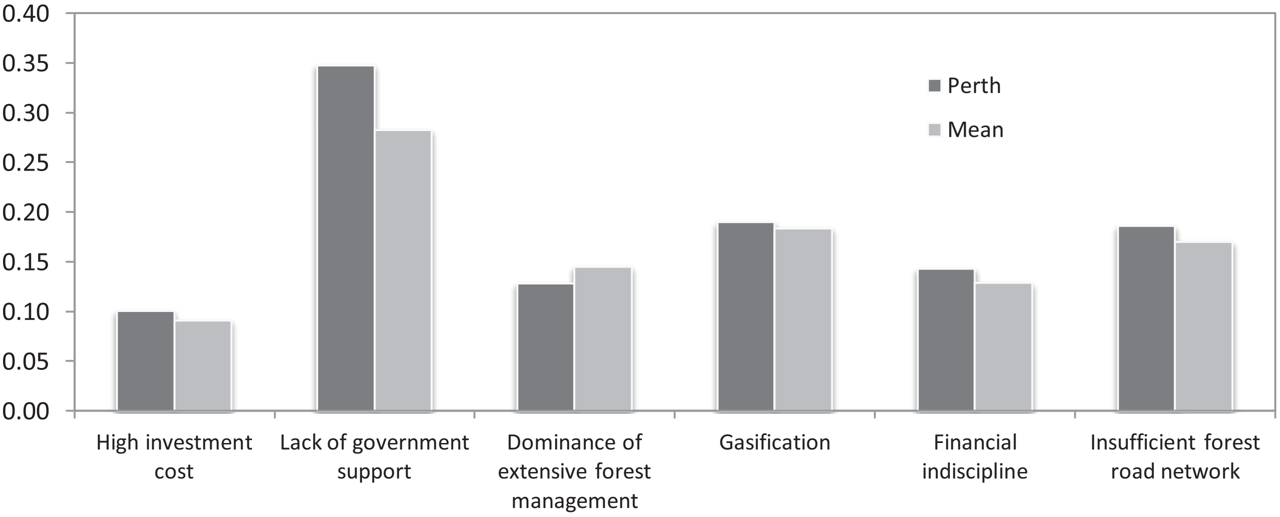


(**b**)

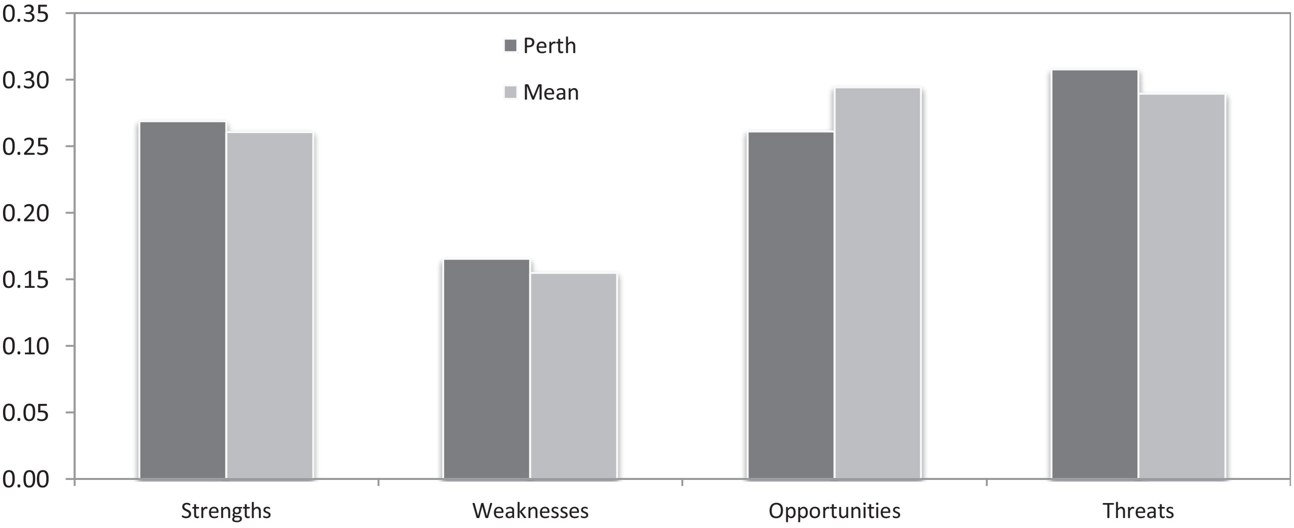
Figure 1. *Cont.*



(c)



(d)



(e)

Table 3. Priority vector W_{swot} and the factors with the highest priority SWOT groups (CR_{swot} = 0.065 is the consistency index; w_{swot} is the weight obtained with the APH procedure per SWOT group).

SWOT group	**Factor with the highest priority**	w_{swot}
Strengths	Contribution to municipal economy (w = 0.32, see Table 2)	0.27
Weaknesses	Lack of development in domestic bioenergy technology (w = 0.33)	0.16
Opportunities	Unlimited source and market potentials (w = 0.28)	0.26
Threats	Lack of government support (w = 0.32)	0.31

In order to establish strategic objectives by the "offensive" approach, both Ws and Ts should be minimized or avoided if transferring the NFES to Karelia. The results show that NFES-related policy should focus much more on Ts than Ws, because the priority factor for Ts (w_{swot} = 0.31) are almost twice that of Ws (w_{swot} = 0.16). Ss (w_{swot} = 0.27) are just as important as Os (w_{swot} = 0.26). This means that Ws should be looked at in order to convert them into Ss. Likewise, Ts should be converted into Os. Lastly, Ss and Os should be matched to optimize the potential of the NFES transfer to Russia.

3.3. A'WOT Results

Os and Ts identified in the A'WOT analysis were divided into three priority groups for further analysis. The matrix of Ts and the matrix of Os are presented in Tables 4 and 5.

Table 4. Analysis of the threats of competitive forces.

Probability of threats	**Impact of threats**		
	Destructive	**Heavy**	**Light**
High	Lack of government support	Low forest road density	Gasification
Average		Dominance of extensive forest management	
Low	Financial indiscipline		

Table 5. Analysis of market opportunities.

Probability of opportunities	**Impact of opportunities**		
	Strong	**Moderate**	**Low**
High	Unlimited source and market potentials		
Average	Transition to intensive forest management	Authority programs for forest sector development	Increasing fossil fuel prices
Low			

Lack of government support (w = 0.32) has been entered in the "High/Destructive" field of the T matrix (Table 4). The appearance of Ts in the sector *insufficient forest road network* (w = 0.17) can be reduced by increasing attention on forest legislation. *Gasification* (w = 0.17) was not regarded to be a big T, because logging companies are working mainly in areas outside the influence of the gas pipeline. The T of *dominance of extensive forest management* (w = 0.12), *financial indiscipline*

(w = 0.13) and *high investment cost* (w = 0.09) can be partially reduced by an alternative strategy and introduction of a range of alternative products for services less exposed to this T.

Unlimited source/market potentials (w = 0.28) and *transition to intensive forest management* (w = 0.26) have been entered in the best fields in the O matrix (Table 5). The probability of the appearance of the second is reduced by the opinion that it is not yet a practice and, therefore, requires more attention to be paid to the development of marketing and sufficient financing from the stakeholders. In turn, *increasing fossil fuel prices* (w = 0.11) has more impact for remote areas of the country than the Republic of Karelia. *Authority programs for forest sector development* (w = 0.13) mainly create distrust among people from the industry. Os are based on a growing market and on the position of being a technology leader, in other words, on the growth strategy. Regional government programs [59,88] can stimulate development of the forest sector and are essential for transferring NFES to Karelia. Use of the NFES, however, is feasible only in the presence or development of forest energy, also, at the federal level [4,92].

4. Conclusions

Based on the experiences of the Nordic countries [3,11,55,93–98], it can be assumed in neighboring Karelia that any increase in the use of energy wood as a local and regional energy source would be good for the local and regional economies. Furthermore, like Finland, the increased self-sufficiency in the regional energy supply is an important factor, due to the Northern Karelian extreme winter conditions. In these areas, any delays or shortages of energy supply for heating can have serious implications [6].

Previous Russia-related studies [21,26,53,67,68,79,80,85] pointed out that since the energy wood sector of Karelia is not well developed, its development would then allow a move to the latest proven technology for the supply and utilization of energy wood. Karelia would then provide new markets for technology and know-how. The use of district heating facilities is available in towns and in most other large residential areas; in addition, there are also combined heat and power (CHP) plants available. Therefore, the basic infrastructure already exists for large-scale utilization of energy wood. The conversion of boilers currently using oil and coal to biomass, like wood, would also reduce the regions net greenhouse gas emissions. However, the current policy of subsidizing prices for oil, coal and natural gas may change, which would make energy wood more competitive.

This study has developed this important topic further; thus, the results and conclusions could be used by those stakeholders who are planning to develop forest energy in Karelia. The main findings of this study provide a framework for estimating the risks and benefits of forest energy business in Karelia. It should be emphasized that we have estimated the most important Os and Ts, Ss and Ws based on the current forest energy conditions in the Republic of Karelia. The developed A’WOT model, however, could be applied for the planning of forest energy in other regions of Russia, too. An A’WOT analysis can be a useful tool for exploring the possibilities for new development programs in the forest energy in Russia. A systematic approach of self-analysis is used in A’WOT analysis to assess future possibilities. The planning of decision making should build on utilizing S, minimizing W, seizing O and counteracting T.

In many situations, it is not possible to differentiate factors clearly into Ss, Ws, Os or Ts. For example, having *unlimited sources and market potential* is an O (positive external effect), and at the same time, it may be a T (a negative effect, because it may lead the business to inaction and depression). As other examples, *lack of government support* may be both a T (a negative external effect) and a W (a negative internal effect, since it may produce many challenges for the company whenever this support is absent). Furthermore, it can be discussed whether *proven Nordic solutions* should be an S (internal effect) or an O (external effect). This strength can also be interpreted like an opportunity, as it actually is an external effect for Karelian conditions. *Low forest road density* in the current Russian context is rather more a T (external effect of state forest ownership, including forest road infrastructure), than a W. However the privatization of forest infrastructure can re-categorize this factor toward Ws.

In addition, some external effects may be overlooked in the interviews. Due to the methodology, *i.e.*, stakeholder consultation within Karelia, the possible influence of the European renewable energy directive (RED) and the Finnish national subsidy programs for supporting wood for energy purposes were not considered. They are probably unknown in Russia/Karelia and, therefore, lack in the SWOT analysis as a possible threat or opportunity.

A'WOT analysis should be flexible and updated regularly. This is true especially in Russia/Karelia, where decisions and actions are made under constant uncertainty and with a lack of profound information from the field [99]. Therefore, a system for processing information could help in strategic planning. Situations may change fast, and an updated analysis should be made accordingly. A'WOT is relatively easy to undertake and is fast and effective, because of its simplicity. Creative use of A'WOT can provide the basis for useful development plans in energy wood procurement organizations.

The results of this study clearly show that a lack of novel bioenergy technology together with the absence of skilled specialists is one of the key factors for the weak forest energy development of forest regions in Russia and the ineffective functioning of wood fuel supply chains. An insufficient forest road network is one of the main determinants of the availability and high cost of woody biomass for bioenergy purposes. It is necessary to improve forest energy technology and to test, tailor and use proven NFES, in particular from nearby Finland and Sweden. Forest chip production with NFES requires economically tailoring solutions to prevailing local conditions. This preliminary assessment of the benefits and risks is approximate for various reasons. Therefore, a cost-benefit analysis should be made to support decision making. The production of forest chips requires attention to planning, use of proven technology, seasonal conditions and construction schedules, load bearing characteristics of the soil, presence of rocks, swamps, category of roads, availability of woody biomass for bioenergy, scaling of the boiler, number of suppliers, use of thinning, costs associated with the payment of salaries and operational costs of machinery, and so on.

It is necessary to use profitability analysis appropriate to local cost conditions and interest rates and also to apply them in forest energy investments. Furthermore, annual maintenance costs need to be assessed. The feasibility of the heat plant location is assessed by calculating the optimal density of the woody biomass resource. This can be achieved by minimizing the cost of energy wood transportation costs by reducing the length of transportation and increasing wood energy content per truck. Heat plant network density is limited to the comparison of the logistic cost and to the woody biomass cost, which is also recommended by NFES. That is why the perspective of the high quality road infrastructure extending together with the advantageous location of settlements extremely reduces cost delivery [11].

This A'WOT analysis provides a broad overview of energy wood procurement in Karelia, in particular from the Nordic countries' perspective. The results of the analysis may be used in energy wood procurement organizations in Karelia as the first step in the identification of factors in their development process. Further studies and analysis are necessary. Russia is transforming and reorganizing herself from the old centrally-planned system to a state with more market-driven patterns. Thus, Os exist in an orientation towards Western models and foreign investment, which can bring wood business know-how into Karelia and help in the transformation process.

Acknowledgments

This work has been carried out under the project "Novel cross-border solutions for intensification of forestry and increasing energy wood use" funded by the Karelia ENPI CBC program (The European Neighbourhood and Partnership Instrument, cross-border cooperation).

Conflicts of Interest

The authors declare no conflict of interest.

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