Business process mapping and discrete-event simulation of two forest biomass supply chains

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ABSTRACT

Previous research in forest biomass procurement has been focusing on reducing harvesting costs. However, organisation and management of supply chains as well are considerable cost factors. The present study applies a methodological framework to investigate two forest biomass supply chains in different operational environments of two European countries (Finland and Germany) in order to identify the business processes and stakeholders making up the supply chains using a business process mapping methodology. Additionally, the work time expenditure for organisational and managerial tasks for each of the supply chains is estimated using discrete-event simulations.

The business process mapping revealed that the number of processes in the supply chains varies considerably involving 213 project objects (activities, information items, others) in the Finnish supply chain and 268 in Germany. The work time expenditure on managerial and organisational tasks assessed by discrete-event simulation was 1483 min/100 m³ in the Finnish and 1381 min/100 m³ in the German supply chain. Even though the results of the study are company specific and cannot be directly generalized, as each supply chain reflects the characteristics of its operational environment, the proposed methodology has shown its potential for the in-depth analysis of supply chains in forest business and it is a step towards holistic cost calculation and business process improvement approaches on supply chain level.

1. Introduction

The essential role of wood-based bioenergy to meet the ambitious targets of the European Union has been recognized by European policy makers [1,2]. The existing forest resources in the EU would allow a considerable increase of wood-based bioenergy utilization when managed on a sustainable basis [3-5]. Even though there is a large potential of technically harvestable wood biomass, the economic availability is still a bottleneck at current market prices as has been cited by numerous studies [6,7].

Closing the gap between technically harvestable and economically available potential is the major task of research on procurement of forest biomass for energy. In recent years numerous studies have tried to offer solutions for this challenge using different approaches. For instance, different alternatives to procure energywood in an economically viable way to maximise forest owners' profit and thus increase the
exploitation of energywood [8–10] through improvement and adaptation of existing procurement systems, e.g. the harvester-forwarder chain [11,12], and new, innovative technologies such as accumulating felling heads and the logging residue bundling system [13,14], in order to lower procurement costs by increasing the productivity of the machines. Furthermore, transportation is a significant cost factor, compounded by the fact that the transportation of forest biomass is a major challenge due to the low density of raw material [15]. Consequently, numerous studies have been published investigating different transport and logistics chains to reduce transport costs [16–18]. A further important field of research in the context of forest technology is the mathematical modelling and optimisation of supply chains. For instance, Gunnarsson et al. [19] modelled a supply network to provide a decision support tool for strategic and tactical planning for the supply of forest fuel. Philpott and Graeme [20] developed an optimisation model for solving tactical and strategic decision problems in a paper supply chain.

However, an important issue concerns the overall organisation of work flows in the supply chains. A quite common example for this issue is the scheduling of machinery [21], particularly trucks, which in many cases leaves space for improvements. For example, a significant part of the delays in chipper operations are caused by poor operational planning [22,23] what underlines the crucial role of operational management and emphasises the role of research that addresses the study of the whole organisation of the supply chain instead of focussing on the individual machine. Addressing the operation as a whole not only involves the improvement of machine productivity and scheduling of machine operations, but also the structure of work input in terms of personnel efforts and supporting technology. Recently Windisch et al. [24] indicated that a considerable potential lays in the reduction of work time expenditure in the management and organisation of forest fuel procurement operations.

This necessarily implies to have a detailed knowledge about the different business processes and stakeholders that conform the forest fuel supply chain. In fact, the study of bioenergy supply chains is extremely relevant as there is an increasing demand for the transfer of technology and know-how from well-established to emerging bioenergy markets. In addition, knowledge about time consumption for organisational and managerial tasks that are not part of the actual production is essential in order to improve the overall efficiency by minimising non-productive workload. However, the large variability of the supply chains and working environments in different regions across Europe pose a great challenge that require the development of appropriate methodological tools.

In this sense, a method to analyse and compare different supply chains that can help to gain a more detailed insight is the method of business process mapping [25]. This method presents the ability to depict processes and procedures within and across functional units which makes it a commonly used tool for identifying starting points for subsequent improvement approaches in many different sectors, for example: construction [26,27], agriculture [28] and public organisations [29]. The application of mapping methodologies for system analyses has been used in different studies. Flow-charting, for example, was used to describe the behaviour of decision making processes [30], describe machine interaction [31] and has been taken as a basis for simulation models. In supply chain management, schematic supply chain or value stream mapping methods are used, in most cases, to investigate the flow of goods or services from raw material suppliers to end customers without focussing on the particular processes involved, particularly in large enterprises in the forest product industry [22,33].

Nonetheless, the number of publications using detailed business process mapping has been increasing during the past decade. It is used for optimisation approaches in roundwood supply chains [34,35], but also to analyse business processes of the wood processing industry [36]. Although, on a lower level of detail, Eberhardinger used this methodology to analyse processes in biomass procurement chains [37]. Therefore, the application of this method together with discrete-event simulation is regarded as a progressive approach to investigate forest biomass supply chains and to gain a deeper understanding of the various processes within.

The aim of this study is to provide a methodological framework for the in-depth analysis of the structure and functioning of forest fuel supply chains in different operational environments. The framework is to be applied to assess the fuel supply chains in two case studies located in Finland and Germany and should involve gathering the relevant information for the construction and analysis of business process maps to identify all the processes and stakeholders involved, the estimation of the times used in each activity involved and the overall simulation for the assessment of the supply chain.

2. Materials and methods

2.1. Overview of the supply chains

The investigated supply chain in Finland supplies a 1.2 MW district heating plant in the city of Eno (ENO) in the region of North Karelia. The supply chain is managed by a local forest service company having the procurement of industrial roundwood and energywood as their core business. The company organises the whole procurement operation from purchasing stands to delivering the chips to the plant using local entrepreneurs. The local forestry centre Metsäkeskus, a public institution supporting private forest owners, assists in finding suitable stands for energywood exploitation. The chipping and transportation to the plant is done independently by the contractor who is also responsible for plant maintenance. Forest biomass from pre-commercial thinnings makes up a major share of the supply. The average removal per operation is 90 m³.

The supply chain in Germany is located in the southern part, in the municipality of Feldkirchen-Westerham (FELD). It supplies a local 1.5 MW district heating plant in the nearby municipality of Glonn. Similar to the Finnish case, this plant is run by a local cooperative which is an affiliated company of the local forest owners association (FOA). The FOA is one of the main suppliers of raw material to the plant.
In general, forest operations solely for energywood procurement from pre-commercial thinnings are not common in Germany (unlike in Finland). Therefore, raw materials for forest fuel mainly are logging residues from integrated harvesting operations. The logging residues are procured by the FOA and sold to the cooperative which takes care of the chipping and transportation using local entrepreneurs. The average removal per logging site is 150 m³. The biomass is regarded as a by-product, and depending on the logging site it makes up roughly 10% of the overall removal and the average removal per operation is 150 m³. Concerning the calculations, there is no distinction between assortments of merchantable roundwood and logging residues.

2.2. Research material and processing

2.2.1. Process mapping

The data for the business process mapping was gathered using expert interviews. The interviews followed a detailed sequence of open questions and involved key actors in the supply chains (Table 1). The sequence of data gathering was as follows: First the exact tasks of the stakeholder were outlined. Then the specific activities involved in them were discussed step by step. Finally, the interactions with other stakeholders in the supply chain were covered including dependencies and contact points between stakeholders, points and methods of communication and data exchange and sources for conflicts and errors. Time was reserved for open discussion so that the sequence of activities could be developed and discussed jointly. After the first round of interviews the maps were created using Sigmaflow® software.

The resulting business process maps were re-evaluated in subsequent meetings with the interviewees. After this second round of interviews, the maps were further developed and corrections or details were added, when necessary, until there was agreement that no more improvements could be made. Finally, the information provided by the different stakeholders was cross-checked to verify whether the resulting interactions matched to each other.

As a starting point for the data processing, basic techniques for business process mapping, as described by Damelio [25], were used. The aim of the study includes the process sequence itself as well as the communication and data transfers between the functional units as well as payment processes. Therefore, process maps presenting the flow of data and information along the supply chain besides the processes. Therefore, process maps presenting the flow of data and information along the supply chain besides the communication and data exchange and sources for conflicts and errors. Time was reserved for open discussion so that the sequence of activities could be developed and discussed jointly. After the first round of interviews the maps were created using Sigmaflow® software.

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2.2.2. Model building

Naturally, the sequence of processes is relatively complex and is influenced by various decisions and events occurring over time. It constitutes a dynamic discrete system [39]. Therefore, discrete-event simulation models were chosen in order to determine the work time expenditure for managerial and organisational tasks. After the development of the business process maps, the mean time consumption for every single activity was estimated by a panel of three experts from the Finnish Forest Research Institute that have been working in the field of forest fuel procurement in both countries. In the

<table>
<thead>
<tr>
<th>Type</th>
<th>Object</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activities</td>
<td>Payment</td>
<td>Transfer of money between functional units</td>
</tr>
<tr>
<td>Communication</td>
<td></td>
<td>Exchange of data and paper documents by means of emails, phone calls, oral conversations, postings</td>
</tr>
<tr>
<td>Action</td>
<td></td>
<td>Action are performed to fulfil sub tasks in the process such as creating maps, evaluating stands, moving between work sites etc.</td>
</tr>
<tr>
<td>Information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>items</td>
<td>Data</td>
<td>Any kind of information produced by an activity</td>
</tr>
<tr>
<td></td>
<td>Paper document</td>
<td>Paper document produced by an activity such as forms, contracts etc. Can involve data produced earlier in the process</td>
</tr>
<tr>
<td></td>
<td>Digital data storage</td>
<td>E.g. a database or Excel file</td>
</tr>
<tr>
<td></td>
<td>Paper document</td>
<td>Data stored in form of paper documents</td>
</tr>
<tr>
<td>Others</td>
<td>Decisions</td>
<td>Decide the path the transaction takes through the process when different alternatives are given</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beginning of the process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Endpoints of the process which can be successful or unsuccessful e.g. when the forest owner did not accept the conditions set by the forest service provider</td>
</tr>
<tr>
<td>Actor</td>
<td></td>
<td>A company, institution or other stakeholders in the process. Can be made up of several functional units or act as standalone functional unit.</td>
</tr>
<tr>
<td>Functional</td>
<td></td>
<td>E.g. an operations supervisor or logging contractor. Carries out activities in the process to fulfil a specific task in the supply chain.</td>
</tr>
<tr>
<td>unit</td>
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</table>
first round, independent estimates were provided by the experts and the resulting values were analysed. If the deviation among the estimates provided was higher than 100% (respect the lowest value), the estimate was then discussed by the experts and re-evaluated in the second round. Finally, as a means of validation, all the estimates and the overall time consumption per stakeholder were verified by the interviewed experts of the supply chains analysed and corrections were included if necessary (Fig. 1).

Based on the process object types activities, others and functional units (Table 2) used in the process maps and the expert estimates of the time consumption, a number of object-oriented discrete-event simulation models were built in order to determine the organisational and managerial work load (OMWL). OMWL includes all activities that are related to organisation and management of the supply chain and the operations. Depending on the activity, random numbers were generated according to different distributions. Communication activities, such as phone calls and personal conversations, were approached by using a left skewed Erlang distribution with shape parameter $k = 3$, based on Gans et al. concerning lengths of phone calls [40]. The other activities were approached by using normal distribution [39]. Since in practice the time consumption of the different activities will vary over a wide range, the standard deviation was set to ±25% of the mean.

For the simulations, 30 different random number streams were used and for each random number stream 30–35 simulations of an average stand were performed, resulting in over 1000 simulations in total. The software used for the model

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**Fig. 1** – Flowchart of the methodological steps taken during the analysis.

**Fig. 2** – Example from the business process map of the supply chain studied in Eno (Finland).
building and running the simulation was SigmaFlow™ Modeller. An independent model was constructed for each functional unit of the supply chain, resulting in 21 different models. Two additional models were constructed in order to assess the following conditions:

- the overall OMWL of ENO and FELD when the OMWL of the Forest Owner is left out of the simulation
- the OMWL of the functional units in FELD that are in charge of managing and organising the supply chain.

The results for the OMWL are presented in min/100 m³. However, the time consumption of many activities of the business processes, such as payments and communication, and also actions like creating maps and moving between work sites are not affected by the procured volume. Therefore, the OMWL is also given in min per operation.

### 3. Results

#### 3.1. Structure of the supply chains

##### 3.1.1. Eno (ENO)

The ENO supply chain involves 6 different actors and 7 functional units (Table 3). The local forest authority Metsäkeskus (Forest Authority) supports private forest owners in forest management activities, supervises operations, and can suggest forest areas to be harvested. The forest owners (Forest Owner) decide to perform a forest management operation in their forest, for instance a pre-commercial thinning, and monitors the operations in this forest. The forest service company (Forest Service Company) usually buys the assortment as standing timber and takes care of planning and carrying out of the procurement operation. Local entrepreneurs are contracted for logging and forwarding (Logging Contractor) as well as chipping and transportation of chips (Chipping Contractor). The last actor in this supply chain is the district heating cooperative which is the customer buying the chips. It is represented by two functional units: The accounting office (Accounting office) and the chairman of the cooperative (Chairman). These two play an active role in the monitoring of deliveries and payment of delivered chips. The accounting of the chips is based on calorific value, like it is common practice in Finland.

##### 3.1.2. Feldkirchen-Westerham (FELD)

The FELD supply chain involves 8 actors and 12 functional units (Table 3). Like in ENO, the forest owner (Forest Owner) and the local forest authority (Forest Authority) are involved in the supply chain. The Forest Authority supports and monitors private forest owners and their forest management activities. If the Forest Owner decides to contract work to the local FOA, the FOA operations supervisor (FOA Operations Supervisor) takes over. In collaboration with the Forest Authority, the FOA Operations Supervisor plans the treatment of the stand. The operations are carried out by a local logging contractor (Logging Contractor) which is contracted by the FOA Operations Supervisor. Once the logging operation is completed, the timber broker (Timber Broker) measures both the roundwood and energywood assortments in the forest. This procedure is used to guarantee unbiased measurement by a neutral individual. After the measurement the energy cooperative, in the form of the logistics manager (MWB Logistics Manager), takes over. The MWB Logistics Manager visits all energywood assortments on offer, checks quality and volume and negotiates the purchase price with the FOA Operations Supervisor. After the purchase, the pile is added to the stock. The MWB Logistics Supervisor is in touch with the second functional unit of the cooperative: the plant manager (MWB Plant Manager). When the bunker of the plant needs to be refilled, the MWB Logistics Manager schedules a suitable time with the chipping contractor (Chipping Contractor) and the haulage company (Hauling Contractor). Contrary to the supply chains in ENO, the responsibility for the processing and transportation of chips lies with the chip customer. When the chipping operation is finished, the monitoring and accounting is done by the accounting office (MWB Accounting Office) and sales manager of the energy cooperative (MWB Sales Manager). The accounting office of the FOA (FOA Accounting Office) monitors the incoming payment and matches them with their database and finally pays the Forest Owner and the Logging Contractor. The accounting of

<table>
<thead>
<tr>
<th>Group</th>
<th>Actor</th>
<th>Functional unit</th>
<th>Group</th>
<th>Actor</th>
<th>Functional unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>FO</td>
<td>Forest Owner</td>
<td>Forest Owner</td>
<td>FO</td>
<td>Forest Owner</td>
<td>Forest Owner</td>
</tr>
<tr>
<td>FA</td>
<td>Forest Authority</td>
<td>Forest Authority</td>
<td>FA</td>
<td>Forest Authority</td>
<td>Forest Authority</td>
</tr>
<tr>
<td>FSP</td>
<td>Forest Owners Association</td>
<td>FOA Operations Supervisor</td>
<td>FSP</td>
<td>Forest Owners Association</td>
<td>FOA Operations Supervisor</td>
</tr>
<tr>
<td>Timber Broker</td>
<td>Timber Broker</td>
<td>Timber Broker</td>
<td>Timber Broker</td>
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</tr>
<tr>
<td>CON</td>
<td>Logging Contractor</td>
<td>Logging Contractor</td>
<td>CON</td>
<td>Logging Contractor</td>
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<td></td>
<td>Chipping Contractor</td>
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<td></td>
<td>Hauling Contractor</td>
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<td>Hauling Contractor</td>
<td>Hauling Contractor</td>
</tr>
<tr>
<td>PLA</td>
<td>MW Biomasse</td>
<td>MWB Logistics Manager</td>
<td>PLA</td>
<td>MW Biomasse</td>
<td>MWB Logistics Manager</td>
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<tr>
<td></td>
<td></td>
<td>MWB Sales Manager</td>
<td></td>
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<td>MWB Sales Manager</td>
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<tr>
<td></td>
<td></td>
<td>MWB Plant Manager</td>
<td></td>
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<td>MWB Plant Manager</td>
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<tr>
<td></td>
<td></td>
<td>MWB Accounting Office</td>
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<td>MWB Accounting Office</td>
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</tbody>
</table>
Forest biomass is based on volume what is still common practice in Germany, among others.

3.2. Business process maps

The business processing mapping revealed a large number of activities in the two supply chains which are undertaken during the procurement process. As presenting the entire process maps is not possible due to their size, a segment of the process map for the ENO case is provided (Fig. 2). Figs. 3 and 4 present the sub-processes involved in the procurement process. The functional units are grouped as presented in Table 3 to lower their complexity: The functional units providing services to the Forest Owner are grouped in forest service providers (FSP). One group represents the contractors (CON) and another one the functional units of the actor running the heating plant (PLA).

The results of the analysis identified 183 activities and a total of 268 process objects for the supply chain of FELD in Germany, and 128 activities and a total of 214 process objects for the chain in ENO, Finland reflecting a higher organisational and managerial effort put into the operations from forest to the plant for the FELD plant.

The differences regarding the responsibilities are reflected by the distribution of activities (Fig. 5) as well as by the number of information items produced (Fig. 6). In the supply chain of ENO a single functional unit, the Forest Service Company, is in charge of organising the entire fuel procurement operation (purchasing, organisation, logging, processing, transportation, payments). In the supply chain of FELD multiple functional units take care of the organisation. The FOA Operations Supervisor, the Timber Broker, and the FOA Accounting Office manage the operation from finding the stands to the logging operation to measuring and selling the raw material. As MW Biomasse
itself takes care of the biomass supply, the MWB Logistics Manager, MWB Sales Manager and the MWB Accounting Office, are involved in the organisation of the chipping operation and the accounting of it. Taking this into consideration the number of activities occurring for the organisation and management of the SC is 72 in ENO and 103 in FELD.

A noteworthy difference between the supply chains is that forest owners in the Finnish supply chain are much more involved in the forest operations compared to the German one. Furthermore, the forest work carried out by the contractors is usually done more independently and contractors are given more responsibility than in Germany. For example, the Logging Contractor in Finland has the final decision on which trees are going to be cut whereas in Germany that decision lies with the Forest Authority. Furthermore, in Germany the logging sites are monitored on a daily basis by the FOA Operations Supervisor and chipping operations by the MWB Logistics Manager. This is one reason for a lower amount of activities in the procurement process in ENO.

Fig. 7 gives an overview of the data exchanges between the different functional units and the links between them. The numbers shown are maxima, meaning that not all of these exchanges are executed in every procurement operation. For instance, if an operation runs without any errors and failures the number can be significantly lower. The total number of data exchanges per operation is 39 and 66 in ENO and FELD, respectively.

### 3.3. Time consumption

The results showed that the overall average time consumption of the organisational and managerial work load (OMWL) in ENO...
and FELD is 1335 and 2071 min/operation, respectively (Fig. 8). The simulations also demonstrated that the supply chain with the highest number of functional units and activities involved (FELD) also involves the highest OMWL. As the assortments produced differ between the supply chains, the results of calculating the OMWL per 100 m³ gives a slightly different picture. While in ENO a work time input of 1483 min/100 m³ is required, in FELD it amounts to 1381 min/100 m³ given the higher output of the roundwood procurement operations.

The share of OMWL per grouping of functional units for both supply chains (Fig. 8) showed a broader range in the case of ENO. In this case, the Forest Service Company has the largest share with a total of 710 min/operation (789 min/100 m³). The organisational tasks carried out by the Forest Service Company are taken care of by multiple functional units in FELD grouped in FSP. If their shares of the OMWL are simulated in a separate model, the result is 913 min/operation (609 min/100 m³). The results also show that the Forest Owner in ENO is more involved in the overall processes compared to FELD. In addition the involvement of the Forest Authority in FELD is higher due to the fact that the district forester is marking stands before harvesting and acts as a mediator between Forest Owner and Forest Owners Association. Also the Logging Contractor’s involvement in FELD is higher than in ENO due to higher organisational effort in the preparation of the logging both in terms of communicating with all involved stakeholders and practical arrangements of the harvesting operation.

4. Discussion

This study focused on business process mapping and simulation of forest operations which has not been carried out earlier in this form. Nonetheless, the general study set up is similar to earlier studies using discrete-event simulation as demonstrated, for example, by Tolvanen-Sikanen et al. [30] and Väätäinen et al. [31]. In these studies as well discrete-event simulation models were developed on the basis of process flowcharts. However, the focus of research in the previous studies was centred on decision making in timber buying processes and machine interaction, respectively. The present study again focused on the investigation of business processes.

There is a wide variability in the results of previous studies related to the estimation of work load of state foresters. While Baumann’s study resulted in a work load of only 270 min/100 m³ [35], Hug determined a much higher figure of 960 min/100 m³ [34]. When comparing similar functional units, the results of this study for FELD and ENO are...
606 min/100 m³ and 792 min/100 m³, respectively. It must be taken into account that there are several differences in the setup of the various supply chains that precludes a direct comparison. For instance, in the FELD case energywood is only a by-product of roundwood procurement from commercial thinnings and final fellings, which covers the overall procurement costs and makes the operation profitable. The ENO case represents an energywood operation from young stands with a significantly lower recovery per ha.

The analysis of forest energy supply chains is a challenge due to the fact that forest energy operations are often integrated into traditional roundwood harvesting operations as

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Fig. 7 – Number of total data exchanged between the functional units of the supply chain in Eno (a) and Feldkirchen-Westerham (b). The numbers shown are totals, meaning that not all of them are necessarily exchanged every time.
was the case in FELD. This makes the analysis more complex and furthermore a clear separation is not possible in many cases. In the future, as the demand for forest biomass for energy is increasing, it can be expected that biomass increasingly will be procured from young stands. As such operations are economically critical, supply chains with lean and efficient business processes will be required.

Generally, the quality of the process maps strongly depends on the knowledge and experience of the interviewees and their awareness of the supply chain. Therefore, an iterative interview process with experienced practitioners involved in the actual operations was chosen as a means of cross-validating the results and the time estimates. Their strong involvement as data suppliers, observers, and evaluators ensures a realistic picture of the real-life working processes. Nonetheless, business process maps cannot show the complete reality since the processes within supply chains are highly flexible, among other reasons. This seems to be the case particularly in small-scale district heating plants where a lot of the work is shared between the different functional units.

The study revealed interesting new results related to the design and set up of supply chains in two different operational environments. The investigation of the supply chains revealed, for example that the number of activities carried out by the Forest Owner in ENO exceeds FELD by one third. The OMWL is even four times higher. This indicates that the Forest Owner’s involvement with their forest is much larger in ENO and that they spend more time monitoring the operations in their forests. However, many of the activities carried out by the Forest Owners, for example monitoring the logging and checking the work sites after the operations, are not of immediate importance for the operation itself. Nonetheless, they influence the overall OMWL in ENO considerably as can be seen from the distribution in Fig. 9. When the Forest Owner’s OMWL is not considered in the simulation, the difference between the total OMWLs of ENO (981 min/operation) and FELD (1986 min/operation) indicates a higher work load in FELD, even when the higher volume recovered is considered (ENO: 1090 min/100 m³; FELD: 1324 min/100 m³). When these models are used for cost calculations it must be considered whether taking the Forest Owner’s opportunity costs into account is meaningful and a careful analysis has to be done which activities performed by the Forest Owner are necessary from an operational point of view.

Finally, the use of process maps for the critical evaluation of each process object is essential to answer the increasing number of questions surrounding the more intensive use of forest biomass for energy, as among others, the reasons of certain operational environments to have less contributors and stakeholders in the chain, the mechanisms involved in the information flows among stakeholders, whether the OMWL can be decreased by eliminating stakeholders and/or by centralising responsibilities, and what are the potentials of modern information and communication technologies to improve the overall chain efficiency.

5. Conclusions

The present study investigated supply chains in two different locations in European countries and provided a detailed insight into their internal structure. The business process mapping revealed considerable differences in the numbers of activities and functional units involved in different operational environments. Additionally, the work expenditure...
related to managerial and organisational tasks defined as organisational and managerial work load (OMWL) was investigated for the supply chains as a whole and for each of the functional units. Although the maps are company specific, both supply chains reflect the characteristics of their operational environments and can be used to analyse similarities and differences between these.

The methods and results provided are essential for understanding the supply chain structure and can be used as a basis for a modelling approach to develop lean business processes for forest biomass procurement. Future research must be addressed to improve the overall efficiency of supply chains for forest biomass for energy, for example by implementing a process re-engineering method.

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