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Analysis of wood fuel chain in Latvia

D. Blumberga, L. Lipsane, I. Laicane, J. Gusca and S. N. Kalnins

Institute of Energy Systems and Environment, Riga Technical University, Kronvalda bulvaris 1, LV-1010, Riga, Latvia; e-mail: dagnija.blumberga@rtu.lv

Abstract: The objective is to investigate solid biofuels logistic system's stages and to develop regional firewood supply network, which would include storage terminals by choice, exploring several possible scenarios and developing conclusions about supply optimization results.
Analysis of supply and demand markets of wood fuel in Latvia, focusing on region that includes Jelgava, Tukums, Dobele and Bauska districts were investigated in the research. In the defined researched region geographical location of boiler houses and storage terminals from perspectives of increasing of solid biofuel demand was observed. A method that allows calculating optimal production flow and expected costs for final customers (boiler houses) within different scenarios and delivery options was developed. In addition the model demonstrates differences between direct production flow of wood fuel and flow through storage terminals. Linear programming and mixed integer programming models implementation is carried out using Xpress *Solver* in combination with geographical data processing with *ArcGis 9.3*.

Keywords: energy wood, wood chips, logistics, terminals, optimisation.

Introduction

The use of energy wood for energy production is increasing in Latvia due to the decisions of the European Union to increase the ratio of renewable energy resources in the Member states. It is expected that the number of combined heat and power (CHP) plants will increase and that will cause additional fuel consumption and an optimization of fuel logistics and the supply chain in Latvia.

The connection among the energy wood supply, processing and use technologies is integrated into a model (Fig. 1). The model represents the wood supply module and end-users module.

The technologies of each module are described with quantitative technical and economic indicators. Existing and future technologies are included in the informative part of the model. The objective of the model is to choose a specific combination of technologies which result in the minimisation of overall costs of the energy system.

The bioenergy market is influenced by the wood fuel market as well as the traditional (fossil) energy market. The price growth of competing energy resources, such as natural gas, presents a long-term opportunity to broaden the scale of use of bioenergy resources. Moreover, policy development effects the development of the bioenergy market:

- objectives of energy policies (for ex. wider use of renewable energy sources, diversity of energy resources, etc.);

- objectives of agricultural policies (for ex., to improve production on-site in rural areas, overgrowth of arable land, etc.);
- objectives of environmental policies (landscapes, pollution prevention, climate policy, etc.);
- objectives of infrastructure policies (overgrow of roads).

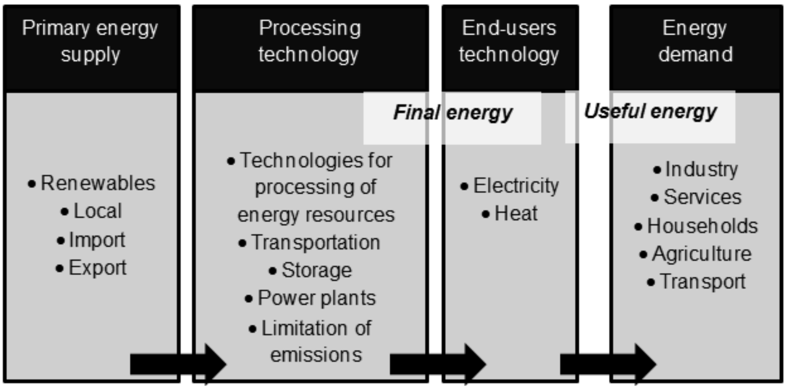

Fig. 1. Structure of the energy supply and consumption system model.

These objectives are reflected in regulations, for example, tax policy and subsidies which will affect production and the use of bioenergy in the future. These and other aspects should be taken into account when forecasting processes in the bioenergy market.

Bioenergy market in Latvia

Data on biomass use for heat and electricity production in Latvian regions and regional centres in 2008 is provided from the data base of the Latvian Environment, Geology and Meteorology Centre (Latvian Environment, Geology and Meteorology Centre, 2012). According to the data, the demand for energy wood in 2008 was as follows:

- wood log – 169,266 t per annum (hereinafter -/a);
- wood chips – 426,705 t a^{-1};
- other wood fuel – 154,734 t a^{-1}.

Fig. 2 shows the allocation of the fuel between the regions. For example, only wood pellets are used for energy generation in Bauska. However when the total fuel balance for energy production is analysed for Bauska, the fraction of wood pellets is very low – only 63 t a^{-1} in 2008 and the greatest part of energy is produced from natural gas. This tendency is typical for other regions in Latvia as well.

Use of wood for energy production has long-standing traditions in Latvia. In the last years, however, a lot heating systems developed in municipalities need a small amount of fuel and thus the fuel transportation distances are short.

The costs of energy fuel transportation constitute a considerable part of the total costs of the fuel system. It is economically feasible to produce the wood chips in the distance of 50 km from the energy production plant (Graudums & Lazdāns, 2006). The biggest proportion of wood chips fired in district heating systems is by-products that come from sawmills.

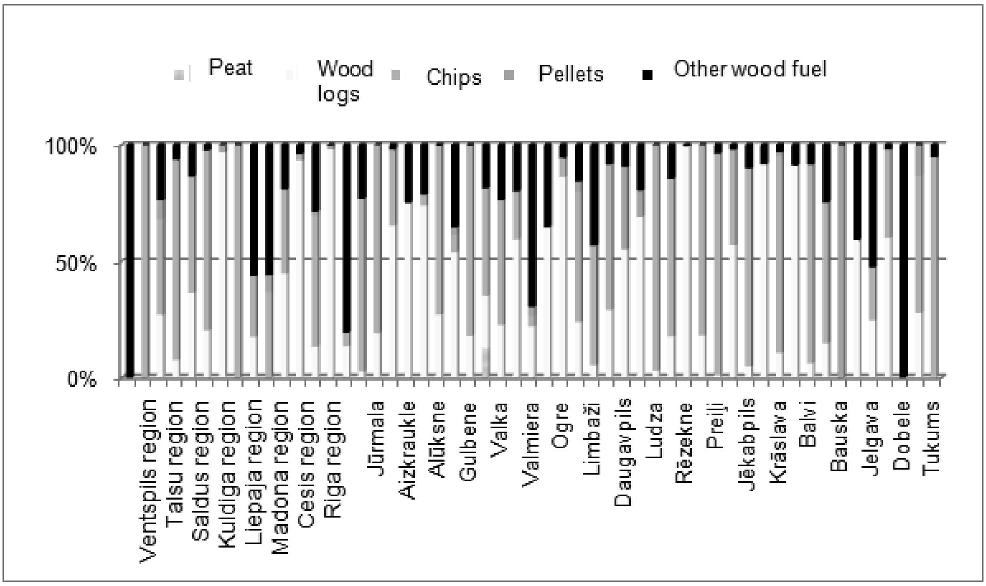

Fig. 2. Consumption of wood fuel in Latvian towns in 2008 (*Latvian Environment, Geology and Meteorology Centre, 2012)*.

A proportion of wood products (prongs, tops and others residues) are now used for energy generation in power plants. The national forest management enterprise 'Latvijas valsts meži' use wood logging residues for wood chip production since 2006: 170,000 bulk m^3 of wood chips were produced in 2007 and 208,000 bulk m^3 in 2008 (Latvijas valsts meži, 2008).

Logistics of energy wood

Normally logistics applies to the flow of raw materials, semi-finished products and finished products and the information related to this flow. The raw materials from forest management are normally spread over a spacious territory. Meanwhile wood fuel products are divided in several flows, incl. territorially widespread consumers of the products. Therefore, the optimisation of wooden materials must begin with the selection of appropriate felling areas.

The logistic chain of energy wood in general might be divided in four parts and subdivisions and includes different factors which are important to operate the entire system:

1. Technologies used in forests (consistency in the selection of the wood felling area, forest exploitation volume, technologies, treatment, type of energy wood, packing and residues, chipping site, loading, etc.);
2. Supply system or delivery to users (storage, transportation types, transportation distances, etc.);
3. End-users or consignee of production (costs, quality, quantity, delivery time);

4. Characteristics and activities of the end-users (type of heating technologies, storage, preparation of fuel, efficient use of fuel).

Each stage builds up a logistics system, which might be optimised from a cost-effectiveness point of view at each stage and level of the system.

The determining factor for operation efficiency of the energy wood chain is also the time which elapses between the moment the energy wood has been produced until its real use by the consumer (user). Production efficiency will decrease if a gateway process from an ordering of materials moment until its real use is long. The time spent for the implementation of the full energy wood supply chain (T) can be defined as follows:

$$T = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7 + t_8 + t_9 + t_{10} \quad (1)$$

t_1 – purchase procedure of wood felling area, h;
t_2 – time from purchase of wood felling area until its technological preparation, h;
t_3 – time for technological preparation of the wood felling area, h;
t_4 – time from technological preparation of wood felling area until fuel pre-production, h;
t_5 – fuel production time, h;
t_6 – time from wood fuel preparation moment until carrying moment, h;
t_7 – fuel transportation time, h;
t_8 – fuel storage time, h;
t_9 – fuel transportation time, h;
t_{10} – time from fuel delivery until fuel use, h.

Another important logistical aspect relates to the storage of wood residues from forests which directly effects the quality of wood chips. Payments for wood chips in Latvia are based on bulk volume and sometimes the cleanness of the fuel fraction is taken into account unlike the greater part of Western European countries where payments for wood chips are adjusted to the calorific value of the fuel. A joint standardisation process has begun in Europe on wood fuel standardisation: the quality of wood chips according to their final use is defined by standard special norms which include the definition of the permissible range of the size of chips, moisture content and other parameters. The usual annual demand /supply structure of energy wood in Latvia is given in Fig. 3.

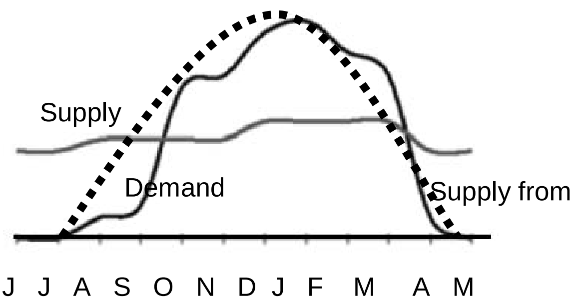

Fig. 3. Annual demand /supply curves of energy wood.

Latvia is on the way to the introduction of standards: the quality of wood chips depends on demand and wood chip producers normally conform to the requirements defined by specific consumers, for ex. requirements of the closest boiler houses. It is observed that the newer the boiler house, the worse the quality wood chips (in sense of size and moisture content) the boiler house requests. Up until now there are only a few boiler houses which are able to use herbal chips. The most suitable technology for Baltic conditions is to bring the non-marketable forest management residues outside of the forested area, place them along the roadside where they can be stored for 3–6 months to dry and then processed to chips.

Terminals for energy wood

Wood fuel terminals might ensure storage and secure delivery of fuel, especially during the winter time. As long as the boiler houses are located in nearby towns, the chipping and shredding processes might be problematic in respect to air and noise pollution. Thus such terminals can be considered as a logistical instrument to ensure a better location for chipping and shredding. Besides, the provision of flexible supplies in the winter period might stabilise changes in vehicle capacities and balance seasonal changes in supplies. A specific, spatial problem is the determination of locations of terminals within the supply chains.

Different methods are used by scientists to evaluate the wood fuel logistics chain. Swedish scientists have evaluated five theoretical wood fuel flows – from forests directly to a boiler house or from forests to a boiler house through a storage terminal (Junginger et al., 2005; Johansson et al., 2006). Calculation results based on linear programming tools show that direct delivery of wood fuel to boiler houses is the most efficient from the economic point of view, as far as additional expenses spent on improvement of fuel quality and secure delivery were not justified. It is forecasted that the introduction of fuel terminals into a fuel supply chain will increase the total costs of the wood fuel. Thus, the authors of the above mentioned research stressed the necessity to minimise the transport costs to reach maximum optimisation of the wood fuel production. To define the location of the storage terminals *Gronalt M*. and *Rauch. P* propose a simple approach based on equal cost graphs and again emphasize the role of total transportation costs and terminal operation costs in the development of an optimal supply chain (Gronalt & Rauch, 2007). A Dutch scientist *Koppejan J.* developed a decision making system for wood biomass and tried to find more appropriate locations and sizes of wood fuel terminals as well as efficient delivery routes within the region. This decision-making model incorporates a geographic information system (GIS) concept and linear programming tools (Koppejan, 2007). Danish scientists (Nordlarsen & Talbot, 2004) used similar optimisation methods by giving a wood fuel; potential indicators for the specific boiler houses. In addition, in Denmark the wood fuel potential was evaluated using marginal delivery graphs. Availability of wood residues in forests was evaluated using the combination of the GIS and the linear programming tools (Kanzian et al., 2009).

Logistics are the main obstacle in the delivery of cost-effective solutions of wood fuel supplies. The production of wood chips in small amounts is not cost-effective due to high transportation costs and might be used only if the transportation distance does not exceed 20 km. The connection between the transportation distance of the wood chips and the total costs associated with it is shown in Fig. 4.

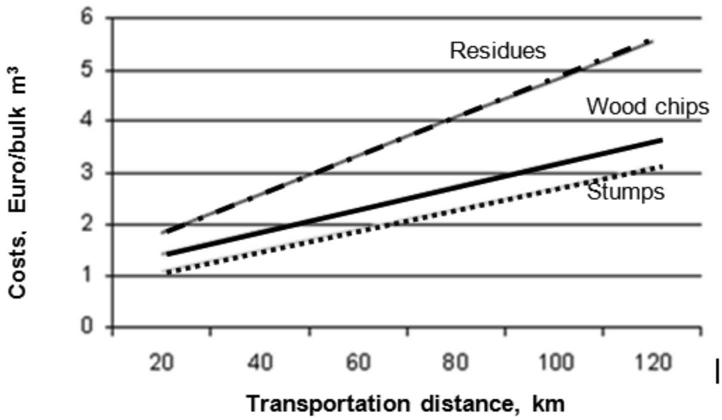

Fig. 4. Impact of transportation distance to fuel costs in Finland *(Antti, 2005)*.

There are three ways to deliver wood chips to consumers: chipping of wood residues in the wood felling area or at the roadside; chipping of wood in storage terminals or at the consumers' site; delivery of residues in bundles packed in forests.

Object of the Research

The objective of the research is to develop an energy wood regional supply chain that includes the use of storage terminals and to propose several scenarios.

The researched area is defined as four regions in the southern part of Latvia: Jelgava region, Bauska region, Dobele region and Tukuma region[1]. Further in the paper the defined areas are referred to as the researched region and data used in the report reflects the situation in 2008.

10 boiler houses (all boiler houses with installed heat capacity greater than 1.5 MW) and reconstructed or newly built and 6 wood chip boiler houses are selected from the researched region. Thus, it is initially assumed that the wood chip demand will increase 6 times, up to 969,540 bulk m^3 a^{-1}.

To reach the research objective, four demand scenarios and three supply scenarios are developed, used for 6 terminals and 16 boiler houses and analysed within the research. The scenarios developed are based on a combination of the GIS and linear programming methods.

The use of existing quality forest residues is recommended for larger boiler houses. In this case, the wood residues are chipped in the terminals, in forests or piled along a road. The optimisation of the wood fuel supply chain requests the introduction of storage terminals to satisfy growing demand and to ensure continuous supply throughout the year.

Methods and definition of demand scenarios

A methodology for optimisation of material flow and expected costs associated with wood fuel delivery at a single boiler house level is developed and used for the analysis of different scenarios within the research. The research includes a scenario-

[1] Latvia has a different territorial division now.

based analysis. A researched region defined, demand on fuel in the researched region and infrastructure needed to be determined. In addition, an assessment of wood fuel potential is conducted by using existing forest inventory data and other research done in Latvia.

Energy resources used in the researched region are various and include both fossil fuels (mainly natural gas) and biomass (Fig. 5).

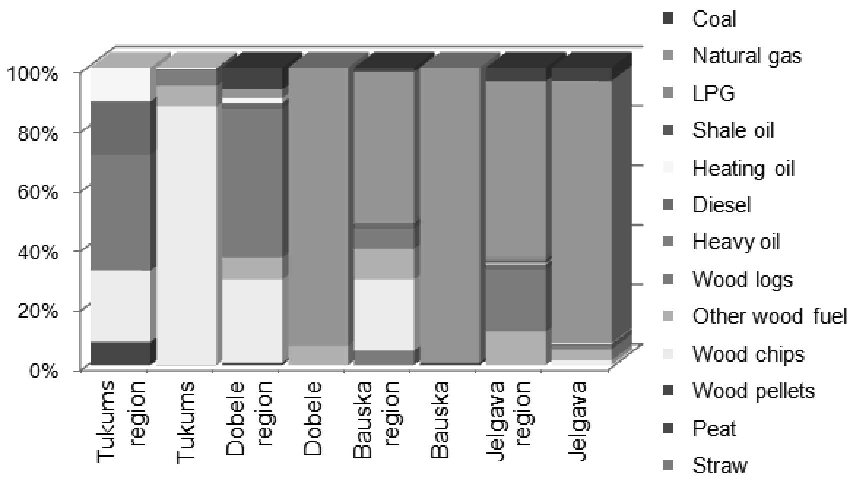

Fig. 5. Balance of the energy resources in the researched region (Central Statistical Bureau of Latvia, 2012).

Four demand scenarios are developed focusing on boiler houses with installed heat capacity greater than 1.5 MW and the demand of wood chips exceeds 4,000 bulk m³ a^{-1} (Table 1):

- Scenario I assumes the existing demand level – 163,001 bulk m^3 of wood chips – excludes the development of new boiler houses or the improvement of existing plants;
- Scenario II assumes improvement of the existing plants or the construction of new small and medium scale plants (1.5–5.0 MW for CHP plants or up to 15 MW for boiler houses) and thus an increase in fuel demand up to 50,000 bulk m^3. The number of boiler houses increases from 10 to 14 and the demand increases to 44%, up to 233,923 bulk m^3.
- Scenario III includes larger reconstruction works in existing plants that would increase the demand up to 969,548 m^3.
- Scenario IV analyses wood chips produced from forest exploitation processes. It is recommended to use wood chips in the larger boiler houses where demand exceeds 6,000 bulk m^3 a^{-1}. Due to the quality, wood chips from felling works constitute 20% of the total energy wood consumption.

As it was stated above, all boiler houses with installed capacity greater than 1.5 MW and consumption of wood chips are greater than 4,000 bulk m^3 a^{-1} are included into the research. Data provided in Table 1 does not affect consumption of wood fuel and are provided for detailed clarifications of the results. For example, the boiler house (k_4) uses wood fuel both for the implementation of the technological processes and the energy production processes, but the defined fuel consumption corresponds only to heat production.

Table 1. Demand of energy wood and capacity of heating installations in researched region

No.	Town	Fuel consumption, t a^{-1}		Capacity	Notes
		wood chips	other wood fuel	MW	
k_1	Tukums	1,228	-	5.9	-
k_2	Tukums	25,835	-	7.0	+ heavy fuel oil, heating oil
k_3	Tukums	3,092	-	1.6	+ wood logs
k_4	Tukums	780	585	3.8	+ fuel for technological processes
k_5	Kandava	1,150	-	3.5	
k_6	Bēne	1,160	-	2.5	+ wood logs
k_7	Auce	4,298	81	3.5	
k_8	Misa	2,985	-	1.5	+ natural gas, additional boiler - capacity 1.5 MW
k_9	Piebalga	-	1,300	4.2	-
k_{10}	Vecumnieki	2,957	189	2.0	-

Scenario II and Scenario III assume the reconstruction of existing boiler houses or the development of new CHP plants or boiler houses. The calculation is based on the definition of heat capacity needed for selected towns or the towns' heating development plans (incl. reconstruction of existing boiler houses).

- In Jelgava, the greater proportion of energy is produced from natural gas. It is assumed that a new CHP plant with the installed electricity capacity 25 MW_e is built and the calculation for biomass CHP (k_{15}) includes definition of heat capacity and fuel consumption per year. One shall assume that the electricity /heat ratio is $\alpha = 0.4$; total efficiency of the CHP is $\eta = 0.80$ and capacity use factor - JIK = 0.50, then:

$$QJ_U = \frac{EJ_U}{\alpha} = 62.5 \text{MW}_{th} \quad (2)$$

where

EJ_U - installed electricity capacity, MW_e;

QJ_U - installed heat capacity, MW_t;

$$h = \frac{JIK\,(\%)}{100} \times 8760 = 4{,}380 \quad (3)$$

where

h – number of hours per year when an energy production unit works with installed capacity;

$$E = EJ_U \times h = 109{,}500 \text{ MWh} \quad (4)$$

$$Q = QJ_U \times h = 273{,}750 \text{ MWh} \qquad (5)$$

where

E – electricity produced, MWh;

Q – heat produced, MWh;

$$Q_{kur} = \frac{E + Q}{\eta} = 479{,}063 \text{ MWh} \qquad (6)$$

where

Q_{kur} – fuel energy consumed, MWh.

Lower calorific value for wood chips (w = 40%) is $Q_z^d = 2{,}791$ MWh t^{-1}, thus the fuel consumption is:

$$B = \frac{Q_{kur}}{Q_z^d} = 171{,}646 \text{ t} = 613{,}020 \text{ bulk m}^3 \text{ a}^{-1} \qquad (7)$$

- Natural gas is mainly used in Iecava and it is discussed to build a new natural gas CHP plant there. Within the research, one shall assume a wood chip CHP plant (k_{11}) is built instead with an installed heat capacity 12.5 MW_{th} and according to the calculation provided for Jelgava CHP, installed capacity of the plant would be 5 MW_e and wood chips consumption – 122,605 bulk m^3 a^{-1}.
- The total installed heat capacity of three boiler houses in the Tervete region is 2.5 MW_{th} and wood logs are used in the boiler houses. These boiler houses might substitute wood log boilers with wood chips boiler houses or one wood chip boiler house (k_{12}). Assuming that thermal efficiency is $\eta_t = 0.85$, capacity factor JIK = 0.25 and working hours of the plant are h = 1,290, then the fuel consumption would be the following:

Heat energy produced:

$$Q = QJ_U \times h = 5{,}475 \text{ MWh} \qquad (8)$$

Fuel energy consumed:

$$Q_{kur} = \frac{Q}{\eta_t} = 6{,}441 \text{ MWh} \qquad (9)$$

where

η_t – efficiency of heat generation.

Thus we can define the consumption of wood chips as 8,242 bulk m^3 a^{-1} and the number does not considerably differ from the current wood log consumption recalculated to wood chips consumption.

- Wood logs and coal are used in Eleja for heat production. The amount of wood chips needed per year for the boiler house (k_{13}) is 6,600 bulk m^3.
- In Bauska, natural gas is used. The amount of wood chips needed for the boiler house (k_{16}) is assumed in the research as 23,100 bulk m^3 a^{-1}.
- In Dobele all existing boiler houses use natural gas except one where wood fuel is used – 2,657 bulk m^3 a^{-1}, but within the research boiler houses with such minimal fuel consumption are not taken into account. Thus the assumption to switch partly to wood chips (k_{14} = 32,980 bulk m^3 a^{-1}) is defined within the research.

Results and discussions

Demand scenario

Table 2 summarises the results of energy demand scenarios. The demand on wood chips for all existing boiler houses is 163,001 bulk m^3 a^{-1}. In Scenario II, the consumption of energy wood increases by 44% due to reconstruction or construction of boiler houses: biomass boiler houses with installed capacity in the range of 1.5 – 5 MW or biomass CHP plant with installed heat capacity up to 15 MW_{th} and fuel demand higher than 50,000 bulk m^3 of fuel per year.

Table 2. Energy wood demand scenarios (Scenario I-IV)

Boiler house	**Demand scenario [bulk m^3 a^{-1}]**			
	I	**II**	**III**	**IV**
k_1 Tukums	4,386	4,386	4,386	-
k_2 Tukums	92,268	92,268	92,268	18,454
k_3 Tukums	11,043	11,043	11,043	2,209
k_4 Tukums	4,875	4,875	4,875	-
k_5 Kandava	4,107	4,107	4,107	-
k_6 Bēne	4,143	4,143	4,143	-
k_7 Auce	15,639	15,639	15,639	3,128
k_8 Misa	10,661	10,661	10,661	2,132
k_9 Piebalgas	4,643	4,643	4,643	-
k_{10} Vecumnieki	11,236	11,236	11,236	2,247
k_{11} Iecava	-	-	122,605	24,521
k_{12} Tērvete	-	8,242	8,242	1,648
k_{13} Eleja	-	6,600	6,600	1,320
k_{14} Dobele	-	32,980	32,980	6,596
k_{15} Jelgava	-	-	613,020	122,604
k_{16} Bauska	-	23,100	23,100	4,620
In Total:	**163,001**	**233,923**	**969,548**	**189,479**

In Scenario III, the demand on energy wood increases 6 times and the most important fuel consumer in this scenario is a new CHP plant in Jelgava.

Analysis of forest exploitation residues potential

Several research works are performed in Latvia to define the potential of energy wood, for example:

- Latvian State Forestry Institute 'Silava' in cooperation with 'Skogforsk', the Forestry Research Institute of Sweden performed a multifactor research on the production of energy resources from by-products of forest clearing processes, ditch and roadsides and stump extraction (Lazdāns et al., 2008);
- Latvian State Forestry Institute 'Silava' developed models for the evaluation of sustainable and economically feasible usage and forecasting of Latvian forest resources (Donis et al., 2009);
- also 'Silava' assessed energy wood resources, its preparation technologies and costs by performing improvement cuttings in 20–40 year old forest stands (Graudums & Lazdāns, 2006) and others.

The results of forestry experts on used and perspective wood fuel sources and available volumes for energy production needs are summarised in Fig. 6.

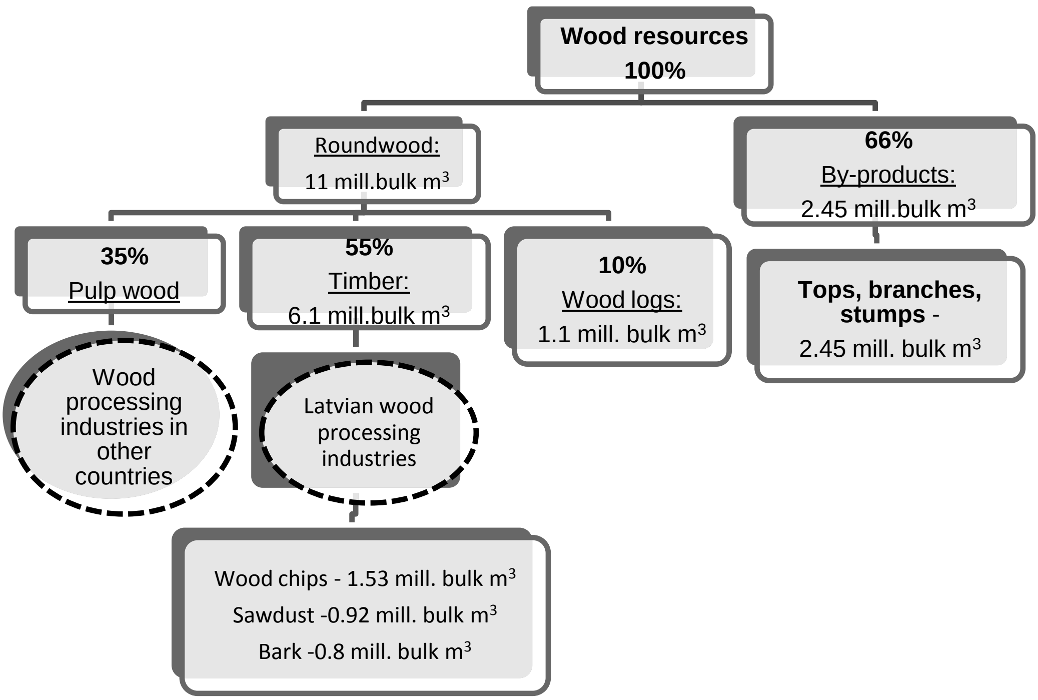

Fig. 6. Potential of energy wood from forest exploitation residues (Donis et al., 2009).

Forest management residues make 2.45 million m^3 a^{-1}. It should be stated that in some reports the amount of forest by-products is 25% higher than stated in *Donis et al., 2009*. By now only half of the by-products are used for energy production needs and the potential of resources from 'non-forest' areas (agricultural areas, roadsides, etc.) is still not evaluated. The collection of bushes along roadsides will lead to 110,000 m^3 of energy wood (approx. 60–65 m^3 ha^{-1}) and from non-used agricultural areas – 650,000 m^3 a^{-1} (approx. 60–150 m^3 ha^{-1}).

Assuming that the relative moisture content of wood chips is 46% (average annual energy wood moisture content in Latvia), the average ash content is 2% and the weight of a bulk volume is 850 kg. Thus it is possible to get, on average, 2.5 MWh of energy from 1 tonne of wood. According to this, energy resources delivered from forest and 'non-forest' areas calculated to energy equivalent summarises to $7.6 \cdot 10^6$ m^3 or 16.2 TWh of energy per year.

Table 3. Forests areas in Latvian regions in 2008 *(Central Statistical Bureau of Latvia, 2012)*

	Total area, 1,000 ha	Area of forests, 1,000 ha	Ratio of forests, %
Latvia	6,458.8	3,220.9	49.9
Bauska region	188.1	74.0	39.3
Dobele region	163.1	47.4	29.1
Jelgava region	166.5	53.4	32.1
Tukums region	245.7	111.7	45.4
Saldus region	218.2	102.4	46.9
Ogre region	184.3	102.9	55.8
Aizkraukle region	256.7	157.3	61.3

Taking into account the information provided above, the approximate potential of energy wood in the researched region can be calculated[2]. The total area of the researched region is 763,400 hectares, forest area – 286,500 hectares, thus the ratio of forests is 37.5% (Tab. 3). The potential amount of energy wood from forest areas in the researched region is $0.61 \cdot 10^6$ m^3 or 2.13 m^3 per forest hectare (i.e. 5.33 bulk m^3 ha^{-1}) and from the so-called 'non-forest' areas $0.12 \cdot 10^6$ m^3 or 0.25 m^3 per a hectare of non-forest area (i.e. 0.63 bulk m^3 ha^{-1})[3].

The defined amount of energy wood is sufficient to introduce any of the scenarios.

Assessment of Terminals

Storage of wood chips plays an important role in determining the quality of fuel, incl. moisture content, calorific value, distribution of microorganisms and even spontaneous ignition, sanitary conditions, etc.

Based on the fuel demand analysis, 9 storage sites are selected for development of potential terminals for fuel storage.

Terminal t_1 is located near Jaunjelgava, terminals t_8 and t_9 – located in western part of Latvia. These terminals do not correspond to the defined researching area. As

[2] Due to the lack of data, some parameters (for ex. felling areas and forest areas per growing types, growing stocks, etc.) were generalized and assumed.
[3] Recalculation coefficient – 1 m^3 = 2.5 bulk m^3.

far as those terminals are not located in the researched region, they are excluded from the research.

Turnover of terminal t_2 is defined on purpose to deliver wood chips to the closest boiler houses located in the western part of Latvia. The defined terminals are not located directly in the centre of the towns but in the surrounding area due to the fact that traffic and chipping processes related to the terminals might cause noise and dust emissions.

Table 4. Defined volumes of storage terminals

Terminal	Volume, m^3 bulk	Turnover, m^3 bulk a^{-1}
t_1 Jaunjelgava	310,000	-
t_2 Kandava	8,500	8,500
t_3 Jelgava	260,000	260,000
t_4 Dobele	48,600	48,600
t_5 Jaunpils parish	115,800	115,800
t_6 Bauska	145,000	145,000
t_7 Iecava	98,700	98,700
t_8 Saldus	4,500	-
t_9 Vānes parish	2,900	-
In total:	**994,000**	**676,600**

The volumes and annual turnovers of the terminals are based on a 12-month storage period.

Conclusions

1. The way in which a wood felling area is spread over a specific territory and the subsequent spread of the raw materials as well as the requirements of boiler houses for specific quality of wood fuels are important factors which limit the application of the logistics methods from other industrial sectors to the wood fuel sector.

2. The use of terminals might increase delivery costs by 10–20% due to the additional transportation and reloading involved. Unlike the one chain system (forest-boiler house), in case of the system with a terminal, it is assumed that the wood fuel is transported two times via roads: forest-terminal and terminal-boiler house. Storage of wood fuel in terminals minimises the moisture content of the fuel, but, at the same time, this storage promotes dry matter loss.

3. The analysis shows that the most optimal delivery scenario is to chip wood logs in forests instead of terminals and to use the wood chips carrier for transportation, loading and unloading. For example, in case of Terminal 2 and Terminal 3, the optimal transportation distance is within 30 km (reduced by 50% from the standard scenario) and this reduces the costs by 41%.

4. A maximum turnover of wood chips in the southern part of Latvia was defined (676,600 m^3 bulk a^{-1}) and based on the optimized demand of wood fuel of the boiler houses within the region.

5. It is recommended to conduct a sensitivity analysis of the data and to compare the effect of transportation distance and transportation costs to the total supply costs of wood fuels.

References

Antti, A. F. 2005. *Forest fuel production in Finland.* Joensuu Research Centre, Finland, 12 pp.

Donis, J., Zālītis, P., Zālītis, T. u.c. 2009. *Latvijas meža resursu ilgtspējīgas, ekonomiski pamatotas izmantošanas un prognozēšanas modeļu izstrāde*. Latvijas Valsts mežzinātnes institūts 'Silava', Salaspils, 130 pp. (in Latvian).

Informative data base 'Gaiss-2'. 2012. Latvian Environment, Geology and Meteorology Centre - http://www.meteo.lv/public/datu_bazes.html

Informative Report. 2008. Latvijas valsts meži, Riga, 22 pp. (in Latvian).

Graudums, M. & Lazdāns, V. 2006. *Enerģētiskās koksnes resursu vērtējums, to sagatavošanas tehnoloģijas un izmaksas, veicot kopšanas cirtes 20-40 gadus vecās mežaudzēs*. Latvijas Valsts mežzinātnes institūts 'Silava', Salaspils, 69 pp. (in Latvian).

Gronalt, M. & Rauch, P. 2007. Designing a wood fuel supply chain network. *Biomass Bioenerg.* **31**, 393–402.

Johansson, J., Lissb, J. E., Gullbergc, T., Björheden, R. 2006. Transport and handling of forest energy bundles – advantages and problems. *Biomass Bioenerg*. **30**, 334–341.

Junginger, M., Faaij, A., Björheden, R., Turkenburg, W. C. 2005. Technological learning and cost reductions in wood fuel supply chains in Sweden. *Biomass Bioenerg*. **29**, 339–418.

Kanzian, C., Holzleitner, F., Stampfer, K., Ashton, S. 2009. Regional energy wood logistics – optimizing local fuel supply. *Silva Fennica*. **43**, 113–128.

Koppejan, J. 2007. *Fuel storage, handling and preparation and system analysis for biomass combustion technologies*. Procede Biomass BV, Netherlands, 112 pp.

Lazdāns, V., Lazdiņš, A., Zimelis, A. u.c. 2008. *Energoresursu ieguve no krājas kopšanas un sastāva kopšanas cirtēm, grāvju un ceļmalu apauguma, celmu pārstrādes, izvērtējot ekonomiskos, tehnoloģiskos, vides un mežsaimnieciskos faktorus*. Uppsala, Zviedrija, 69 pp. (in Latvian).

Nordlarsen, T. & Talbot, B. 2004. Assessment of forest-fuel resources in Denmark: technical and economic availability. *Biomass Bioenerg*. **27**, 97–109.

Statistical Data on Energy Resources in regons. 2012. Central Statistical Bureau of Latvia - http://www.csb.gov.lv /