Supply Chains of Wood Biomass

University of Eastern Finland 15.11.2019
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Supply and Energy Use of Lignocellulosic Biomass
Objectives

The main objectives of this session are:

- To review the most common procurement and supply chains of forest biomass.
- To understand the limitations and main factors that define a supply chain.
Outline

• General aspects of wood biomass
• Wood for Energy
• Forest Chips
• Supply Chains of Wood Biomass
• Quality aspects of Forest Biomass
• Biomass from forests – cost supply estimation
• Where is the money – economic viability of forest bioenergy
General aspects of wood biomass

- Bioeconomy
- Forest sector in Finnish bioeconomy
- Use balance of Finnish forest industry
Bioeconomy – the next wave of economy

Political and operational environment support bioeconomy
Bioeconomy in Finland

VALUE ADDED OF BIOECONOMY, 2018

- Water treatment and supply: EUR 1.7 billion
- Food sector: EUR 3.9 billion
- Construction: EUR 4.4 billion
- Energy: EUR 2.0 billion
- Other industries: EUR 3.5 billion
- Forest sector: EUR 9.1 billion
- Bioeconomy, total: EUR 25.2 billion

The share of bioeconomy: 12%

Value added of national economy: EUR 202.4 billion

*Preliminary data. Sources: Statistics Finland and Natural Resources Institute Finland.*
FOREST AND FOOD SECTORS IN FINLAND’S BIOECONOMY, 2018

- Whole bioeconomy
  - Output: 72,955 mll. €
  - Investments 2017: 6,401 mll. €
  - Exports of goods 2017: 17,874 mll. €
  - Employed: 303,227 persons

Forest and food sectors broken down by sub-sector:
- Forestry
- Wood-products industries
- Pulp and paper industries
- Agriculture
- Food industry

*Preliminary data
Sources: Statistics Finland and Natural Resources Institute Finland
Bioeconomy responds to global growing material demand and changing climate

IN THE YEAR 2030, IN FINLAND

Wood demand has reached 80Mm³/a
Mean annual temperature has risen by 2°C
Winter of Salpausselkä in 1980’s is approaching Kainuu

Green bioeconomy plays a central role in balancing the climate challenge and forest-based sourcing of goods and services

Source: A. Asikainen 2018
FROM STUMP TO MARKET
- forecast of fellings, processing and export of forest industry products 2020

Volume of growing stock 2.5 bn m³
Maximum annual sustainable felling removal 82 mill. m³

Roundwood imports 11.5 mill. m³

Industrial roundwood removals 63.3 mill. m³
-3%

Sawlogs 25.5 mill. m³
-5%

Pulpwood 37.8 mill. m³
-2%

Pulp and paper industry

Wood products industry

Plywood 1.2 mill. m³
-1%

Sawnwood 11.0 mill. m³
-5%

Wood chips

Pulp 8.1 mill. t
-1%

Paperboard 3.8 mill. t
+1%

Paper 5.6 mill. t
-10%

MARKETS

Export plywood 1 mill. m³ 559 €/m³ 0%
Export sawnwood 8.4 mill. m³ 150 €/m³ -3%
Export pulp 4.2 mill. t 535 €/t +3%
Export paperboard 3.5 mill. t 794 €/t +1%
Export paper 5.3 mill. t 687 €/t -10%

% Indicates change over the previous year
Higher use of wood for bioeconomy has minor effects on annual growth

Source: A. Asikainen 2018
USE BALANCE OF THE FINNISH FOREST INDUSTRY 2017 (mill. dry-matter tons of wood)

Return of forest industry by-products, to be used in the forest industry and energy generation 8.2

**USE**
- Logs and pulpwood 29.0
- Forest industry by-products and wood residues 9.4
- Energywood 6.0
- Recovered paper and paperboard 0.4
- Small-scale housing 2.8

**PRODUCTION**
- Sawmillng industry 6.0
- Plywood and veneer industries 0.7
- Other wood-products industries 0.2
- Mechanical pulp industry 13.5
- Chemical pulp industry 6.9
- Black liquor and other concentrated liquors 9.9
- Paper and paperboard industries 7.4
- Sawn goods 4.8
- Plywood 0.7
- Heating and power plants 5.2
- Small-scale housing 3.2
USE BALANCE OF THE FINNISH FOREST INDUSTRY 2017 (mill. dry-matter tons of wood)

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- Paper and paperboard industries 7.4
- Paper and paperboard 4.3
- Heating and power plants 5.2
- Small-scale housing 2.8

energy use
Bioeconomy & integrated use of woody biomass

- Bioeconomy leans heavily on the forest sector
- Use of woody biomass is also integrated to forest industry
- A large share of productions ends in energy use
Wood for Energy

- Reasons
- Consumption of wood fuels
Reasons behind: Climate
Reasons behind: **Resources**

- Forests cover 23 million ha (76%)
- Boreal forests
- Private forest cover 83% of roundwood removal
- Forestry and forest industries account for 6% of the GDP
CONSUMPTION OF WOOD FUELS, 2018

- Total energy consumption: 384 TWh
  - Renewable energy: 141 TWh
    - Wood fuels: 105 TWh
    - Small-scale combustion of wood: 17%
    - Black liquor and other concentrated liquors: 45%
    - Heating and power plants: 37%
  - Other renewable: 26%
  - Fossil fuels: 35%
  - Nuclear energy: 17%
  - Others: 8%

The data for 2018 are partly preliminary.

Sources: Statistics Finland, Natural Resources Institute Finland

1 Other renewable energy includes wind and hydro power, heat pumps, solar energy and other biofuels.
Consumption of fossil fuels and renewables

Source: Natural Resources Institute Finland, Statistics Finland.
Total energy consumption by energy source

Source: Natural Resources Institute Finland, Statistics Finland.
Total wood fuels consumption by energy source

Source: Natural Resources Institute Finland, Statistics Finland.
CO₂ storage grows fast in Finnish forest despite energy use of wood

Source: A. Asikainen 2018
Forest Chips

- Raw materials of modern firewood
- Use of forest chips
SOLID WOOD FUEL CONSUMPTION
IN HEATING AND POWER PLANTS, 2018 (mill. m³)

Total consumption
19.9 mill. m³
Solid wood fuel consumption in heating and power plants

Source: OSF: Natural Resources Institute Finland, Wood in energy generation.
Solid wood fuel consumption in heating and power plants by woof fuel assortment

Source: OSF: Natural Resources Institute Finland, Wood in energy generation.
Raw materials of modern firewood

Logging residues
Small-sized wood

Stumps
Large-sized, (rotten) wood
(Stem wood loss)
Consumption of forest chips in heating and power plants by raw material

Source: OSF: Natural Resources Institute Finland, Wood in energy generation.
Total consumption of forest chips

Source: OSF: Natural Resources Institute Finland, Wood in energy generation.
Consumption of forest chips by plant type

Source: OSF: Natural Resources Institute Finland, Wood in energy generation.
Supply Chains of Wood Biomass

- Forest energy supply chains
- Integration of operations
”From the first societies and economies in Egypt, Mesopotamia/Persia, China and Central America, the wellbeing of mankind depended on the ability to transport and store goods effectively and efficiently.”

Biomass supply
Harvesting
Biomass supply

Source: Prinz 2019
Integration of Roundwood & Energy Wood Harvesting: benefits for entrepreneurs
Forwarding
Storage
Chipping
Transport
Logging Residues
Thinning

Delimbed stems supply chain from thinnings with roadside chipping

© Natural Resources Institute Finland
Stumps
Integration of Roundwood & Energy Wood Harvesting: more options & raw materials
STUMP AND ROOT WOOD

- Uprooting & splitting of stumps by excavator
- Forwarding of stumps

LOGGING RESIDUES

- Piling of logging residues integrated into roundwood harvesting
- Forwarding of loose residues
- Communion in the terrain
- Transportation of chips by truck
- Transportation of residue logs & loose residues
- Communion at the end use facility

SMALL Sized ROUNDWOOD

- Mechanized felling-bunching of thinning wood
- Manual felling-bunching of thinning wood
- Forwarding of small sized energy wood
- Comminution at the landing
- Transportation of residue logs & loose residues
- Comminution at the end use facility
- Transportation of chips by truck
- Comminution at the end use facility

GENERATION TO ENERGY OR BIOREFINING

Source: J. Laitila 2006
Different terrain: Using cable yarding operation in steep terrain

Integration of manual full tree harvesting operations in steep terrain
Different scale of operations
Different management of operations

Eno, Finland

Feldkirchen-Westerham, Germany

The diagrams illustrate the operational processes in Eno, Finland, and Feldkirchen-Westerham, Germany. Each process is divided into stages such as finding stands, preparation of logging, logging, and follow-up activities. The charts highlight the differences in the management of these operations between the two locations.
Different management of operations

See literature:

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

Johannes Windisch a,*, Dominik Röser b, Blas Mola-Yudago c, Lauri Sikanen c, Antti Asikainen a

a Finnish Forest Research Institute, Jonesuu Research Unit, P.O. Box 68, FIN-80101 Joensuu, Finland
b FPinnovations, 2665 East Mall, Vancouver, BC V6T 1W5, Canada
c University of Eastern Finland, School of Forest Sciences, P.O. Box 111, FIN-80101 Joensuu, Finland
Different raw material (Short Rotation Coppice)
Different methods of harvesting & off-road transportation

Tree-Length (TL) vs. Cut-To-Length (CTL) harvesting
Different methods of harvesting & off-road transportation using skidder

manual

Tree-length harvesting system with manual felling and skidding to the roadside landing

Feller buncher

Mechanized full tree harvesting system with a feller buncher and processing at the landing
Different methods of off-road transportation

bundling of logging residues

chipping at a terminal
Different methods of chipping

- Terrain chipping
  - Manual whole tree felling from thinnings with terrain chipping

- Chipping at plant
  - Whole tree procurement chain from thinnings with chipping at the plant
Different chip transportation modes:
Different methods for stump lifting:

Infres innovation demonstration: stump drill with theoretical possibilities to expand resource base
Different truck transportation alternatives:
Terminal as alternative to direct supply
Different truck transportation alternatives: Terminal as alternative to direct supply

See literature:

Alternative operation models for using a feed-in terminal as a part of the forest chip supply system for a CHP plant

Kari Väätäinen¹, Robert Prinz¹, Jukka Malinen², Juha Laitila¹ and Lauri Sikanen¹

¹Natural Resources Institute Finland (LUKE), Joensuu, Finland, ²University of Eastern Finland (UEF), Joensuu, Finland
Different methods to study biomass supply depending on focus & objectives

<table>
<thead>
<tr>
<th>Method</th>
<th>Harvesting</th>
<th>Comminution</th>
<th>Transportation</th>
<th>Terminal handling</th>
<th>Transportation</th>
<th>Machine data &amp; measurements</th>
<th>Time study data &amp; measurements</th>
<th>Simulation</th>
<th>Simulation</th>
<th>Solutions to increase energy efficiency &amp; performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of machine settings</td>
<td>Introduction of new machine</td>
<td>2 chipper alternatives</td>
<td>2 raw material alternatives</td>
<td>Introduction of terminal option</td>
<td>Supply alternatives from terminal</td>
<td>Alternative chip-truck options</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: modified from: Prinz 2019
Quality aspects of Forest Biomass

- EU standards and classifications
- Moisture content management
Specification and classes (EN 14961-1)

- Classification is based on origin and source, major traded forms and properties
- Hierarchical classification system in table format:
  1. Woody biomass
  2. Herbaceous biomass
  3. Fruit biomass
  4. Biomass blends and mixtures
     - blends = intentional
     - mixtures = unintentional
- Part 1 for all user groups, Parts 2–6 for non-industrial use
- Special requirements for chemically treated biomass
- Chemical treatment defined as any treatment with chemicals other than air, heat or water (e.g. glue and paint)

Source: Eija Alakangas, VTT
## Woody Biomass

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Forest, plantation and other virgin wood</td>
<td>1.1.1 Whole trees without roots</td>
</tr>
<tr>
<td></td>
<td>1.1.2 Whole trees with roots</td>
</tr>
<tr>
<td>1.1.3 Stemwood</td>
<td>1.1.3.1 Broadleaf</td>
</tr>
<tr>
<td></td>
<td>1.1.3.2 Coniferous</td>
</tr>
<tr>
<td>1.1.4 Logging residues</td>
<td>1.1.3.3 Blends and mixtures</td>
</tr>
<tr>
<td></td>
<td>1.1.4.1 Fresh/Green, Broadleaf (including leaves)</td>
</tr>
<tr>
<td>1.1.5 Stumps/roots</td>
<td>1.1.4.2 Fresh/Green, Coniferous (including needles)</td>
</tr>
<tr>
<td></td>
<td>1.1.4.3 Stored, Broadleaf</td>
</tr>
<tr>
<td></td>
<td>1.1.4.4 Stored, Coniferous</td>
</tr>
<tr>
<td></td>
<td>1.1.4.5 Blends and mixtures</td>
</tr>
<tr>
<td>1.1.6 Bark (from forestry operations)</td>
<td>1.1.5.1 Broadleaf</td>
</tr>
<tr>
<td>1.1.7 Segregated wood from gardens, parks,</td>
<td>1.1.5.2 Coniferous</td>
</tr>
<tr>
<td>roadside maintenance, vineyards and fruit</td>
<td>1.1.5.3 Short rotation coppice</td>
</tr>
<tr>
<td>orchards</td>
<td>1.1.5.4 Bushes</td>
</tr>
<tr>
<td>1.1.8 Blends and mixtures</td>
<td>1.1.5.5 Blends and mixtures</td>
</tr>
</tbody>
</table>

*Alakangas (2010)*
Quality of forest biomass

Boiler size

Quality requirement
Properties of Forest Chips

- chips made of different raw materials and with different technologies differ in properties such as
  - moisture content
  - basic density
  - lower heating value
  - bulk density
  - chemical content
  - ash content
  - impurities

Hakkila (2004)
Properties of Forest Chips

Proportion of solids in forest fuels. All loads have the same solid content. (Modified after Nilsson 1983).
Moisture in wood increases production costs of forest energy

- affects costs in every work phase after felling
  - Forwarding ↑
  - Chipping / crushing ↓
  - Transport↑
  - Storage & handling ↑
  - Conversion ↑ (↓)

Sikanen et al. 2012
Moisture content in long distance transportation

- Truckloads: 1,435, 2,241
- Chip demand (m³): 157,742, 210,206
- Costs (€): 36,000, 62,600
- CO₂ emissions (t): 859, 1,341

Fuel need: 170,000 MWh/a

150 km roundtrip

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Biomass from forests –
cost supply estimation

- Cost estimations on EU level
- Cost-supply curves
- Limitations

Robert Prinz & Perttu Anttila (INFRES project)
Holistic planning of supply chains

Availability of raw material
Area & volume / ha
Annual increment
Cuttings and savings
Ownership and markets
Characteristics of material

Harvesting and comminution
Technology
Productivity in varying conditions
Entrepreneurship
Earning possibilities
Unit cost calculation

Transportation
Technology
Productivity in varying conditions
Entrepreneurship
Supervision and control
Earning possibilities
Unit cost calculation

Combustion
Technology
Efficiency
Fuel quality requirements
Ownership
Cost of fuel => pricing
Customer needs
Resource-Focused Cost-Supply Method

• based on forest resource data
  - tree & plot level data
  - stand-level data
  - regional data
• varies in time and space
• biomasses estimated with biomass models or factors
• constraints for wood production and procurement
• road network
• available data varies case by case -> you have to play with what you have!

Photo: R. Prinz
Categorization & Selection of chains

- **Categorization**
  
  NEU: Northern Europe (FI, SE, UK, IE, EE, LT, LV)  
  CEU: Central Europe (AT, DE, FR, DK, LU, BE, NL)  
  EEU: Eastern Europe (CZ, PL, HU, RO, SK, SI)  
  SEU: Southern Europe (IT, BG, PT, ES)

- **Selection of dominant supply chains**
  
  - for stemwood and stem and crown biomass from early thinnings
  - for logging residues
  - for stumps
  - transportation of chips by truck
Selection of dominant supply chains

Source: Diaz-Yanez et al. 2013
Selection of dominant supply chains

See literature:

Forest chips for energy in Europe: Current procurement methods and potentials

Olalla Díaz-Yáñez a, Blas Mola-Yudego a,b,*, Perttu Anttila c, Dominik Röser c, Antti Asikainen c

a School of Forest Sciences, University of Eastern Finland, PO Box 111, FI 80101 Joensuu, Finland
b Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), PO Box 7016, S-750 07 Uppsala, Sweden
c Finnish Forest Research Institute (METLA), PO Box 111, FI 80101 Joensuu, Finland

Source: Diaz-Yanez et al. 2013
### Example: Dominant supply chains

**Selection of procurement method until the roadside:**

<table>
<thead>
<tr>
<th>Stemwood and stem and crown biomass from early thinnings</th>
<th>Logging residues</th>
<th>Stumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felling &amp; bunching by harvester</td>
<td>Piling of residues by harvester</td>
<td>Extraction by excavator</td>
</tr>
<tr>
<td>Off-road transport by forwarder</td>
<td>Off-road transport by forwarder</td>
<td>Off-road transport by forwarder</td>
</tr>
<tr>
<td>Commination by mobile chipper</td>
<td>Commination by mobile chipper</td>
<td>Commination by mobile grinder</td>
</tr>
</tbody>
</table>
Unit costs in mechanised harvesting of roundwood by felling method

Source: Metsäteho Oy.
Survey of cost factors related to forest harvesting operations

Additional factors

Cost factors related to forest harvesting operations

Costing model

Machine costs (€/h)

Additional factors
- fuel cost (for ref. in survey)
- labour cost (survey)
- interest rate (survey)
- machine costs
- other machine parameters (fuel consumption, salvage value, maintenance costs etc.)

The costing model developed for the Cost Action FP0902 was utilized in machine cost calculations (Ackerman et al. 2014)
Survey of cost factors related to forest harvesting operations

Factors related to forest harvesting operations

Raster data
- removal at felling area (m3/ha)
- average dbh of removal (cm)

Biomass models
- based on selected species
- broadleaf & conifer species
- defined species in CEU, NEU, EEU, SEU

Survey data
- off-road distance
- other relevant factors

Raster data
- removal
- dbh

Productivity models
- based on selected machines
- proven models
- fixed transportation distance (60km)
’The Raster Calculation Approach’
Survey of cost factors related to forest harvesting operations

Additional factors

Cost factors related to forest harvesting operations

Raster data
  • removal at felling area (m³/ha)
  • average dbh of removal (cm)

Biomass models

Productivity models

Potentials (m³)

Productivity (m³/h)

Connect cost to potential

Costing model

Machine costs (€/h)

NUTS-level supply costs (€/m³)
Logging Residues

Logging residues with chipping at roadside
Logging residues

Logging Residues Conifers

€/m³

<table>
<thead>
<tr>
<th>Region</th>
<th>Transportation</th>
<th>Chipping</th>
<th>Forwarding</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEU</td>
<td>10</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>EEU</td>
<td>15</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>NEU</td>
<td>20</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>SEU</td>
<td>25</td>
<td>20</td>
<td>5</td>
</tr>
</tbody>
</table>

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Thinning

Delimbed stems supply chain from thinnings with roadside chipping
Thinning

€/m³  Stems from Thinning Conifer

- CEU
- EEU
- NEU
- SEU

- Transportation
- Chipping
- Forwarding
- Harvesting (CTL)
Thinning

Higher harvesting costs in Northern Europe due to smaller average tree volume.
Stems from final felling

Stem wood with chipping at the roadside
Stems from felling

€/m³ Stems from Final Felling Conifer

- CEU
- EEU
- NEU
- SEU

- Transportation
- Chipping
- Forwarding
- Harvesting (CTL)
CTL, Manual with Cable Yarding & Skidding

€/m³ Stems from Final Felling Conifer in EEU

- CTL mechanized
- CTL Innovations
- Manual + Skidding
- Steep Terrain
- Manual + Miniskidder
Stumps

Stump Lifting Conifers NEU

€/m³

Finland  Sweden  United Kingdom

- Transportation
- Grinding
- Forwarding
- Stump lifting

© Natural Resources Institute Finland
Supply cost estimation - EU

- EU cost supply based on mechanized Cut-To-Length method applied with conifers and an average transportation distance of 60km

Potential $10,000,000\text{m}^3$

Cost-Supply EU

- Graph showing cost supply in €/m³ for different potential volumes.
Discussion/Uncertainties

There are several uncertainties & limitations in the calculated costs!

- One supply chain per biomass category (dominating chains with varying feasibility vs. comparability of the costs)
- Machine-level input data were assumed constant among the countries (without VAT)
- Point of time for input data
- Labour costs are based on broad Eurostat data (not real labour cost of operators)
- One productivity model per biomass category and work phase
- Accuracy of the intensity and average diameter data is unknown
- Terrain slope currently not considered in cost calc.
- Estimation of stem, crown and stump volumes was simplified (one species for each of the four country categories)
- Input data: difficult to obtain at regional or even country level (limited statistics, survey with expert opinions)
So, having seen some details of supply chain calculations for different parts of the EU…

…what are the factors affecting supply costs in general?
Factors affecting supply costs, among others:

- **Performance details**
  - Load space
  - Weight limitations & Payload
  - Un-/Loading times
  - Fuel consumption
  - Productivity
  - Unit piece size
  - Speed
  - Set-up time & Relocation time
  - Bulk density
  - Moisture content
  - Availability
  - Machine utilization
  - Working shifts/days/hours
  - etc.

- **Capital factors/ fixed costs**
  - Investment costs
  - Insurance
  - Administration
  - Lifetime
  - Salvage value
  - Interest
  - Risk

- **Salary costs/ Operator costs**
  - Hourly wages
  - Indirect salary costs

- **Variable costs**
  - Fuel consumption
  - Repair/service
  - Tyres etc.
Test:

• What do you think is more cost efficient combination of truck and chipper for the delivery of chips from a roadside storage to a heating plant in distances from 20km to 140km?

  – Trucks:
    • 52t semitrailer
    • 60t ”standard” truck & trailer combination
    • 69t ETS truck & trailer combination

  – Logging residues & small diameter trees
## Performance details

<table>
<thead>
<tr>
<th></th>
<th>52-tonne semitrailer</th>
<th>60-tonne truck-trailer</th>
<th>69-tonne ETS truck-trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame volume of the load space [bulk-m³]</td>
<td>92.0</td>
<td>129.0</td>
<td>157.4</td>
</tr>
<tr>
<td>Unloaded weight of the truck-trailer [kg]</td>
<td>17,000</td>
<td>23,000</td>
<td>27,000</td>
</tr>
<tr>
<td>Payload of the truck-trailer [kg]</td>
<td>35,000</td>
<td>37,000</td>
<td>42,000</td>
</tr>
<tr>
<td>Weight/volume ratio, [kg bulk-m⁻³]</td>
<td>380.4</td>
<td>286.8</td>
<td>266.8</td>
</tr>
<tr>
<td>Total permissible weight of the truck-trailer [kg]</td>
<td>52,000</td>
<td>60,000</td>
<td>69,000</td>
</tr>
<tr>
<td>Set-up time at roadside storage [h]</td>
<td>0.15</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Scaling-unloading at plant [h]</td>
<td>0.25</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Fuel consumption [l 100 km⁻¹]</td>
<td>45</td>
<td>55</td>
<td>62</td>
</tr>
</tbody>
</table>

## Capital factors

<table>
<thead>
<tr>
<th></th>
<th>52-tonne semitrailer</th>
<th>60-tonne truck-trailer</th>
<th>69-tonne ETS truck-trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck [€]</td>
<td>124,200</td>
<td>144,200</td>
<td>166,300</td>
</tr>
<tr>
<td>Trailer + equipment [€]</td>
<td>97,300</td>
<td>142,800</td>
<td>185,500</td>
</tr>
<tr>
<td>Number of truck wheels</td>
<td>8</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Truck wheels [€ piece⁻¹]</td>
<td>725</td>
<td>725</td>
<td>725</td>
</tr>
<tr>
<td>Number of trailer wheels</td>
<td>6</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>trailer wheels [€ piece⁻¹]</td>
<td>450</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>Truck life time [years]</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Trailer life time [years]</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>max distance for tyres [km]</td>
<td>120,000</td>
<td>120,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Interest percentage [%]</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Insurance [€ year⁻¹]</td>
<td>5,500</td>
<td>8,000</td>
<td>8,500</td>
</tr>
<tr>
<td>Administration costs [€ year⁻¹]</td>
<td>8,085</td>
<td>8,319</td>
<td>8,443</td>
</tr>
<tr>
<td>Entrepreneurial risk, margin percent [%]</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

## Salary factors

<table>
<thead>
<tr>
<th></th>
<th>52-tonne semitrailer</th>
<th>60-tonne truck-trailer</th>
<th>69-tonne ETS truck-trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver's hourly wages [€ h⁻¹]</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Indirect salary percentage [%]</td>
<td>68</td>
<td>68</td>
<td>68</td>
</tr>
</tbody>
</table>

## Variable cost factors

<table>
<thead>
<tr>
<th></th>
<th>52-tonne semitrailer</th>
<th>60-tonne truck-trailer</th>
<th>69-tonne ETS truck-trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel price [€ l⁻¹]</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>Repair/service [€ year⁻¹]</td>
<td>16,000</td>
<td>16,000</td>
<td>16,000</td>
</tr>
<tr>
<td>Tyres (coating) [€ piece⁻¹]</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>
the answer in theory:

Source: Prinz et al. 2019
the answer in theory:

..., but...

Source: Prinz et al. 2019
...it depend also on the objectives:

- are the total supply costs the main focus?

- or are maybe other efficiency aspects as the main objective...?
…it depend also on the objectives:

- or are maybe environmental aspects (fuel consumption, CO₂ emissions etc.) the main objective…?

Source: Prinz et al. 2019

Scattergram of the fuel consumption (l m⁻³) data as a function of stem size, for two harvester setting treatments. The analysis excludes the Ergo machine and BAU setting input data. [Source: Prinz et al. 2018]
...it depend also on the objectives:

- or maybe some other aspects such as time spent/ not spent for certain operations...?

- or maybe some other aspects (flexibility, safety, employment...)...?
…more information on mentioned two cases:

See literature:

**Analysis of energy efficiency of forest chip supply systems using discrete-event simulation**

Robert Prinz\textsuperscript{a}, Kari Vääätäinen, Juha Laitila, Lauri Sikanen, Antti Asikainen  
*Natural Resources Institute Finland (Luke), Production Systems, Ylöpohuokatu 6, 80100 Joensuu, Finland*

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**Modifying the settings of CTL timber harvesting machines to reduce fuel consumption and CO\textsubscript{2} emissions**

Robert Prinz\textsuperscript{a,\textsuperscript{*}}, Raffaele Spinelli\textsuperscript{b}, Natacia Magagnotti\textsuperscript{b}, Johanna Routa\textsuperscript{a}, Antti Asikainen\textsuperscript{a}  
\textsuperscript{a}Natural Resources Institute Finland (Luke), Ylöpohuokatu 6, 80100, Joensuu, Finland  
\textsuperscript{b}CNR AVALS, Via Madonna del Piano 10, Sesto Fiorentino, FI, Italy
…it does not always work as planned…

Photo: D. Röser
Where is the money – economic viability of forest bioenergy

- Forest owners
- Forest fuel entrepreneurs
- Energy producers
Biannual stumpage prices of logs and pulpwood 2011-2020e in 2018 prices (cost-of-living index)
Roundwood dominates in forest owner’s income, case Finland, approximately/simplyfied:
Energy wood in forest owner’s economy

• **Thinnings**
  – Income from the biomass ca. 200 €/ha
  – Subsidy to make the first thinning: 260 €/ha
  – Value growth of forest improves: fewer but bigger trees

• **Final fellings**
  – Income from biomass ca. 200 €/ha
  – No subsidies
  – If stumps harvested, soil preparation for planting is free e.g. savings 500€/ha
  – Better regeneration result; small plants survive better
### Table 1: Procurement Costs Delivered at Plant, €/m³

<table>
<thead>
<tr>
<th>Distance</th>
<th>Whole Trees</th>
<th>Residues</th>
<th>Stumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 km Kokopu &amp; W</td>
<td>30 m³</td>
<td>30 m³</td>
<td>30 m³</td>
</tr>
<tr>
<td>90 km Kokopu &amp; terminal</td>
<td>30 m³</td>
<td>30 m³</td>
<td>30 m³</td>
</tr>
<tr>
<td>Delivery from terminal</td>
<td>25</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Long distance transp.</td>
<td>15</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Chipping</td>
<td>10</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Forwarding</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Baling</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Stump lifting</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Felling &amp; Bunching</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Admin. costs</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Legend:**
- vv = välivarastohaketus
- kp = käyttöpaikkahaketus
- terminaali = terminaalihaketus

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**Laitila et al. 2011**
Energy producer’s perspective:
Replacing oil with biomass is profitable

Prices without tax, Finland

Source: A. Asikainen 2018
Business in form of heat entrepreneurship

Source: TTS Institute
Examples of Success: Big scale CHP plants, FORTUM

- Can use different raw material: Wood, Reed, Canary Grass and Peat
- Cover 95% of district heat needed in Joensuu which means around 40,000 people
- District heating network is ca. 200 km long
- Innovative: Pyrolysis Oil production
Examples of Success: Small scale Kuittila Farm, Nurmes

- Remote location,
- Close to resources
- High energy demand on site
  - Heating grid
  - Drying of raw materials
  - Small scale CHP (110kW) for electricity production too
Examples of Success: Big scale and Small scale CHP or heating plants

- Each one has different supply chains, depending on the raw material used and possible given the technology used, depending on the objectives
Lessons learned & perspectives

• Forest fuels can generate remarkable business and local welfare.
• Increased use of wood for traditional pulping and sawing increases also wood energy production.
• Holistic planning of value chains is crucial to ensure reliability.
• Supply chains depend also on objectives.
• “hot” chain with chipping at roadside (directly to truck) most common.
• There is not one supply chain solution, there are several, depending on the operational environment.
• Logistics need to be developed when volumes get higher.
Thank you!