Adoption of logistic principles in WOODY-biomass energy clusters

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Abstract. Applying logistics principles within production technologies is not an objective or not even a magic potion. It is a tool for getting and maintaining some competitive advantage. This is true in the case of production technology of arboreal biomass for heating purposes too. The produce is not only to compete with other arable land outputs (food or forage), but the energy gained through burning it should be competitive compared to energy coming from other sources. Our investigation dealt with questions related to the raw material provisioning of a virtual energy-cluster. We examined those elements of production technology, in which the logistics methods and the optimisation of the flow of materials showed tangible results. The competitiveness of actors in the economic sphere is significantly determined by the effectiveness of their provisioning chain. The optimal solution to these tasks is provided by that combination of apparatus wherein both the “time factor” (JIT) and the efforts to minimise costs are realised. The provisioning chain we examined comprised of harvesting, transport and storage process elements; of these, harvesting in particular, due to its exceptionally high operating costs. We sought an answer to the question of whether it is better to transport the raw material directly to the processing plant or indirectly after temporary storage. In the case of indirect delivery, where should storage facilities be established and how many should there be, in the interests of minimising total costs? We created and utilised a simulation model to solve the task.

Keywords: logistics, energy-cluster, optimization, harvesting, simulation model

JEL Codes: C67, Q42, Q51,

1. Introduction

Woody biomass energy production is one of the key questions of sustainable energy supply. According one of the early conceptual definitions of the sustainability, the sustainable natural conservation strategy should include managing the resources in such a way that, satisfy all demands of the present generation without reducing the future generation’s opportunities. [NRC Board on Agriculture] Nowadays the sustainability has a wide interpretation.[Bongiovanni, Lowenberg-DeBoer, 2004] In according the Burtland report [World Commission on Environment and Development, 1987] the sustainable development is a development that includes the today and the future, where the requirement system and its necessity of the present meet the later own demand of the future generation in it. [Willers, 1994]
The woody biomass energy production is one of the renewable sources of alternative energy production. Woody biomass as an exhaustible, but renewable natural resources today is almost used for heat and rarely for electricity.

- **Woody biomass**: The trees and woody plants, including limbs, tops, needles, leaves, and other woody parts, grown in a forest, woodland, or rangeland environment, that are the by-products of forest management.
- **Woody biomass utilization**: The harvest, sale, offer, trade, or utilization of woody biomass to produce bioenergy and the full range of bio-based products including lumber, composites, paper and pulp, furniture, housing components, round wood, ethanol and other liquids, chemicals, and energy feedstocks. [Anonymous, 2003]

This means that the social sustainability means together, the manufacturing in a quantity according to a social need of food and industrial (energetic aim) materials, the correspondence to economical criteria, and the responsibility for the environment.

The new explanation of sustainability is the thermodynamic approach of natural and social processes. Considering the earth’s ecological system as a closed one, beyond running out of available limited resources will cause the increase of the entropy of the system. The bounds of sustainable development can be traced back to quantitative and qualitative limits. [Georgescu-Roegen, 1979; Ayres, 1995; Kerekés – Szlávik, 2001; Martinás, 2006] The efficiency of artificial energy taken into the agro-ecosystem with technological elements can be increased as far as the efficiency of solar energy can be increased by using it. [Jørgensen – Svirezhev, 2004; Neményi, 2009] From this aspect it is necessary to examine the potential woody biomass producing systems from the logistic side, too.

It is also important to highlight the role of innovation from the alternative energy use. Here – because of the space limit – we mention only two aspects of the question. As economists dealing with the cooperation theory suggest that within the small and medium-size enterprises, the operation along the cooperation helps the continuous innovation and the development of their innovational skills. From the point of view of the woody biomass producers the cooperation in the frame of innovation cluster can develop not only the above mentioned skills, but can reduce the investment process and with the help of building up logistic clusters – with the energy producer in the center – the transaction costs coming from the material input side can also be reduced. [Miles et al., 2006; Maciejczak – Szczupska, 2012] The human capital is interpreted as the condition of the long-term success, but not merely the human capital, as an input, but the contact capital being incarnated in the people. The significance of the relational capital higher within small and medium-size enterprises’ innovative cooperation, as the base of knowledge based growth. [Welbourne – Pardo-del-Val, 2009; Takács – Takács-György, 2011; Macieczjak, 2012] In the dispersion of woody biomass use one other element is the notoriety of the technology beside the available technical facilities and of course the land can be used for energy production. Here the clusters –they are the platform to meet the chain participants – are the area of interpersonal communications chains as well, because the individuals make their decisions on the adaptation of new technologies on the base of information coming through these channels. [Csizmadia, 2009]

Our investigation dealt with questions related to the raw material supply of a virtual energy-cluster. We examined those elements of production technology, in which the logistics methods and the optimisation of the flow of materials showed tangible results. The competitiveness of actors in the economic sphere is significantly determined by the effectiveness of their supply chain. The optimal solution to these tasks is provided by that combination of apparatus wherein both the “time factor” (JIT) and the efforts to minimise costs are realised. The supply chain we examined comprised of harvesting, transport and storage process elements; of these, harvesting in particular, due to its exceptionally high operating costs. We sought an
answer to the question of whether it is better to transport the raw material directly to the processing plant or indirectly after temporary storage. In the case of indirect delivery, we wanted to know where storage facilities should be established and how many should there be in the interests of minimizing total costs. We created and utilised a simulation model to solve the task. We established that in case of short transport distances (1-3 km), direct transport is feasible. In the case of greater distances, indirect transport and the development of micro-logistical storage centres is justified. The number and location of these micro-logistical storage centres can be exactly determined with the help of our model.

2. Material and method

The application of logistic principles primarily depends on the special features of agricultural production (living organisms, weather, environmental conditions etc.). Of these influencing factors the most significant one may be seasonality and time factor (the need for having the jobs done at the right time and within the appropriate period). Under the term seasonality we mean the seasonality of expenditure (operational, materials etc.) and revenue. Due to it, the utilization of instruments (cultivating, sowing, plant protection, harvesting, transporting etc.) is unfavourable. Non-optimal utilization incurs increased costs (in the present case the running costs).

The utilization of machinery can be improved by contracting workers to engage free capacity if there is a need for that. Another way for decreasing the costs of non-optimal utilization is employing contracted workers. (In the case of valuable machines it is small enterprise size and integration). The logistic examination of biomass cluster for heating utilization starts with optimizing the micro-logistic processes (RST) of arable plant production connected to the time factor by paying attention to the time limitation and cost minimization.

Data necessary for the examination derive from AKII and MMI databases as well as by processing own data. The method of processing takes RECAM heuristic simulation model into consideration that stresses JIT principles. Examinations were carried out on all agricultural tasks with high demands for transportation so in this way the organization of a basic material producing cluster of any size and crop rotation on the basis of logistic principles is feasible. The method is the heuristic simulation model that pays utmost attention to JIT principles, which makes it possible to calculate the time necessary for complex (two or three-stage) work processes.

2.1. Optimizing the processes of biomass production in agriculture as a micro-logistic system linked to time constraints

To execute JIT ‘just in time’, such labour organizational procedure must be sought and applied that considers the strive to cost minimizing (economical running), stresses the alternative of doing work within an optimal period of time, i.e. optimizes plant production processes. The optimum is where the time constraints and cost minimization are realized. By means of working on arable land meeting this double objective is quite a complex task. The definition of capacity and the selection of such a system of instruments adapted to the size of the company, crop rotation, production site (ecological environment, shape of parcels, slopes, distance from the manor etc.) only hold true in the surroundings where calculations were made. Organizing labour processes is the most economical if the capacity of all machines and machinery participating in the process are fully utilized. The fixed costs of the capacity not covered by sensible operation (loss of time, waiting, idle time) increases the costs of productive performance.

Time function: \[ T_0 = (T_R + T_{RV}) + (T_{SZ} + T_{SZV}) + (T_F + T_{FV}) \] hour

\[ T_0 = \text{total execution time hour/task} \]
\[ T_R = \text{loading} \]
\[ T_{RV} = \text{waiting time of loading machines} \]
\[ T_{SZ} = \text{transportation} \]
\[ T_{SZV} = \text{waiting time of carriers} \]
\[ T_F = \text{processing} \]
\[ T_{FV} = \text{waiting time of processing} \]
\[ T_{OPT} = T_{RV} = T_{SZV} = T_{FV} = 0 \]

Of course, it is only theoretic in the case of a given machine combination. That is why it can only be operated with the highest costs so that the waiting time of the rented instrument should be 0.

2.2. The supply logistic system of biomass based energy cluster

Raw material supply of the virtual energy cluster we analyse can be realised three ways:

1. At the time of harvesting each production unit transports the high humidity level wood-chips (45-50%) to the central storage facility of the power plant.
2. The harvested amount is stored in temporary storage facilities on the production site, and is transported to the power plant in the rhythm of usage.
3. In the case of large distances micro-regional storage facilities are established for temporary storing the wood-chip output of the given micro-region until the time of usage. Production units nearby still transport directly to the power plant.

Figure 1 is showing these variations.

**Figure 1: Direct and combined supply systems**

Direct supply from the production units

Combined supply with temporary storage facilities (R_i)

Source: own construction
We tried to find out which solution leads to the lowest total costs. For this we utilised the heuristic simulative method (RECAM) for optimising harvesting-transport. For establishing the number of regional centres we built a simulation model shown in figure 2. The calculation method applies for the model is the one used by Cselényi (1997).

**First we calculate total costs in the case when we are not using temporary (regional) storage facilities – everything is transported directly to the power plant (3, 4).**

In this case total costs:

\[
K = K_{sz} + K_r
\]

\[
K_{sz} \quad \text{Cost of transportation}
\]

\[
K_r \quad \text{Cost of storage} = 0\text{Ft}
\]

Total transportation costs:

\[
K_{sz} = \sum_{i=1}^{n} k_i s_i \frac{Q_i}{c_i}
\]

\[k_i\quad \text{specific cost of transport from field i}\]

\[s_i\quad \text{distance from field i to power plant}\]

\[Q_i\quad \text{yield on land i}\]

\[c_i\quad \text{capacity of vehicles transporting from field i}\]

During calculation we assumed one kind of transportation and one kind of vehicle. Our RECAM survey showed that MTZ 82 (tractor) + Fliegel EDK 130 (trailer) is the lowest cost means of transport.

If full transport is done by the same machines:

\[k_1 \approx k_2 \approx \ldots \approx k_n \quad \epsilon s \quad c_1 \approx c_2 \approx \ldots \approx c_n\]

The total storage costs:

\[K_r = r_e R_e T_e\]

\[r_e \quad \text{specific maintenance costs of the power plant storage}\]

\[R_e \quad \text{average stock at the power plant storage}\]

\[T_e \quad \text{average storage time at the power plant storage}\]

Cost \(K\) resulted will be the base – algorithm cycle starts from here. **After this we analyse total costs in case of \(1,2,\ldots, m\) storage facilities.** In these cases

\[
K = K_{sz} + K_r
\]

\[
K_{sz} \quad \text{szállítási költség}\]

\[
K_r \quad \text{ raktározási költség}\]

This time the transportation costs consist of two factors:

\[
K_{sz} = K_{sz}^r + K_{sz}^f
\]

\[K_{sz}^r\quad \text{cost of transportation from storage to power plant}\]

\[K_{sz}^f\quad \text{cost of transportation from fields to storage}\]

Detailed calculation is as follows:
This is one of the key factors in calculation since total costs can be reduced significantly if we minimise transportation cost from storage to power plant.

When transporting biomass from filed to storage the following costs arise:

Assuming that storage facilities $R_1, R_2, \ldots, R_m$ are associated with territories $t_1, t_2, \ldots, t_m$

$$K_{sz}^r = \sum_{j=1}^{m} k_{(r)j} s_{(r)j} \frac{Q_{(r)j}}{c_{(r)j}}$$

- $k_{(r)j}$ specific cost of transport from storage $j$
- $s_{(r)j}$ distance from storage $j$ to power plant
- $Q_{(r)j}$ yield on fields belonging to storage $j$
- $c_{(r)j}$ capacity of vehicles transporting from storage $j$

Storage costs are to calculated here too, of course:

$$K_{r} = K_{e} + K_{f}^r$$

- $K_{r}$ storage costs of storage facilities
- $K_{e}$ storage costs of power plant

$$K_{f}^r = \sum_{j=1}^{m} r_j R_j T_j$$

- $r_j$ specific maintenance costs of storage $R_j$
- $R_j$ average stock at storage $R_j$
- $T_j$ average storage time at storage $R_j$

In this case total costs are:

$$K = \sum_{j=1}^{m} k_{(r)j} s_{(r)j} \frac{Q_{(r)j}}{c_{(r)j}} + \sum_{j=1}^{m} \sum_{p_j=1}^{t_j} k_{jpj} s_{jpj} \frac{Q_{jpj}}{c_{jpj}} + \sum_{j=1}^{m} r_j R_j T_j$$

We should notice that there are going to be fields from which transportation is directly to the power plant. In our calculation in such cases the power plant functions as storage facility but no further transportation is needed.[3,4]

The following in equation demonstrates things stated above:
Thus, if transportation and storage costs of field \( i \) directly to the power plant are lower than total transportation costs to any storage \( R_j \), it is better to transport directly to power plant. This calculation should be performed for all fields and storage facilities. As a result we will be able to see the limits of the area around the power plant within which fields belong directly to the power plant. These fields will transport directly to the plant, the rest to allocated storage facilities. (see Figure 1.).

### 2.3. Planning the supply system of the virtual energy cluster we established

The task: designing the supply system for a 1 MW biomass based hot water and heating plant based on the methodology presented earlier.

Starting data:

**Raw material need:**
- 1,100 t/year (18-20% humidity level wood-chips)
- 2,500 t/year (45% humidity level wood-chips)

**Need of land:**
- 110-120 ha (energy poplar /AF 2/, 45 t/ha yield, 2 year cutting cycle)

Analysing the distance features (1-10 km) of the virtual cluster based upon the RECAM method the MTZ 82 (tractor) + Fliege EDK 130 (trailer) proved to be the lowest cost means of transport. Following RECAM simulative model methodology we calculated total costs in the case of various scenarios. Data and results of direct, indirect and combined supply are shown in table 1-3.

<table>
<thead>
<tr>
<th>Name</th>
<th>Distance (km)</th>
<th>Area (ha)</th>
<th>Yield (t)</th>
<th>Specific cost (Euro/ha)</th>
<th>Cost (Euro)</th>
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<td>270</td>
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<td>692,3</td>
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<td>135</td>
<td>118,9</td>
<td>356,8</td>
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<td><strong>66</strong></td>
<td><strong>62</strong></td>
<td><strong>2,790</strong></td>
<td><strong>1,319,9</strong></td>
<td><strong>8,398,3</strong></td>
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Source: own calculation
Table 2: Costs in the case of indirect supply

<table>
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<th>Name</th>
<th>Distance (km)</th>
<th>Area (ha)</th>
<th>Yield (t)</th>
<th>Harvest and transportaition cost (Euro)</th>
<th>Loading cost (Euro)</th>
<th>Number of rounds</th>
<th>Transportation cost (Euro)</th>
<th>Total cost (Euro)</th>
</tr>
</thead>
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<td>1077,7</td>
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Source: own calculation

Table 3: Costs in the case of combined supply

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<th>Name</th>
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<th>Area (ha)</th>
<th>Yield (t)</th>
<th>Harvest and transportaition cost (Euro)</th>
<th>Loading cost (Euro)</th>
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<td>1</td>
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<td>6 604</td>
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</table>

Source: own calculation

Based on the results we can draw the following conclusions:
- Total logistic costs are the highest in the case of direct supply (8 398,3 Euro). Base logistic cost amounts to 3,01 Euro/t.
- Total logistic costs in the case of indirect supply are 7 113,3 Euro, leading to a base logistic cost of 2,55 Euro/t.
- Combined supply results in considerable savings – total logistic costs in this case are 6 604,2 Euro with a base logistic cost of 2,36 Ft/t.
- Savings amount to 1 794,1 Euro compared to direct supply and 509,1 Euro compared to indirect supply.
- Direct supply is justified for shorter distances (1-3 km) – for distances larger than this storage facilities are to be built.
- In line fields must chose the nearest storage facility.
- Positioning micro-regional storage facilities – in the case of a geometrical arrangement – is to be based on GPS coordinates, production/yield data and logistic points of equilibrium.

3. Summary, conclusions

Systematic thinking and total cost approach are the prerequisites of planning and operating logistic systems together with meeting the 6 points of logistics (getting the right product at the right place at the right time in the right quantity and quality with the right costs to the consumer). Special attention can be paid to cost as it is one of the decisive factors of competitiveness. Total cost approach means that all the costs of the parts of the system should be minimum. Therefore, the cost minimizing opportunities for the constituents of the system must be examined together with the mutual impact of the costs of the single parts. The objective is that the decreasing costs on the side of a part should not result in cost increase that exceeds the decrease in the case of another part. The quantity of raw material (biomass) production (woody and soft stemmed plants) is influenced by the size of the production area and the yield per unit. It is essential to choose a production site that meets the ecological needs of the plant to be produced to reach the targeted yield. In most cases the size is determined by demand. On the basis of the raw material requirements of existing or would-be end-user, heating centre or power plant total energy needs= energy producible on the unit area x size of the area.

Of course, a larger part of a production site can be suitable for producing biomass (competitive with crop production)-in such cases products are sold in a processed form (pellet, briquette...) so a supply market emerges. In this case the logistic chain works in a PUSH system. In the case of the construction of the logistic system of the biomass cluster for heating the application of a PULL system is more likely as meeting the local, micro-regional, regional and cluster needs decide on the quantity of the plant produced based on the requirements of consumers and customers in time and quantity.

Of course, we must not disregard the possibility of placing extra, excess products (They can influence sales price, and the costs of extra transport and storage increase logistic costs, which decreases competitiveness). The special feature of the system is that the basic material is produced on agricultural arable land and harvesting takes place during a predefined period of the year. In the case of ensuring continuous supply crop structure, plantation structure and species structure play a vital role.

The competitiveness of woody biomass depends on two factors. It should be competitive with the crops and forage produced on arable land on the one hand, and should also compete with heat and electricity deriving from fossil energy resources, on the other hand.

From the point of view of logistics, the most important parts in production technology with the highest costs incurred are harvesting and transportation (in bulk, long distance). That is why it is essential that the operation should be arranged by paying continuous attention to logistic principles so that costs are kept to the minimum. It can be realized by totally synchronizing the process elements of harvesting, transportation and product processing. When harvesting woody biomass a great bulk must be transported, which also means a peak in labour during the winter months from November to March. Severe weather conditions in winter makes harvesting and transportation even more difficult or sometimes impossible. Ensuring the maximum use of the valuable harvesting machine can only be carried out by trailers that carry 5-8 tons due to the weather conditions. Transporting by them, however, is only worth for distances of 4-5 km. The cost of harvesting increases in line with the distance of transportation then at a certain distance it breaks down an steeply goes up. Of course, this is not novelty but when examining the breaking point we can conclude that it is due to the fact that some of the vehicles do not return to the harvesting machines. The costs of unused capacities of the machine with high operating (rental) costs (fixed with the price of the rent and area) also increase the costs of running. The competitiveness of the product (chop of wood) lies in the minimum
running costs of technology. That is why a number of vehicles with proper capacity must be selected for the distance. The optimal solution is the combination of machines where both the time factor (JIT) and minimal costs are considered.

Cooperation in the sustainable energetic cluster can result in optimal harvesting and transporting connections. The members of the cluster can realize a significant decrease of 10-15 % in the costs of transportation and warehousing. At the same time, the capacity of instruments has significantly been improved, which results in decreasing accumulated logistic costs.

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