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REGIONAL WOOD ENERGY LOGISTICS – OPTIMIZING LOCAL FUEL SUPPLY

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Abstract: *The promotion of electric energy production based on solid biomass by the Austrian government induced a boom in the installation of new combined heat and power plants (CHP). In planning CHP´s with a high feedstock demand, fuel availability and the design of the supply chains must be taken into consideration.*
The total demand of forest chips in our research area for energy purposes is 70.000 m³ of loose volume chips per year. The current planned expected increase in demand is more than 4 times greater: up to 300.000 m³ of loose volume per year. The single biggest CHP will consume two third of that volume.
Even if the energy wood feedstock potential is satisfactory the design of the supply chain is still unresolved. In addition optimization focused on a single system is not sufficient, and supply chains have to be tailored according to the needs. To give the decision-makers a base for further development, different scenarios of supply for 9 and 16 plants were designed. The scenarios were developed using a combination of a geographic information system (GIS) and linear programming methods. For every scenario the costs including transport and chipping was calculated separately for each plant. The results indicated that direct transport of solid fuel wood as round wood and chipping at the plant is the cheapest supply system with a resulting cost of 5.40 - 6.80 EUR/m³ loose. Using harvesting residuals can only be recommended for large plant because of low fuel quality. For residues the supply chain uses chipping at or near the landing to a pile and transport via self-loading truck is favourable with costs between 8.40 and 9.10 EUR/m³ loose.
To meet the increasing demand and the requirement of continuous supply, especially during the winter and spring time (snow, closed roads), it is necessary to optimize the supply chain by including temporary terminal locations. However, using terminals and increased demand leads to higher logistic costs. For example, if the total volume is handled via terminals the average supply costs inclusive of storage will increase by 28%. A higher demand raises the costs by 14%. Nevertheless the possibility to buffer and dry the fuel might lead to higher value enhancement than the increase of the costs.

1. Introduction

New regulations to promote bioenergy increase the demand of forest fuel in Austria. One resource is forest chips burned as fuel at combined heating and power plants (CHP). Subsidies are such that a lot of new CHP crop up all over Austria, which will double the forest fuel demand from 2000 to 2010 (Katzensteiner and Nemestothy, 2006).

Use of wood as fuel has a long tradition in Austria, whereas during the last two decades a lot of new district and house heating systems have been installed. As most of them required little fuel, short transport distances with maximum of 30 km were typical. In addition, most of chips burned in district heating plants are purchased as sawmill by-products. Forest chips had not been competitive, because of high supply costs and varying quality (Stockinger and Obernberger, 1998). Beside costs and quality a constant supply is required during the whole year. Because of weather conditions in winter time, mountainous regions are inaccessible. Therefore wood terminals to store fuel can be an option to secure supply. As CHP plants are mostly located close to settlements chipping or crushing at the plant is sometimes is a problem because of noise and dust emissions. To date supply networks to meet the arising needs do not exist.

Eriksson and Björheden (1989) evaluated five theoretical production flows of fuel from forest to plant and from forest to terminal to plant respectively. Using linear programming methods the computed results show that direct supply is the most economic way, because the expected added cost of improved fuel quality and secure supply does not pay off. Eriksson and Björheden (1989) pointed out: "optimizing forest-fuel production essentially means minimizing transport costs".

To determine terminal locations Gronalt and Rauch (2007) presented a simple approach based on iso-cost curves, but also mentioned that for an optimal supply network total cost of transport and terminal must be considered.

The aim of this study is to develop a supply network with optional fuel network via terminals. Optimal material flows and expected costs at plant level for three demand scenarios and supply options are calculated to demonstrate the differences between direct and flow via a terminal. Therefore a survey of demand, fuel wood potential and existing infrastructure of terminals must be documented. To compute optimal material flows, the linear programming technique will be used.

2. Material and methods

For the logistics of supplying feedstock to heat plants different supply chains are available, including place to chip as well as the option of using interim terminals. In addition to current demand level of 73,000 m³/a loose the upgrading of existing plants and new installation are accounted for in scenarios II and III respectively. Scenario II includes upgrading and installation of small and medium seized plants, with a demand less than 50,000 m³/a loose. In scenario III the realization of a major project, which will increase the demand up to 300,000 m³/a loose (Table 1), is considered. Three supply options assume different usage of terminals in the supply chain accounted for as a share of the whole yearly demand in the region. The first option is based on transport of round wood directly to the plant, chipping at the plant and without using any terminal. In option two and three 50% and 100% of the demand are handled via terminals respectively. From terminal to plant only chipped material is transported, because this is the cheapest transport mode and no additional trans-loading is required. Due the high demand in scenario III and the insufficient capacities of terminals, the combination of scenario three with option three cannot be solved. For the question if a big terminal in the region is optimal, an additional fourth option with 100% share via terminals and full utilization of the biggest terminal is considered.

Based on questionnaires and interviews with plant operators, wood chips from harvesting residues are just recommended for big plants. Therefore the biggest four plants in the region are supplied with wood chips from harvesting residues. The yearly potential of harvesting residues in the region is about 24,000 m³ solid. But this is not enough to cover the demand of these plants. As supply chain for these harvesting residues the combination chipper and self loading chip truck is chosen. With this system the chipper can work independent from transport, therefore delays can be avoided (Ganz et al., 2005; Kanzian and Holzleitner, 2006).

Table 1: Overview of supply chain scenarios and options

Scenarios	Options 1	Options 2	Options 3
Demand [m³ loose/a]	Share via Terminals 0%	50%	100%
I - 73,000	I - 1	I - 2	I - 3
II - 96,000	II - 1	II - 2	II - 3
III - 306,000	III - 1	III - 2	

2.1. Model description

Erikson and Björheden (1989) optimized the supply for only one consumer with linear programming methods (LP). Number and size of decision variables within LP-models determine the size of the problem and the memory requirements to solve it, whereas is easy to exceed the memory limits of 32-bit computing As the model should be solvable for a network of 8 terminals and 16 plants with standard software, the number of material flows were reduced. The following three flows are considered: (1) direct transport from forest to plant of solid fuel, (2) transport from forest to terminal solid and (3) transport from terminal to plant chipped (Figure 1). The network analysis assumes that all sinks and sources are available in form of locations, therefore terminals and heating plants are geo-referenced. Sources of fuel wood are represented by a square grid of one by one kilometer. Each point will so present 100 ha of forest land.

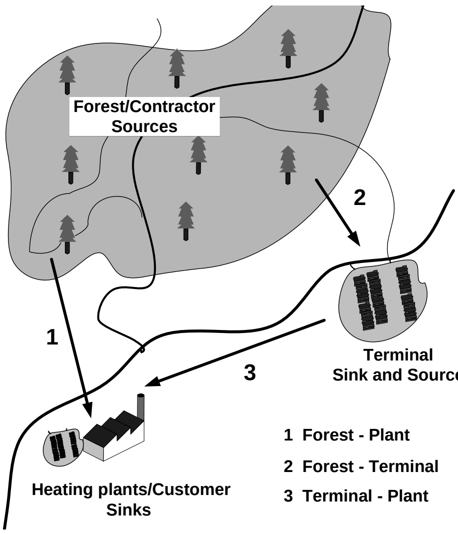

Figure 1: Flow of wood chips from forest to terminal/plant

The calculation of different scenarios and options is done in several steps. Geographic information and data based on time studies for the static simulation have to be linked before (Figure 2). Data concerning real supply areas of the plants are not considered. During routing and linear programming theoretical supply areas are calculated. The model for optimizing contains a list of assumptions and simplifications:

- The fuel wood potential is uniformly distributed over the forest area.
- Transport costs consist of a variable part and a fixed part based on the capacity. The variable part is calculated with network analysis in combination with routing. Fixed costs contain loading and unloading.
- The costs of chipping are constant and dependent on the location. Chipping at the plant or terminal is considered with lower costs than at the landing.

- The period under consideration is one year.
- At terminals the maximum storage capacity will be turned over once a year. Considering time for drying from four to six months and peaks of demands at turn of the year don't allow more than one turn over.
- There are no limits for storage capacities at heating plants. It is assume that the yearly turn over can be handled at plant.
- Every source delivers to the nearest sink. Effects by markets, regional in- or outflows of fuel wood are not considered.
- The model contains only plants with a yearly demand of 1.000 m³/a loose.
- Only costs for transport and chipping are included without any harvesting or raw material costs.

The variable costs during optimization, which have to be minimized, are the transport costs. The objective function of the analysis computes the transportation costs, whereas defined constraints must be taken into account (Domschke und Drexl, 2005). In the first step the transport from terminal to plant is optimized (1), considering that the demand of plant has to be satisfied (2) and the maximum capacities of terminals has not to be exceeded (3).

$$z = \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij} \tag{1}$$

$$\sum_{i \in I} x_{i\,j} = d_j^{plant} p^{share} \qquad \forall j \in J \tag{2}$$

$$\sum_{j \in J} x_i \leq v_t^{\max.capacity} \qquad \forall i \in I \tag{3}$$

Transport costs per entity of potential from source to sink (c_{ij}) include driving, loading, unloading, the hourly costs and load volume. Demand (d_j^{plant}) of each plant was collected during interviews, digitized and georeferenced (Figure 4). The potential of sources x_i is determined in a separate study of fuel wood potential in the region. Quantities which have to be transported from source to sink are described with x_{ij}. The maximum capacity of terminals is fixed with $v_t^{max.capacity}$. (Figure 3, Table 3) The amount of chips handled via terminals (p^{share}) depends on chosen option and is 0, 50 and 100% respectively. A matrix with sources and sinks is setup including the information of costs for each sink source combination.

In the second step a cost optimal flow from forest to plant or terminal will be compute. In this case terminals are acting as sinks too, whereas the optimal turnover calculated by step 1 is treated as demand now. To ensure that every source point will be assigned to one sink, the objective function has to be extended by a binary decision variable f_{ij}. (4). Constraint (5) and (6) ensure the limits of fuel wood potential and satisfy the demand.

$$z = \sum_{i \in I} \sum_{j \in J} c_{ij} x_i f_{ij} \qquad f_{ij} = \{0,1\} \tag{4}$$

$$\sum_{i \in I} f_{ij} x_{i\,j} = d_j^{termplant} \qquad \forall j \in J \tag{5}$$

$$\sum_{j \in J} f_{ij} x_i \leq x_i \qquad \forall i \in I \tag{6}$$

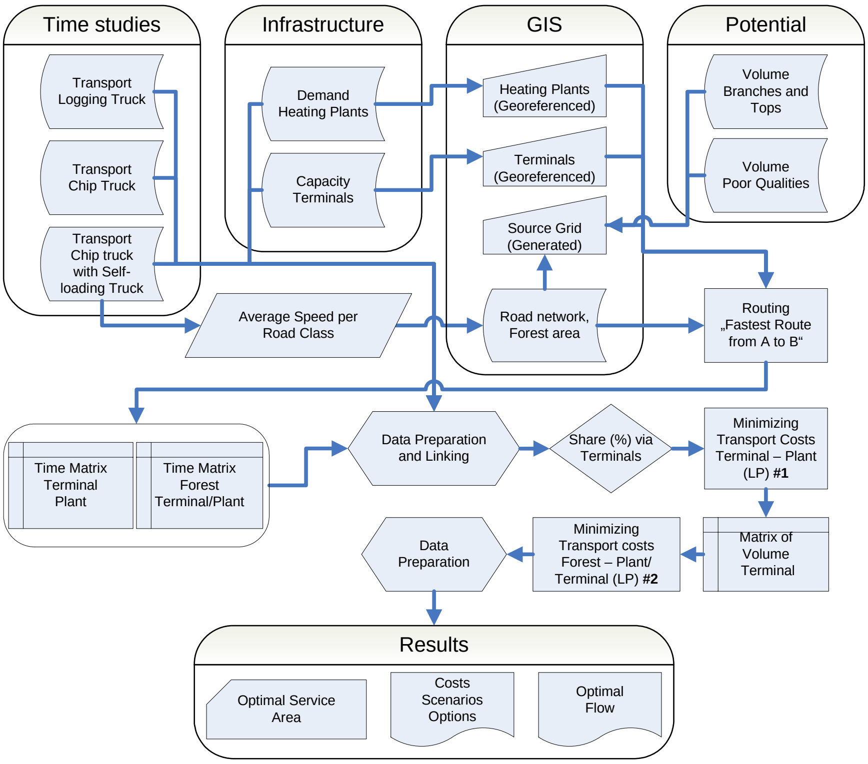

Figure 2: Database, Dataflow and used methods for the static simulation and optimization.

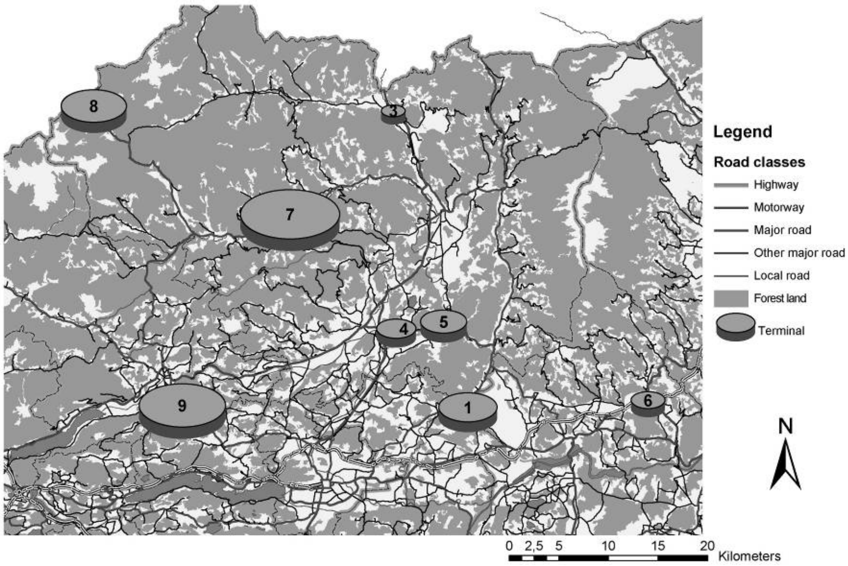

Figure 3: Map of optional terminal locations with storage capacities in the region.

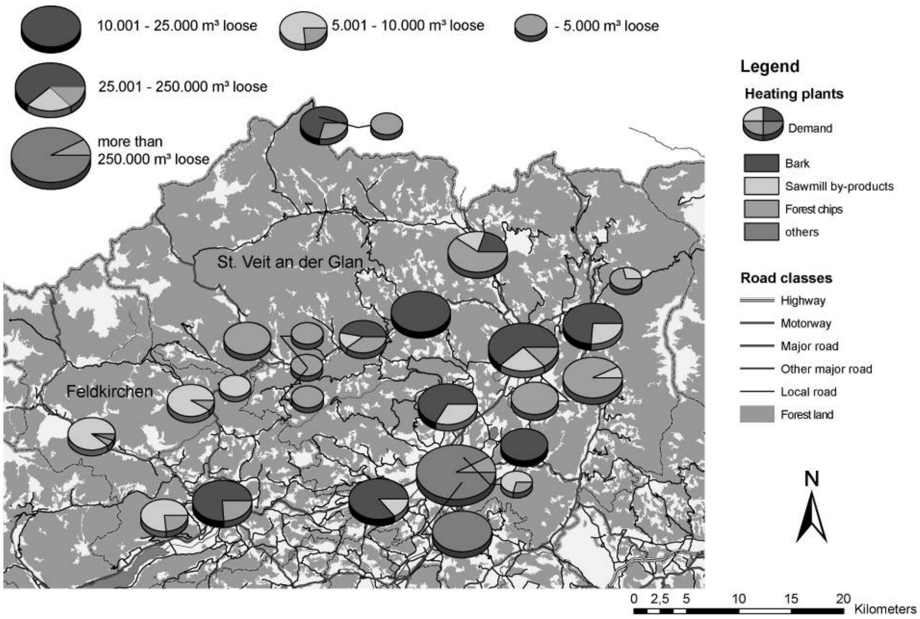

Figure 4: Demand level of heating plants and distribution of used fuel types.

2.2. Data preparation and processing

Via network analyses the shortest drive time for each sink-source connection is calculated and stored in form of a transport matrix. Afterwards the loading, unloading and waiting times are added. This total transport time is multiplied by the hourly costs and finally divided by the load volume to achieve the costs per entity. A network analysis requires a specific road network dataset, which is digitized and attributed properly. More precisely each road is split in sections connected via nodes. All sections include information about distance, travel time, average speed and restrictions. As these data are not freely available, a license has to be purchased. As the database contains no drive time of trucks as it is normally used by car navigations systems, time of transport must be computed for each section of the road with the information of distance and average speed. Average speeds of trucks on different functional road classes are taken from Ganz et al. (2005).

The processing of geographical information, the routing and building maps are done with ArcView 3.x® and ArcGIS® from ESRI. Data preparation and linking is carried out in a spreadsheet using MS-Excel. The implementation of linear programming is done in MS-Excel® with the application of Premium Solver® using the “Large Scale LP-Solver” package. All the calculations are based on results of the study for potential useable energy wood in the region. Due to the reduced usage of branches and topes in the plants the potential of energy wood is reduced from 1.47 m³/h/a to 0.60 m³/ha/a solid. Converting the solid mass into loose cubic meters is done by the factor 2.5 (ÖNORM, 1998). So each source represents an amount of 150 m³/ a of loose fuel wood. To determine the maximum capacity and the yearly turnover respectively, a storage time of 12 months and an area usage of 200 m²/1,000 m³ loose is considerate (Table 2).

Table 2: Data for calculating fuel potential per source and terminal capacities.

Potential-Forest Site			Terminal		
Grid Size	100	[ha]	Time of stoarge	12	Months
Potential	0.6	[m³/ha]	Area	200	m²/1,000m³ loose
Potential	60	[m³/Point]			
Potential	150	[m³ loose/Point]			
Conversion	2.5	[m³ loose/m³]			

Table 3: Demand of heating plants (a) Capacities of terminals (b)

(a)

Plant	Demand
[ ]	[m³ loose/a]
22	25,000
3	16,800
26	16,470
15	3,000
5	2,800
9	2,500
1	2,500
10	1,750
14	1,450
20	1,000
27	**210,000**
28	**4,400**
29	**2,200**
8	**1,893**
21	**9,600**
31	**1,173**
	302,536

(b)

Terminal	Area	Capacity per Year
[ ]	[m²]	[m³ loose/a]
1	4,020	20,100
3	680	3,400
4	1,800	9,000
5	2,500	12,500
6	1,350	6,750
7	11,500	57,500
8	5,000	25,000
9	8,800	44,000
		178,250

3. Results and conclusions

The computed costs – supply costs at plant level - include chipping, transport and variable terminal costs. This supply costs reflect the viewpoint of forest owners and suppliers respectively, so there are no terminal costs calculated at plant, as they are paid by the plant owner. At a yearly demand level of 73,000 m³ forest chips the optimal supply cost will be 5.80 EUR per cubic meter loose on average, if the material is delivered directly to plant. Fuel flow via terminal creates additional need for transport and the costs for the terminal must be added. Therefore the costs increase to 6.40 and 7.40 EURm^{-3} loose respectively. Another effect appears if demand rises like in scenario II and III. Supply costs of direct transport will increase from 5.80 to 6.60 EUR m^{-3} loose (Table 4).

Forest chips made of harvesting residuals have poor quality and can only be burnt in large boilers. For this an additional supply scenario beside the scenarios presented in Table 1 was computed using the self-loading truck, presented by Kanzian and Holzleitner (2006), as transport vehicle and direct transport from forest to consumer. A potential of 0.18 m³ solid per hectare and year as well as only larger plants with a minimum demand of 15,000 m³ loose per year are considered in the calculation. In the research area only plant 22, 3, 26 and 27 consume more than that per year. The assumed potential of harvesting residuals covers 22% of selected plants demand. Referring to the given parameters, supply costs at plant level between 8.40 till 9.10 EURm^{-3} loose can be expected. Be aware that the results can not be compared to scenarios I to III as different sources transported and also some costs of 2.0 EURm^{-3} loose include for the short pre-transport of raw material.

Table 4: Supply costs of computed scenarios and options in Euro per cubic meter forest chips.

Scenarios	**Options - costs [EUR*m^{-3} loose]**		
	1	**2**	**3**
Demand	**Share via Terminals**		
[m³ loose/a]	**0%**	**50%**	**100%**
I - 73,000	5.80	6.40	7.40
II - 96,000	5.90	6.50	7.40
III - 306,000	6.60	6.90	

Beside the optimal cost allocation of sources, also the material flow from terminals to plant is optimized. To answer the question which terminals should be used the scenario III variant 2 would be taken as example. The optimization assigns a high yearly turnover to Terminal 7, which is located at the center of the study area. A total volume of 57,400 m³ loose should distribute to plants 3, 26, 5, 1, 10 and 27 with optimal flows of 8,500; 8,200; 1,900; 1,200; 1,000 and 36,600 m³ loose per year (Table 5). All terminals except number 8 operate in full capacity, which implies that this location is less competitive against the others. As this terminal position is close to border of the research area, high transport costs arise. Comparing all other scenarios and options terminals 5, 7 and 9 seems to be promising locations for terminals.

As each source point was allocate to one sink, optimal trading areas can be displayed. The areas are more or less located around the plants along major roads. Because of the given potential and the low demand only small supply areas appear (

Figure 5). If the demand rises, like at scenario III where a new CHP will consume most of the forest fuel, the supply areas of existing plants will move. For example the fuel for plant 22 will only be delivered from the east. To fulfill the consumption of heating plant 27 nearly the source of the whole research area must be taken (Figure 6).

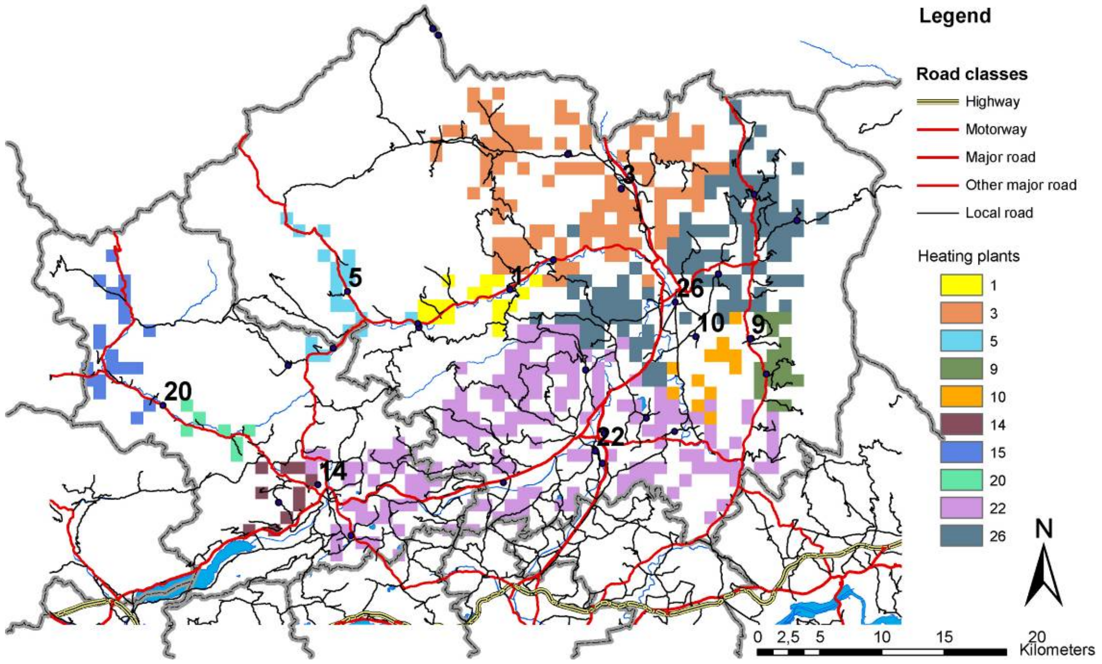

Figure 5: Optimal supply areas at scenario I variant 1 and cost optimal allocation of potential respectively.

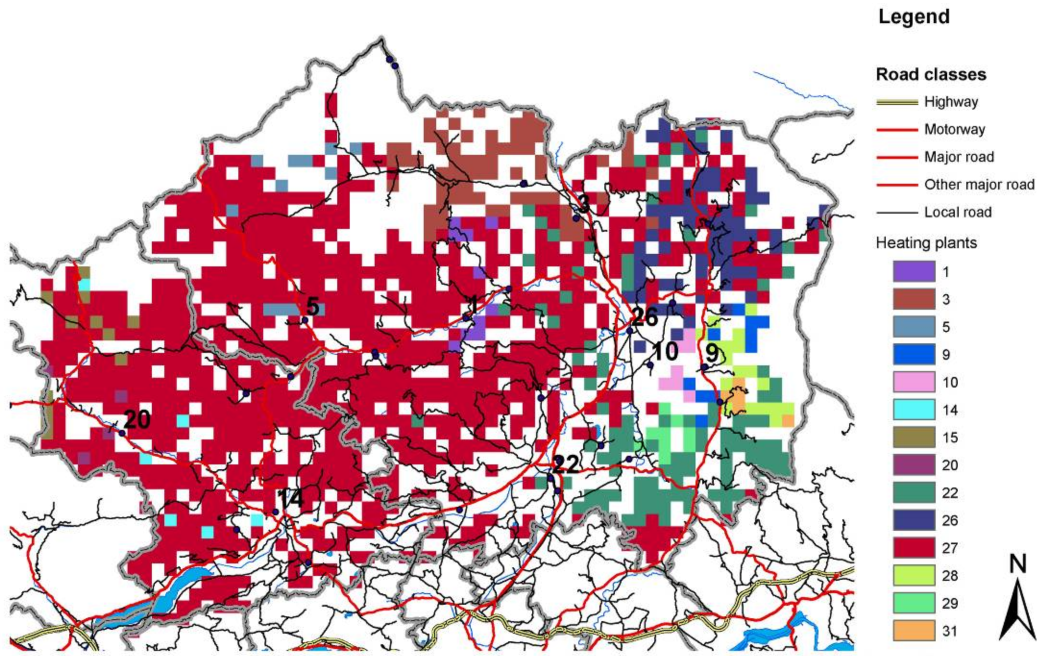

Figure 6: Optimal supply areas at scenario III variant shows that most of the potential will be allocated to heating plant 27.

Table 5: Optimized fuel flow from terminals to plants at scenario III option 2 in cubic meter loose per year.

	Terminal								
Plant	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum plant**
22	12600	-	-	-	-	-	-	-	12600
3	-	-	-	-	-	**8500**	-	-	8500
26	-	-	-	-	-	**8200**	-	-	8200
15	-	-	2700	-	-	**-**	-	-	2700
5	-	-	-	-	-	**1900**	-	-	1900
9	1500	-	-	-	-	**-**	-	-	1500
1	-	-	-	-	-	**1200**	-	-	1200
10	-	-	-	-	-	**1000**	-	-	1000
14	-	-	-	700	-	**-**	-	-	700
20	-	-	500	-	-	**-**	-	-	500
27	2200	2400	5800	11900	2200	**36600**	-	**43900**	105000
28	2200	-	-	-	-	**-**	-	-	2200
29	1200	-	-	-	-	**-**	-	-	1200
31	500	-	-	-	-	**-**	-	-	500
8	-	1000	-	-	-	**-**	-	-	1000
21	-	-	-	-	4600	**-**	200	-	4800
Sum terminal	20200	3400	9000	12600	6800	**57400**	200	43900	153500
Percentage of max capacity	100%	100%	100%	100%	100%	100%	**1%**	100%	

With this simple approach, material flows from forest to plant and optional via terminal can be optimized based on traceable calculations and different scenarios as well as supply options can be evaluated quiet quickly. The outcomes can be seen as a benchmark for the region. Keep in mind that the results ignore market behavior. Simulation of market behavior in biomass supply is done by Gronalt and Rauch (2006) via different assumptions. Nevertheless the findings are computed by models and a comparison to real world is still missing. The main reason for that is that plant owners do not want to share sensitive data, because of suspected disadvantages against competitors.

Due to the chosen stepwise procedure, the model provides only local optimums. A global optimal solution must take all components along the supply chain, which are causing costs, in consideration. Also the limits of spreadsheet calculations will be reached quite quickly, if expanded objective functions must be implemented. Data exchange between a GIS system and spreadsheet calculations needs improvement and so on. Professional solver platforms overcome those barriers and offer a wide range of interfaces as well as tailor to solve mathematical problems scripting and programming language respectively.

Further development of the approach has been carried out, whereby global optimums for material flows and terminal locations can be achieved.

4. References

Domschke, W. & Drexl, A. (2005), *Einführung in Operations Research*, Springer, Berlin [u.a.].

Eriksson, L. O. & Bjoerheden, R. (1989), 'Optimal storing, transport and processing for a forest-fuel supplier', *European Journal of Operational Research* **43**(1), 26--33.

Ganz, M.; Holzleitner, F. & Kanzian, C. (2005),'Energieholzlogistik Kärnten -- Transport von Energieholz', Technical Report, Institut für Forsttechnik, Uni. für Bodenkultur, Wien, 89.

Gronalt, M. & Rauch, P. (2006), *Alternative Strategien für die Landwirtschaft*, Facultas, chapter Kostenvorteile einer Kooperation und die Bestimmung der Systemkosten im Versorgungsnetzwerk Holz-Biomasse, pp. 173-187.

Gronalt, M. & Rauch, P. (2007), 'Designing a regional forest fuel supply network', *Biomass and Bioenergy* **31**(6), 393--402.

Kanzian, C. & Holzleitner, F. (2006),Wertschöpfungsketten für Waldhackgut - Einsatz eines selbstladenden Lkw für den Transport, *in* 'Formec 2006, 39. Internationales Symposium'.

Katzensteiner, K. & Nemestothy, K. P. (2006), 'Energetische Nutung von Biomasse aus dem Wald und Bodenschutz - ein Widerspruch?', *Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft* **74**, 1-10.

ÖNORM (1998),'M-7132 Energiewirtschaftliche Nutzung von Holz und Rinde als Brennstoff Begriffsbestimmungen und Merkmale', 9.

Stockinger, H. & Obernberger, I. (1998), Life Cycle Analysis of District Heating with Biomass, *in* '10. Eurpean Bioenergy Conference', pp. 1-4.