bio hub INFOSHEET

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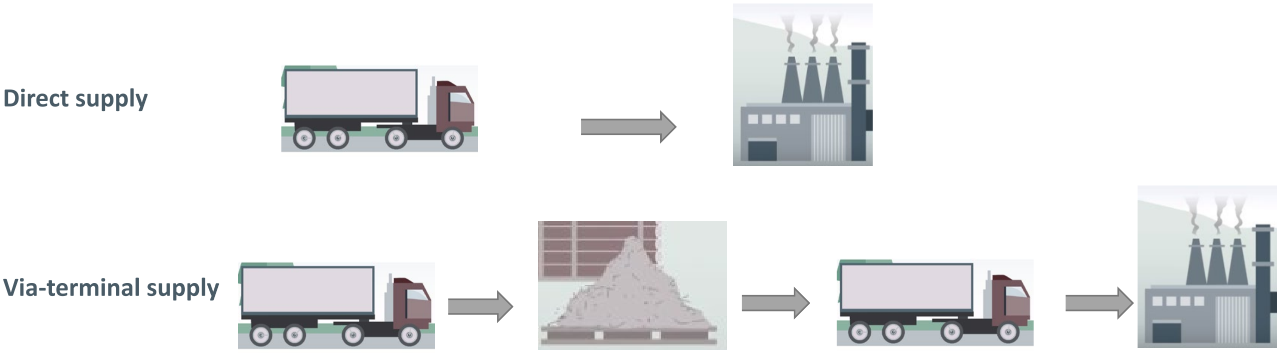
Supply chain simulation results

direct versus combined supply via-terminal of forest chips

By using simulations, we compared the supply cost of chipped logging residues and small-diameter trees to an energy plant (heat and power) and a biorefinery. Two supply options were considered: either direct supply from the forest roadsides or combined supply via-terminal. Combined supply via-terminal yielded, on average, 9% higher supply costs than direct-only supply from the forest. However, the terminal secured feedstock supply during periods of peak demand and problems in the forest machine fleet (when the direct-only supply chains failed to fulfil demand on time).



SIMULATION AIM

The main objective of this simulation study was to compare the supply cost of chipped logging residues and small-diameter trees to an energy plant (EP) and a biorefinery (BR), separately, considering direct-only or combined supply via-terminal, and industry's ("end-user") demand profile (Figure 1).

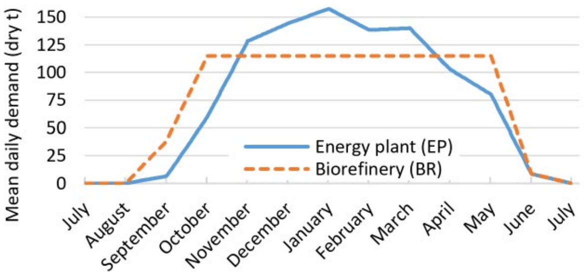
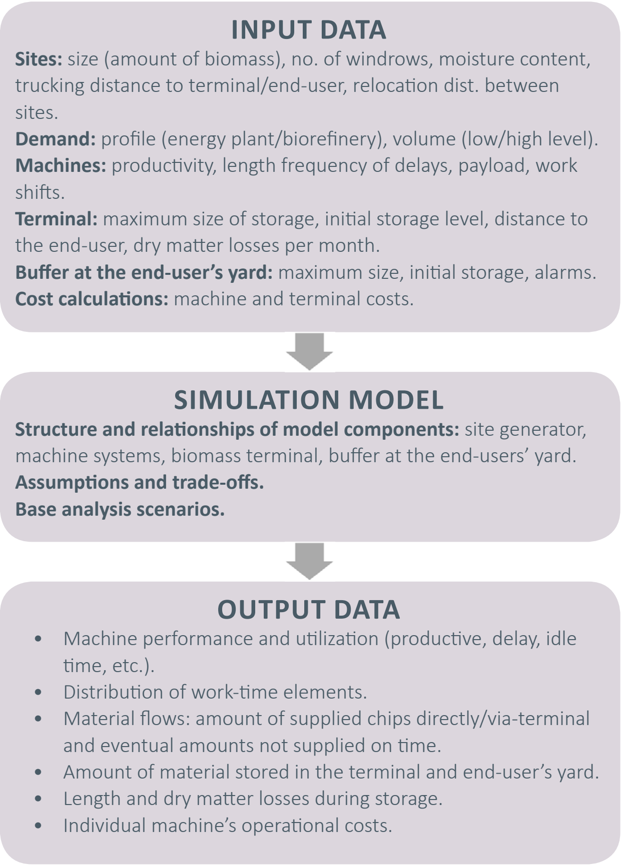


Figure 1. Mean daily demand of chips from the simulated end-users.

DESCRIPTION OF THE SIMULATION MODEL

A preliminary study plan was presented in [1]. A dynamic model for supply of forest chips was constructed using discrete-event simulation in ExtendSim®. An operational environment was designed and the annual work of a theoretical forest chip supplier in northern Sweden was modelled. To imitate real-world operation, stochasticity was



INPUT DATA

Sites: size (amount of biomass), no. of windrows, moisture content, trucking distance to terminal/end-user, relocation dist. between sites.

Demand: profile (energy plant/biorefinery), volume (low/high level).

Machines: productivity, length frequency of delays, payload, work shifts.

Terminal: maximum size of storage, initial storage level, distance to the end-user, dry matter losses per month.

Buffer at the end-user's yard: maximum size, initial storage, alarms.

Cost calculations: machine and terminal costs.

SIMULATION MODEL

Structure and relationships of model components: site generator, machine systems, biomass terminal, buffer at the end-users' yard.

Assumptions and trade-offs.

Base analysis scenarios.

OUTPUT DATA

- Machine performance and utilization (productive, delay, idle time, etc.).
- Distribution of work-time elements.
- Material flows: amount of supplied chips directly/via-terminal and eventual amounts not supplied on time.
- Amount of material stored in the terminal and end-user's yard.
- Length and dry matter losses during storage.
- Individual machine's operational costs.

Figure 2. Summary of main inputs and outputs in the model.

included through probability distributions controlling biomass characteristics, process time of machine activities, length and frequency of delays, forecasted biomass demand, etc. Input data was inserted directly in the model blocks, while relevant output data was exported to a spreadsheet for further calculations (Figure 2). The simulated biomass flow began with the generation of sites and ended at the storage yard (buffer) at the end-user (Figure 3). The model was designed to choose amongst two supply alternatives: either direct supply from the forest to the end-user or combined supply via-terminal (direct & via-terminal deliveries). Detailed characteristics of the generated sites are described in [2]. The simulation considered two levels of demand: low demand, set to 21 000 dry tonnes (t), and high demand, set to 29 000 dry t per annum (ca. 40 and 55%, respectively, of current supply of primary forest fuels for heat and power in Umeå). Both end-users were assumed to consume the same type of feedstock, and further processing of the incoming material was left outside the model boundaries. A daily delivery plan for the supply, for each demand level and end-user, was calculated, matching with the daily shares of forecasted demand (Figure 1) and including a spread of ±20%.

The machine fleet working for the modelled supplier consisted of two systems for comminution and transport of biomass from the forest. System 1 was integrated by a forwarder-mounted chipper (Figure 4) and two self-loading chip-trucks (Figure 5), while System 2 was integrated by a chipper-truck (Figure 6). The simulation assumed a partial untrafficability of forest roads due to freeze-thaw and snow melting during spring (to also avoid soil damages), limiting the access to forest sites and thus, halving the chip flow from the forest roadsides. Supply cost comprised comminution, transport operations in the supply chain, relocations, and eventually, terminal activities (wheel-loader, shuttle chip-truck and terminal operational cost). Upstream activities in the supply chain (e.g. harvest and forwarding) and overhead costs were excluded. Experiments with the model were executed according to defined analysis scenarios (Table 1), keeping inputs and system configurations constant between runs (5 replications for each setting).

Table 1. Base analysis scenarios in the simulation.

End-user	*Demand level*	*Supply alternative*	*Scenario*
Energy plant	Low (21 000 dry t)	Direct (only)	1
		Combined (direct & via-terminal)	2
	High (29 000 dry t)	Direct (only)	3
		Combined (direct & via-terminal)	4
Biorefinery	Low (21 000 dry t)	Direct (only)	5
		Combined (direct & via-terminal)	6
	High (29 000 dry t)	Direct (only)	7
		Combined (direct & via-terminal)	8

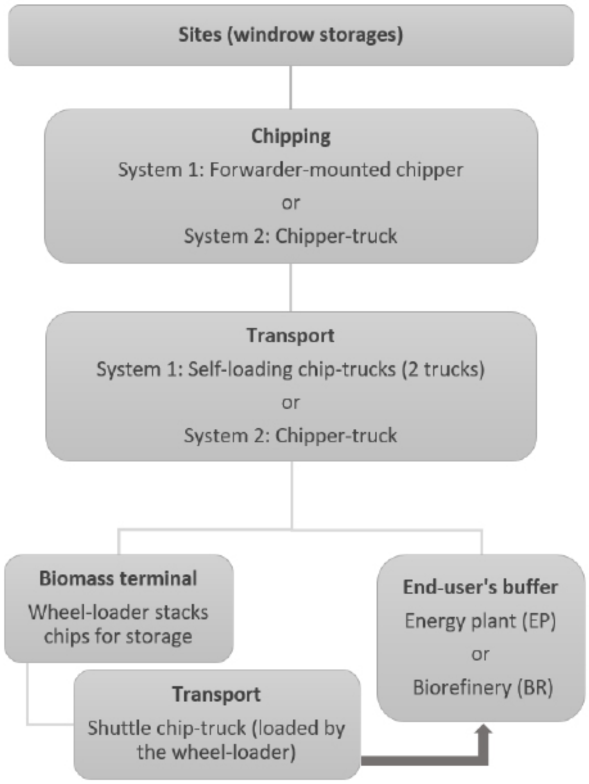


Figure 3. Outline of the combined supply chain (direct & via-terminal).

Figure 4. Operation of the modelled forwarder-mounted chipper.

Figure 5. Operation of the modelled self-loading chip-trucks.

Figure 6. Operation of the modelled chipper-truck.

Figure 7. Operation of the modelled wheel-loader and shuttle chip-truck in the terminal.

TERMINAL CHARACTERISTICS

A feed-in terminal was modelled (total 2 ha, paved), used for storage of chips and increasing the reliability of supply. A wheel-loader and a shuttle chip-truck (driving between the terminal and the end-user on a fixed path of 10 km) were modelled to operate the terminal (Figure 7). Facilities and machinery were shared with other suppliers. The maximum allowed storage size for our supplier was set to 3425 and 4729 dry t (≈4391 and 6063 m2), for the low- and high-demand scenarios, respectively. A mean dry matter loss of 2% per month during storage was modelled. The terminal operating cost was calculated to 8.3 €/dry t (investment and overhead costs), assuming a material turnover of 1.5 times/year. Storage levels at the industry's yard controlled upstream processes and biomass flows in the model. If storage levels exceeded 95% of total capacity, all material was redirected to the terminal. For levels between 60-95%, only direct deliveries from the forest were allowed. When storage levels at the plant decreased below 60%, outbound deliveries from the terminal were allowed, combining direct and via-terminal deliveries.

RESULTS

The simulation outputs revealed that the mean supply cost of chips was comparatively 5-11% higher (mean 9%) for the combined than direct-only supply scenarios. Mean supply cost averaged 47.0 vs. 43.2 €/dry t (≈9.7 vs. 8.9 €/MWh), for the combined and direct-only supply scenarios, respectively. Thus, placing a terminal in the supply chain increased mean supply cost by 3.8 €/dry t. Cost of direct supply to the EP averaged 42.7 €/dry t and combined supply 47.0 €/dry t. Direct supply to the BR averaged 43.8 €/dry t and combined supply 47.0 €/dry t. No significant differences were found between end-users amongst combined supply scenarios.

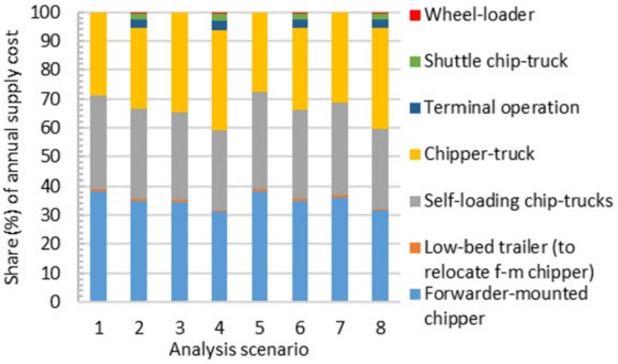


Figure 8. Share of each machine in the annual supply cost.

Machine System 1 (forwarder-mounted chipper and two self-loading chip-trucks) accounted for 59-72% of the annual supply costs (including relocations), whereas System 2 (chipper-truck) was responsible for 28-35% (Figure 8). Terminal activities (comprising the wheel-loader, shuttle chip-truck and terminal operational cost) accounted for 5-6% of the annual cost. System 1 yielded 8% higher operational cost than System 2 (44.2 vs. 40.8 €/dry t). The wheel-loader and shuttle chip-truck yielded a mean operational cost of 6.5 and 0.8 €/dry t, respectively. The factual (annual) utilization of machines was similar between end-users, but combined scenarios allowed a comparatively higher and more constant machine utilization. In contrast to the EP (with a seasonal demand), machine utilization when supplying to the BR was relatively constant throughout the year, regardless of the scenario.

Considering a low demand, the modelled chip supplier provided all biomass on time for both supply alternatives. However, for a high demand, supply was only fulfilled on time in the combined supply chains (scenario 4 and 8). In chains relying only on direct deliveries (scenario 3 and 7), a volume representing ca. 8% of the yearly demand was not provided on time. In scenario 3, the EP's demand was not met on time for several days in January and February, but the biggest problems aroused from March until the beginning of May (Figure 9). In scenario 7, the BR's demand was not met on time for several days from the middle of March until the middle of May. For combined supply scenarios, the amount of biomass passing through the terminal ranged between 15-17% of total supply.

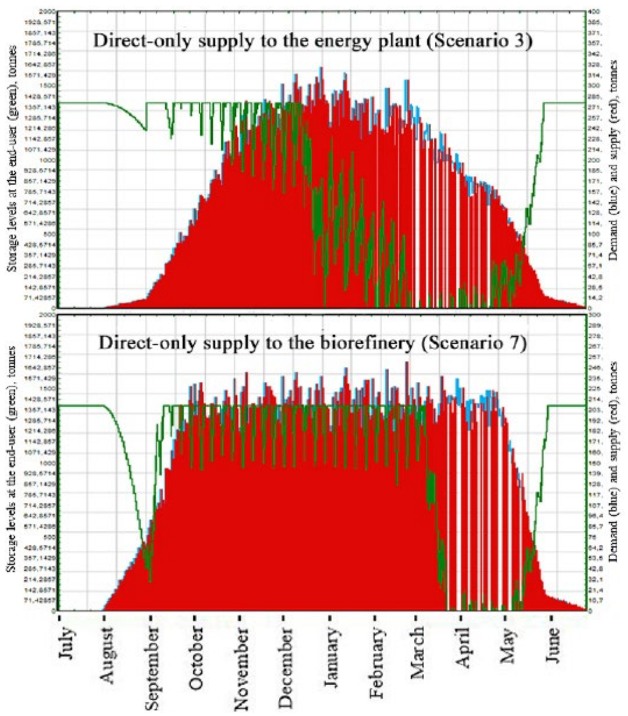


Figure 9. Storage levels at the end-user (left Y-axis, green line) when relying only on direct supplies (high-demand scenarios). Demand and supply are represented in blue and red, respectively (right Y-axis).

When supplying to the EP (Figure 10), the terminal storage was built up from September and reached its highest level in November. Outbound deliveries began already at the end of October, and increased for short periods in December and January. However, the majority of outbound deliveries occurred from the end of February until the beginning of May, decreasing storage levels drastically. Terminal storage was built up uniformly when supplying the BR (Figure 10), reaching its highest level at the beginning of March. The majority of outbound deliveries occurred from March onwards. Mean storage time at the terminal was 4-22% longer when supplying the EP than the BR (Table 2). Longer storage time, together with larger mean storage levels, resulted in 12-43% comparatively larger dry matter losses when supplying to the EP.

Table 2. Mean storage time, storage levels and dry matter losses at the terminal.

End-user	**Energy plant**		**Biorefinery**	
Demand	Low	High	Low	High
Analysis scenario	2	4	6	8
Mean storage time (weeks)	28	15	27	12
Mean storage levels (dry t)	2 095	1 563	1 998	1 182
Dry matter losses (dry t)	547	400	488	279

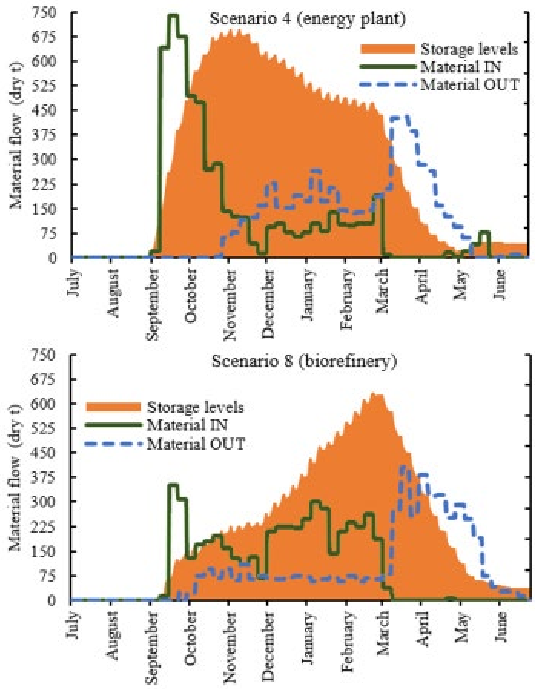


Figure 10. Daily storage levels and mean material flow in/out of the terminal for a high-demand level.

CONCLUSIONS AND FINAL REMARKS

- The current study showed the importance of terminals in increasing security of supply of forest feedstock to industries. Relying only on direct deliveries from the forest was feasible for the low-demand scenarios. Conversely, a higher demand could only be fulfilled if placing a terminal in the supply chain.
- The terminal made the supply chain resilient to peak demand (especially during January when supplying the EP) and operational problems in the supply fleet, caused by the untrafficability of forest roads during freeze-thaw and snow melting in spring (which limited the access to the forest sites).
- Even if terminal operations added extra costs in the chain (comparatively 5-11% higher cost than direct-only supply), comminution at roadside accounted for the bulk of costs.
- Supply to the EP resulted in 12-43% comparatively larger dry matter losses than supply to the BR.
- The use of terminals (for supply to EP/BR) and supply of forest feedstock to new customers such as BR may allow a constant, year-round operation of chipping entrepreneurs.
- When designing a terminal and managing material flows, dry matter losses should be minimized, finding a balance between keeping a low storage versus being able to fulfil demand when required.
- Restrictions to inbound/outbound deliveries to/from the terminal and different storage capacities could be tested in the simulation. Simulations can be particularly useful to assist decision-makers in terminal design and management.

- Specific results from this study are only valid for the considered input data and relationships between model components. The simulation used real data from a case study within 80 km around Umeå, so specific results should not be extrapolated to larger regions or countries.
- However, the model could be tailored to another case by changing input values, modelling alternative machine systems, or considering other industries and demand profiles, depending on the specific case and simulation purpose.

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[3] Fernandez-Lacruz R., Eriksson A., Bergström D. Direct versus combined supply via-terminal of forest residual biomasses: a simulation-based analysis (on-going manuscript).

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