Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe

S2Biom Project Grant Agreement n°608622

D3.2
Logistical Concepts

31 August 2015

About S2Biom project

The S2Biom project - Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe - supports the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies, and roadmaps that will be informed by a "computerized and easy to use" toolset (and respective databases) with updated harmonized datasets at local, regional, national and pan European level for EU28, Western Balkans, Moldova, Turkey and Ukraine. Further information about the project and the partners involved are available under www.s2biom.eu.

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About this document

This report corresponds to D3.2 of S2Biom. It has been prepared by:

Due date of deliverable:	31 August 2015 (Month 24)
Actual submission date:	31 August 2015 (version 1)
Start date of project:	2013-01-09
Duration:	36 months

Work package	WP3
Task	3.2
Lead contractor for this deliverable	DLO
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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services):	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Version	**Date**	**Author(s)**	**Reason for modification**	**Status**
0.1	31/7/2015	E. Annevelink	First version sent to WP3 partners with request for additions & comments	Sent
1.0	31/8/15	E. Annevelink et al.	All contributions and comments of partners processed	Ready

This project entitled S2Biom (Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe) is co-funded by the European Union within the 7th Framework Programme – Grant Agreement n°608622 The sole responsibility of this publication lies with the author. The European Union is not responsible for any use that may be made of the information contained therein.

Executive summary

The main objective of this deliverable was to define logistical concepts: what logistical concepts can be described (both existing & new) that enclose several types of biomass delivery chains.

A survey of various logistical biomass value chains in various European projects was made. A biomass value chain connects the available biomass types with the final conversion process through various logistical components. Based on the survey of biomass value chains the most important logistical concepts were identified. A logistical concept is broader and more general than a specific biomass value chain. A chosen logistical concept always still needs to be further specified and translated in order to obtain a specific biomass value chain (specify all the components). Often several possible biomass value chains fit within that general logistical concept. A qualitative assessment of each logistical concept was made.

Finally the merits of existing logistical assessment methods (cost calculation and GHG calculation methods) were judged for the purposes of use within the S2Biom project.

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1. Introduction

1.1 Aim of Task 3.2

The Description of Work of S2Biom specifies the details of Task 3.2 'Identify and assess logistical concepts to optimize sustainable non-food biomass feedstock delivery chains'. The subtasks are summarized below.

1) Define logistical concepts: what logistical concepts can be described (both existing & new) that enclose several types of biomass delivery chains that were found?

The first subtask is to identify existing logistical concepts and conceptual designs at both centralised and decentralised scale, incorporating some elements of pre-processing/densification. The aim is to develop new logistical concepts and conceptual designs that potentially could be used within sustainable non-food biomass feedstock delivery chains at centralised and decentralised locations, taking into account the logistical components as identified in Task 3.1 (Annevelink et al., 2014a). For identifying new logistical concepts a close cooperation will be established with the existing three EU-FP7 logistical projects that were started in 2013 being: LogistEC (biomass crops), EuroPruning (biomass pruning residues) and INFRES (forest residues) through the project partners that are also involved in these projects (INRA, CIRCE, LUKE & BTG).

2) Assess logistical concepts: what are the costs and GHG effects of these logistical concepts?

The next subtask is to use available logistical tools to assess theoretically both existing and new logistical concepts on their economic results and GHG emission impacts. For the forestry sector in particular, the integration of energy feedstock supply chains into large industrial wood supply streams using road, rail and waterway transport and terminal hubs will be analysed using dynamic discrete-event simulation models. It should also include assessing transportation properties and safety issues in the logistical pathways.

3) Map logistical concepts: where can these logistical concepts be implemented optimally (on an EU-level and on a regional level)?

Finally the third subtask is to identify on a map the most promising locations for the optimal logistical concepts, both at decentralised regional and at national scale in the EU27. The mapping activity on the EU-level is part of the analysis with the BeWhere tool (see Section 1.3) and will not be dealt with any further in this report. BeWhere has defined certain 'logistical regions' in the EU based on certain parameters that define the logistical situation, e.g. average transportation distances. The type of logistical concept that is most suited for a certain logistical region will be determined in the case studies with the LOCAgistics tool and will also not be part of this report.

1.2 Survey of biomass value chains to define general logistical concepts

A survey of various logistical biomass value chains in various European projects was made. The general set-up of a biomass value chain (see Figure 1) is described in Chapter 2. A biomass value chain connects the available biomass types (WP1) with the final conversion process (WP2) through various logistical components (WP3). Based on the survey of biomass value chains in Chapter 3 the most important logistical concepts were identified in Chapter 4. A logistical concept is broader and more general than a specific biomass value chain. A chosen logistical concept always still needs to be further specified and translated in order to obtain a specific biomass value chain (specify all the components). Often several possible biomass value chains fit within that general logistical concept.

1.3 Assessing logistical concepts

The merits of existing logistical assessment methods like cost calculation and GHG calculation methods (e.g. BeWhere, Bioboost, COST model for calculation of forest operations costs, DBFZ model, LOCAgistics and WoodChainManager) were judged for the purposes of use within the S2Biom project in Chapter 5.

In the S2Biom project two methods will be chosen for the third project phase as briefly described in Chapter 6. The analysis on the EU- and country-level will be performed with the BeWhere tool and for the regional advanced case studies it was decided to further develop and implement the LOCAgistics tool.

In this deliverable D3.2 the defined logistical concepts were only assessed qualitatively for a generic situation (so not placed in a specific region/country yet) with an advantage-disadvantage analysis looking at average values for the most important parameters such as type of biomass, transportation distance, conversion method, etc. The detailed assessments will be made in the case studies in Task 3.3 and will be described in D3.3.

2. Biomass supply chains

2.1 Introduction

The logistics of a biomass supply chain may (Figure 1) include several logistical components such as feedstock handling, pre-treatment, storage and transport. Pre-treatment technologies like comminution (size reduction), compaction/densification and drying are needed in the biomass supply chain to convert the biomass 'as received' at the roadside (an amount in t, with certain costs €/t at roadside) to an intermediate biomass feedstock with the required quality at the gate of the biomass conversion facility (an amount in t, with certain costs €/t at factory gate). Storage bridges gaps in time between supply and demand and finally transport is needed to get the biomass from a large number of different sites of origin to one specific location 'at the gate' of a certain conversion technology.

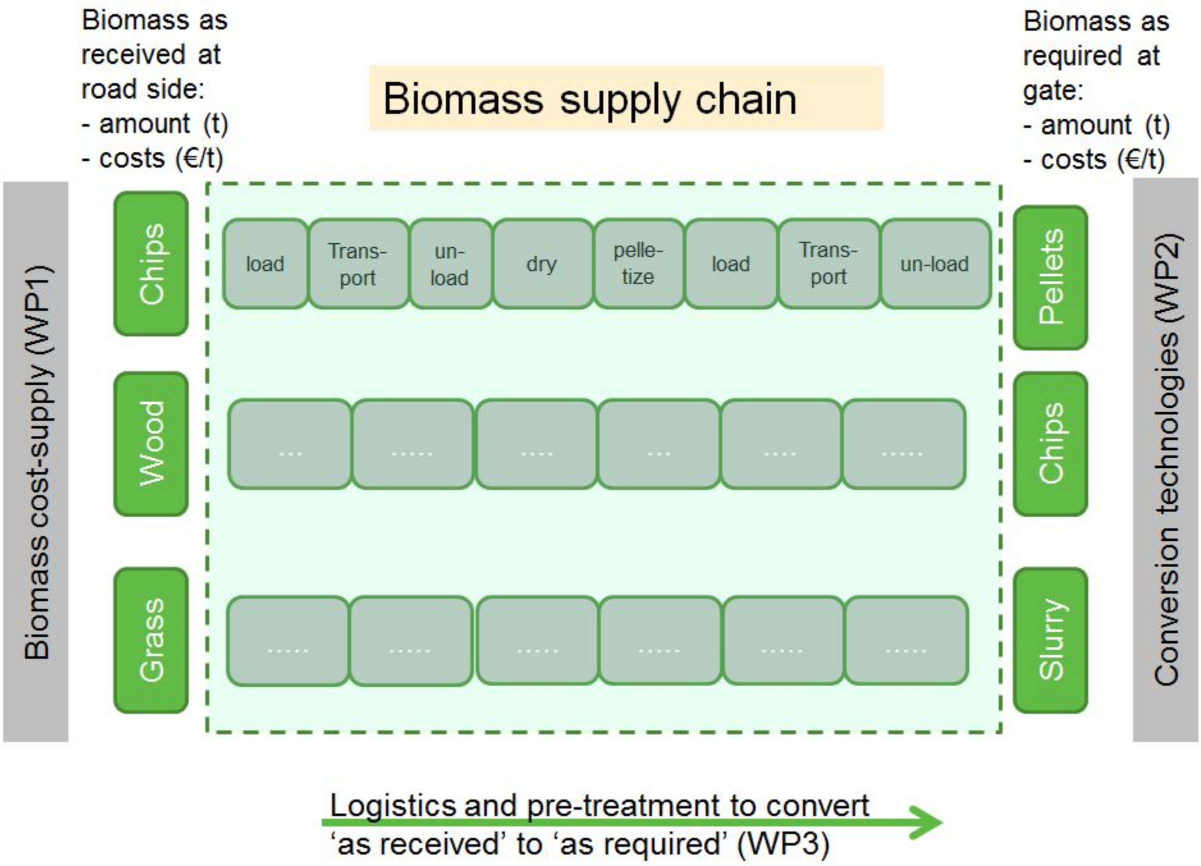


Figure 1. Role of logistics in matching biomass supply at the roadside with biomass demand at the gate of the conversion technology.

In the S2Biom project a biomass value chain is split up into three separate parts:

- the biomass including harvesting (WP1);
- the logistical chain with several logistical components (WP3) and;
- the conversion process (WP2).

2.2 Biomass types (WP1)

Many different types of lignocellulosic biomass can be available at the source. These were described in WP1 by origin and category-level 1 (Table 1). However, this category level-1 is then even further divided into category-level 2 and category-level 3 (Table 2). For the logistics in the biomass value chain this does not always make a big difference (e.g. 'wood is wood' for a chipper), but when real biomass value chains are designed in the end it will be necessary of course to go into further detail (category-level 2 and category-level 3).

Table 1. Lignocellulosic biomass divided by origin and category-level 1 as defined by WP1 of S2Biom (Dees et al., 2015).

Sector	Category-level 1
1. Forestry	1.1 Primary production 1.2 Primary residues 1.3 Harvests from traditional coppice forests that does not focus on stemwood production
2. Agriculture on arable land & grass land	2.1 Primary production of lignocellulosic biomass 2.2 Primary residues of production for food, feed and other utilisations 2.3 Grass land
3. Other land use	3.1 Biomass from trees/hedges and other biomass from areas outside forests and outside of agriculture
4. Production based on lignocellulosic biomass	4.1 Secondary residues from wood industries 4.2 Secondary residues of industry utilising agricultural products 4.3 Secondary residues of industries utilising biomass
5. Post-consumer biomass (tertiary residues)	5.1 Biodegradable Municipal Waste (BMW) 5.2 Post-consumer wood

Table 2. An example of the detailed classification of lignocellulosic biomass from the forestry sector divided by category-level 1, category-level 2 and category-level 3 as defined by WP1 of S2Biom (Dees et al., 2015).

Category-level 1	Category-level 2	Category-level 3
1.1 Primary production	1.1.1 Stemwood from thinnings and final fellings	1.1.1.1 Stemwood from final fellings originating from broadleaf trees
		1.1.1.2 Stemwood from final fellings originating from conifer trees
		1.1.1.3 Stemwood from thinnings originating from broadleaf trees
		1.1.1.4 Stemwood from thinnings originating from conifer trees
	1.1.2 Stem and crown biomass from early thinnings	1.1.2.1 Stem and crown biomass from early thinnings originating from broadleaf trees
		1.1.2.2 Stem and crown biomass from early thinnings originating from conifer trees
1.2 Primary residues	1.2.1 Logging residues from final fellings	1.2.1.1 Logging residues from final fellings originating from broadleaf trees
		1.2.1.2 Logging residues from final fellings originating from conifer trees
	1.2.2 Stumps from final fellings	1.2.2.1 Stumps from final fellings originating from broadleaf trees
		1.2.2.2 Stumps from final fellings originating from conifer trees

2.3 Logistical components (WP3)

A special logistical component is harvesting or collection (Table 3) that is strongly connected with the biomass at its source. In S2Biom the costs of harvesting are dealt with in WP1 and not in WP3.

Table 3. Examples of logistical components connected to harvesting and collection in the biomass value chain (Annevelink et al., 2014).

Sector	Subcategories
Agriculture	bale wrapper; baling (round, square); bio flail mulcher; chopping; cutter; forage harvester; in field hauling; loading; mower; mower conditioner; raking; SRC harvester (chips, whole stem); sugar cane harvester
Forestry	baling; cable yarding; chipping; forwarding; harvesting; skidding; stump extraction
Landscape management	pruning; whole tree harvesting; clearing; mowing

Logistical components are used to solve mismatch problems in the biomass value chain from the original biomass source to the final conversion. The quality of the biomass is changed in the value chain so that in the end the biomass is more suitable for the conversion process. Logistical challenges that are related to the biomass feedstock quality can take different forms:

- too large or too irregularly shaped (inhomogeneous quality) → comminution (size reduction);
- too low a density → compaction/densification;
- too wet (relatively high moisture content) → drying;
- not in place at the correct logistical component or process → feedstock handling;
- contaminated with soil etc. → sieving, washing (other pre-treatments);
- not available in each period of the year (seasonal supply patterns) → storage;
- not on the correct location (small quantities scattered over many sources locations) → transport.

Examples of the logistical components are given in Table 4 (Annevelink et al., 2014; Annevelink et al., 2015). Most of the conventional logistical components are at Technology Readiness Level 9 (ready for full-scale deployment)'; although e.g. some more advanced pre-treatment/fractionation concepts (category other) are still at a lower TRL.

Table 4. Examples of types of logistical components in the biomass value chain (Annevelink et al., 2014).

Logistical component type	Subcategories
Comminution (size reduction)	chipping; chunking; crushing; debarking; grinding; milling; screening; shredding
Compaction / densification	briquetting; centrifugation; pelletizing; bundling
Drying	active/forced drying (artificial): belt dryer; dryer equipment; heating with residual heat; rotary drum dryer; ventilation with fans or blowers passive drying (natural): inside in barn; outside covered; outside in open air and sun
Feedstock handling	bucket grab; conveyor; crane; front loader; gravity feed; intake system; loading/unloading system; pneumatic blower; pumped flow; screw type auger feed; shovel; squeeze loader; stacker; telehandler; tipping platform
Other	biological pre-treatments (fungi); blending; conservation (e.g. silage); de-watering; separation (e.g. S/L); sieving; sorting out metal with a magnet; ultrasonic pre-treatment; washing
Storage	indoors versus outdoors; covered versus uncovered; base type: asphalt, bare soil, bearers or concrete floor; permanent storage structure type: bunker, container, silo or tank; temporary bulk form type: big bag, ensiled, pile or stack
Transportation technologies	Inland waterway: deck barge; dry bulk cargo barge; hopper barge; tug-boat Maritime: handymax bulk carrier; handysize bulk carrier; Panamax bulk carrier Rail: closed bulk wagon; closed wagon with rolling roof; open bulk wagon; open wagon; wagon suitable for 3 TEU containers; wagon suitable for WoodTainersystem Road: bulk van/chip van; farm trailer; flatbed trailer; log trailer; open-end bulk van; removable cargo container lorry/trailer; tanker, grain or animal feed vehicle; timber haulage wagon; tipper trailer or truck walking floor trailer/self-unloading floor/live floor

2.4 Conversion Technologies (WP2)

Biomass conversion technologies form the essential link between the different available lignocellulosic biomass sources including their wide range of properties (described in WP1) and the different end uses and markets. Conversion technologies (including bio-refineries) and end-use applications (both bio-energy and bio-based products) are the essential elements of each pathway, and are being identified and characterised in detail in this task.

The overall objective of WP 2 is:

- to identify and extensively characterise existing and future non-food biomass conversion technologies for energy and biobased products;
- to develop a standardized methodology according to which the different biomass categories identified and quantified in WP1 need to be characterised;
- to assess the optimal match of biomass categories of different quality with the existing and future non-food biomass conversion technologies.

Two main categories of conversion technologies are described in WP2 (Table 5).

Table 5. Examples of types of conversion technologies in the biomass value chain (Vis et al., 2015).

Conversion technology	Subcategories
Thermal conversion technologies	direct combustion; gasification; fast pyrolysis; torrefaction; syngas platform; treatment in subcritical water; treatment in supercritical water;
Chemical and biochemical conversion technologies	anaerobic digestion; techniques from pulp & paper industry; chemical pretreatment; explosion processes; biochemical hydrolysis & fermentation processes

Each of the subcategories can be further divided into primary conversion technologies (Table 6).

Table 6. Examples of specific of primary conversion technologies within the subcategory direct combustion (Vis et al., 2015).

Conversion technology & subcategory	Specific conversion technology

Thermal conversion technologies - direct combustion	• Domestic wood-burning appliances
	  o Residential batch-fired wood-burning appliances
	    ▪ Wood stoves
	    ▪ Fireplace inserts and zero clearance fireplaces
	    ▪ Heat storing stoves
	    ▪ Wood log boilers
	  o Pellet appliances and burners
	    ▪ Pellet stoves
	    ▪ Pellet boilers (CV system)
	  o Wood chips appliances
	    ▪ Pre-ovens
	    ▪ Under-fire boilers
	    ▪ Stoker burners
	• Combustion technologies for industrial and district heating systems
	  o Fixed bed combustion
	    ▪ Grate furnaces
	    ▪ Underfeed stokers
	  o Fluidized bed combustion
	    ▪ Bubbling
	    ▪ Circulating
	  o Pulverised fuel combustion

For each conversion technology the input specifications are gathered in a database. That database can then be used to define which logistical tools are needed to link the road-side characteristics of a certain type of biomass to the input specifications of a certain type of conversion technology, so that the whole value chain can be defined.

3. Examples of biomass supply chains

3.1 Introduction

The purpose of this chapter is to describe examples of biomass value chains, including the logistical concepts that are applied. These examples are then used in the next chapter to deduce general logistical concepts that can be applied to optimize the design of sustainable non-food biomass feedstock delivery chains

Unfortunately, it will not be possible to describe a separate biomass value chain for all possible biomass types specified by WP1 in combination with all possible conversion technologies specified by WP2. This would lead to an enormous amount of possible combinations leading to specific biomass value chains. Therefore, it was decided to choose some important examples of biomass value chains from recent European research projects that were dealing with biomass logistics. The choice of these examples was based on:

- good distribution over different biomass types (see Table 1 and 2);
- sufficient overall supply quantities of a specific biomass type in Europe (most promising feedstocks);
- sufficient regional availability of the biomass feedstock (feasible feedstocks);
- feedstock quality (is there still a need for quality improvements in the logistical chain);
- good distribution over the use of different logistical components (see Table 3 and Table 4);
- good distribution over different conversion technologies (see Table 5 and 6);
- both existing and new biomass value chains;
- being part of a chosen case study in Task 3.3 (Burgundy-France, Miajadas as first option in Spain, Zaragoza as second option in Spain, & Äänekoski-Finland);
- sufficient data available for further analysis.

The examples of biomass value chains will all be described in a standard format in the next sections of this Chapter and then they will be further studied in Chapter 4 to deduce general logistical concepts. They could also supply an advice for projects that want to set-up a new regional biomass value chain advice (also linked to the matching tool of WP2).

An example of a biomass value chain with several steps/links (each of them described in the form of what operation, how and where) is given in Table 7. A biomass value chain can be represented by a sequence of specific individual records in the WP3 logistical components database. In some cases it might also be possible to create standard descriptions of sub-sections of a biomass value chain ('composed logistical components'), that contain a standard sequence of logistical components (e.g. load vehicle – transport vehicle – unload vehicle).

Table 7. An example of a biomass value chain in the standard description format.

What?	How?	Where?
felling and bunching of thinning wood	with harvester	in forest
forwarding of stems	with forwarder	from forest to roadside
storage & drying of stems	in piles on ground	at roadside
chipping	with mobile chipper	at roadside
loading of chips in walking floor vehicle	by blowing	at roadside
transport	with walking floor vehicle	from roadside to biomass yard
unloading chips from walking floor vehicle	by dumping	at biomass yard
storage & drying of chips	in piles on concrete floor	at biomass yard
loading of chips in container vehicle	by shovel	at biomass yard
transport	with container vehicle	from biomass yard to conversion site
unloading chips from container vehicle	by tipping	at conversion site
storage of chips	in bunker	at conversion site
on-site conveying of chips to combustion installation	by conveyor belt	at conversion site
bioenergy production	by combustion	at conversion site

Several EU research project are dealing with the logistics of biomass value chains. This chapter will describe examples of biomass value chains that were studied in these projects and that could be relevant for description of logistical concepts within the S2BIOM project. An overview of possible biomass value chains is given in the next sections.

The following EU-projects have been screened for examples of biomass value chains:

- Bioboost (2012-2015);
- Biocore (2010-2014);
- BiomassTradeCentres I and II (2007-2014);
- COST Action FP0902 (2009-2013);
- EuroPruning (2013-2016);
- Infres (2012-2015);
- LogistEC (2012-2016).

3.2 Bioboost[1]

The pathways studied in the FP7-project 'Biomass based energy intermediates boosting biofuel production' (BioBoost) included the concentration of bioenergy in decentral plants and transport of energy carriers to large, central plants for upgrading to transportation fuel as usable bioenergy commodity (Figure 2). In focus was the decentral conversion to bioenergy carriers and the heuristic optimisation of the logistic network, plant size and plant location.

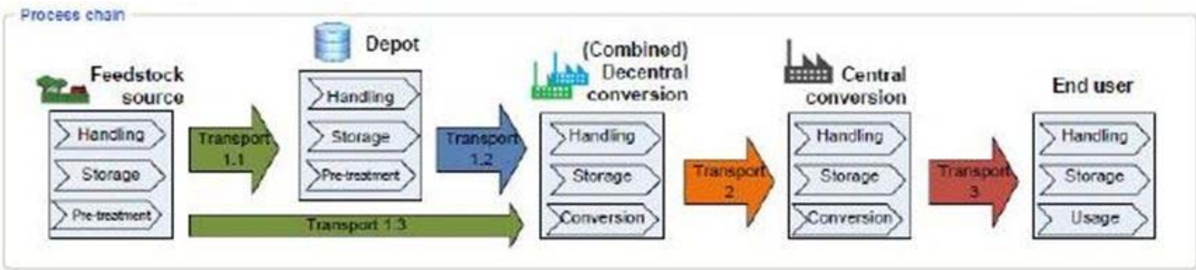


Figure 2. General description of the process with depots, decentral conversion and central conversion (Bioboost, 2013).

The feedstock demand of the envisaged decentral catalytic- and fast-pyrolysis plants is in the order of several 100,000 tonnes per year. The produced intermediate bioenergy carriers biosyncrude (Fast Pyrolysis), bio-oil (Catalytic Fast Pyrolysis) and biocoal (Hydrothermal Carbonisation) are characterised by an increased energy concentration (up to 300%) and improved handling (e.g. pumpable), enabling efficient long distance railway transport to central upgrading plants. These may have a large size (several Giga-Watts) or they are integrated in refineries and they profit of scale-of-unit-effects (production costs reduction per unit with increasing capacity) or synergies.

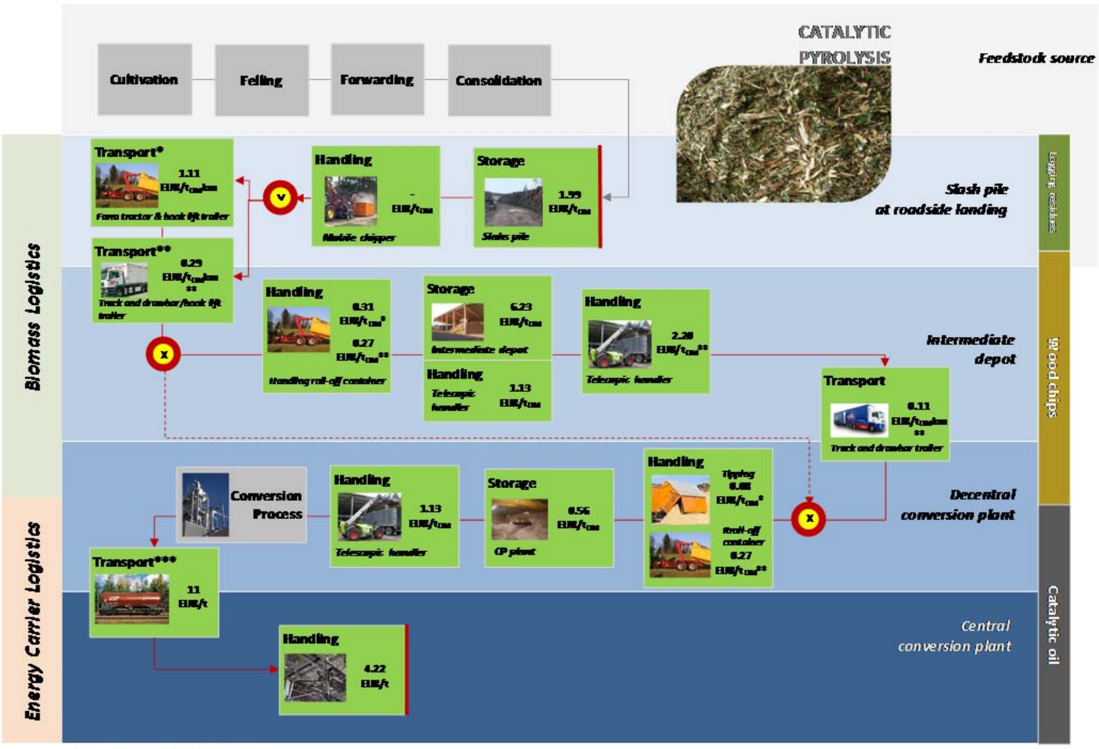
Concerning biomass feedstock, technically available and sustainable potentials were taken into account after the deduction of the demand of the primary sector (production of food, feed, pulp, etc.). The commodities cereal straw, forest fuels (logging residues, thinning wood, stumps) and organic municipal waste were studied in detail as feedstock of the reference pathways. Other studied biomasses included land management matter, waste wood and various residues of the alimentary industry.

The high feedstock demand of the decentral plants requires the utilisation of the most efficient technologies for feedstock procurement typically operated by dedicated subcontractors. These were identified in some advanced countries: The supply of

[1] Sources: Bioboost, 2013; Pitzer & Rotter, 2012; Kronberger, G. & E. Pitzer, 2015; Rotter & Rohrhofer, 2012 & 2014

forest fuel was developed and industrialized in Finland and Sweden. Forest management, residue forwarding, chipping, truck payload and forest fuel use are optimized and broadly implemented. For straw reference countries are Denmark, Great Britain and Spain with efficient agriculture, high density large square balers, automatic bale chasers and large straw consumers. The most efficient technologies and procurement strategies were identified in these countries. Today, these systems are not necessarily operated in every country of the EC. This will change with the demand.

The example for the BioBoost - Catalytic Fast Pyrolysis reference pathway in Figure 3 has been translated to the S2Biom biomass value chain format in Table 8. This procurement chain is compatible to forest residues from thinning and logging as well as for woody biomass from land management and roadside clearing.



* transports by farm tractor
** transports by trucks
*** transports by rail
[1] Rail transport costs depend on transport relation (east/west) and distance classes (from 200 km to 2000 km); costs range from 11 to 60 EUR/t

Figure 3. **The description of a biomass value chain (reference pathway) for Catalytic Fast Pyrolysis in the BioBoost-project (Copyright: S. Rotter, FHOÖ).**

Table 8. The biomass value chain Catalytic Fast Pyrolysis. Shaded in grey is an optional intermediate storage in a biomass center.

What?	How?	Where?
starts with: thinning wood or logging residues in forest		
forest residue forwarding	forwarder	forest
storage logging residues	pile un/covered	at roadside landing
chipping	truck-mounted chipper	at roadside landing
transportation	hook-lift containers, truck	from roadside landing to intermediate depot
handling - unloading	tipping	at intermediate depot
handling	telescopic handler	at intermediate depot
storage	covered in warehouse	at intermediate depot
handling - loading	telescopic handler	at intermediate depot
transportation	truck and drawbar trailer	from intermediate depot to decentral conversion plant
handling	tipping	at decentral conversion plant
storage	covered in warehouse	at decentral conversion plant
handling	telescopic handler and screw conveyor	at decentral conversion plant
decentral conversion process	catalytic fast pyrolysis	at decentral conversion plant
handling - loading	pumping	at decentral conversion plant
transport pyrolysis oil	tank wagon (railway transportation)	from decentral conversion plant to central conversion plant
handling - unloading	pumping	at central conversion plant
central conversion process	deoxygenation/transp.fuel	at central conversion plant

Figure 4 and Table 9 show the Fast Pyrolysis reference pathway as studied in BioBoost. It is compatible to herbaceous energy crops (like Miscanthus and switch grass) and dried land management matter (hay in the broader sense).

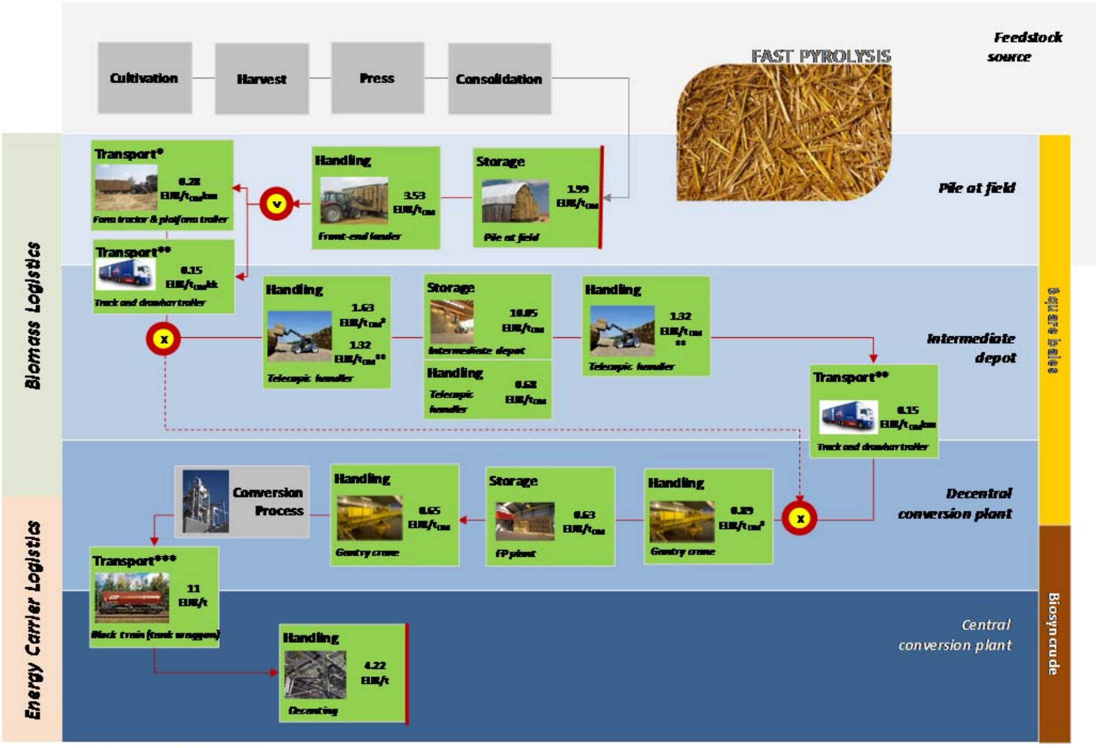


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Figure 4. **The Fast Pyrolysis reference pathway as studied in the BioBoost-project (Copyright: S. Rotter, FHOÖ).**

Table 9. **The biomass value chain for Fast Pyrolysis (BioBoost reference pathway). fast pyrolysis: Option 2 immediately to a decentral conversion plant (Rotter & Rohrhofer, 2014).**

What?	How?	Where?
starts with: straw in swath on a cereal field		
straw baling	high density large square baler, 90x120x240 dim.	field
bale collection and stacking	bale chaser	at roadside landing
storage	pile uncovered	at roadside landing
handling - loading	telehandler	at roadside landing
transportation	platform, drawbar truck	from roadside landing to decentral conversion plant
handling - unloading	gantry crane	at decentral conversion plant
storage	covered in warehouse	at decentral conversion plant
handling	gantry crane	at decentral conversion plant
decentral conversion process	fast pyrolysis	at decentral conversion plant
handling - loading	pumping fast pyrolysis	at decentral conversion plant
transport pyrolysis oil	tank wagon (railway transportation)	from decentral conversion plant to central conversion plant
handling - unloading	pumping	at central conversion plant
central conversion process	gasification/synfuel	at central conversion plant

Finally Figure 5 and Table 10 show the biomass value chain with Hydrothermal carbonisation of organic municipal waste on a waste yard.

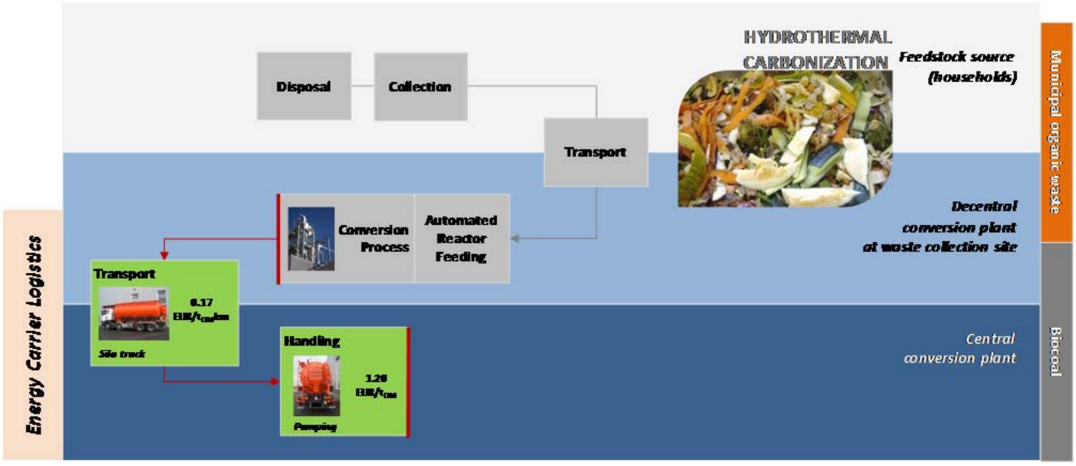


Figure 5. **The Hydrothermal Carbonisation reference pathway as studied in the BioBoost-project. (Copyright: S. Rotter, FHOÖ)**

Table 10. **The biomass value chain Hydrothermal Carbonisation (BioBoost reference pathway).**

What?	How?	Where?
starts with: sorted organic municipal waste on a waste yard		
handling	telehandler	waste yard
decentral conversion process	hydrothermal carbonisation	at decentral conversion plant
handling - loading	pumping	at decentral conversion plant
transport biocoal	silo trailer	from decentral conversion plant to central conversion plant
handling - unloading	pumping	at central conversion plant
central conversion process	combustion	at central conversion plant

The main logistical concepts that appear in these descriptions are:

- application of most efficient equipment;
- combination of different forest residues in one procurement chain;
- optional use of intermediate depots;
- decentral biomass conversion to energy carriers to improve transport properties;
- economic upgrading to marketable bioenergy products (e.g. transportation fuel) in large central plants (due to unit of scale effect and/or synergies).

3.3 Biocore[2]

The studied biomass types in the French case were straw (barley, wheat, cereal & rice) and Miscanthus. The research focused on the quantification of the availability of biomass for a 150 kt/y CIMV Organosolv process from 2015 and 2025 (Figure 6). Residual feedstock, made available after harvesting the main crops, was identified as primary resource to sustain the biomass supply chain, because of the widely spread cultivation of food crops in the area (wheat in particular). Wheat straw availability, though, was conditioned by several competitive uses increasing over time. Thus, an increasing share of the feedstock supplied to the biorefinery was represented by Miscanthus grown in marginal lands.

Figure 6. Schematic representation of the biomass value chain in the Biocore project (Biocore, 2014).

Increasing competitive uses over the time horizon considered (e.g. for bedding, organic farming, heating purposes) for straw caused an enlargement of the supply area across the whole region.

Table 11. The French biomass value chain based on straw and Miscanthus in the Biocore project: option 1. direct transportation from field (Patel et al., 2013).

What?	How?	Where?
baling straw or Miscanthus	baler	on the field
loading	telehandler	at roadside
transportation of bales	truck	from roadside to biorefinery
unloading & pile up	telehandler	at biorefinery
storage of bales	covered in piles	at biorefinery
on-site handling	telehandler	at biorefinery
chipping	chipper	at biorefinery
on-site conveying of chips	conveyor belt	at biorefinery
biorefinery that produces cellulose, hemicellulose and lignin	CIMV Organosolv fractionation process	at biorefinery

[2] Sources: Patel et al., 2013; Biocore, 2014

Table 12. The French biomass value chain based on straw and Miscanthus in the Biocore project: option 2. transportation from storage at farm (Patel et al., 2013).

What?	How?	Where?
baling straw or Miscanthus	baler	on the field
loading	telehandler	at roadside
transportation of bales	tractor & trailer	from roadside to farm
unloading & pile up	telehandler	at farm
storage of bales	uncovered or covered in piles	at farm
loading	telehandler	at farm
transportation	truck	from farm to biorefinery
unloading & pile up	telehandler	at biorefinery
storage of bales	covered in piles	at biorefinery
on-site handling	telehandler	at biorefinery
chipping	chipper	at biorefinery
on-site conveying of chips	conveyor belt	at biorefinery
biorefinery that produces cellulose, hemicellulose and lignin	CIMV Organosolv fractionation process	at biorefinery

The French case study (Table 11 and 12) showed remarkable effects of the seasonality of resources: straw can be collected only in summer, while Miscanthus is available only in winter. Thereby, storage played a major role allowing for the bioresources to be gathered in convenient facilities until they are exploited in the biorefinery. The most common storage typology available in the region was in the field or at barns in the farm.

Among the potential transportation modes studied (i.e. trucks and railways) truck turned out to best suit the biomass supply needs considering the quality of the transport infrastructure available in the area.

In the German case study, the focus was on the development of a hardwood-to-biorefinery supply chain integrating the use of hardwood felling, from forest management, with transformed hardwood (i.e. dried, chipped and pelletized) made available by the existing industrial infrastructure present in the area. It appeared likely that an emerging hardwood-based biorefinery could develop from the existing softwood transformation chain, although at higher processing costs (i.e. for chipping and pelletisation).

The combination of the biomass transport options in the region (i.e. roads, railways, barges) could allow a cost-efficient logistics and favour the development of an emerging biorefining system.

The wood supply chain needs to account for biomass moisture reduction down to 10 % as well as comminution in order to be processed in an Organosolv facility. Wood seasoning in dedicated biomass storage facilities, chipping/pelletizing or microchipping-thermal treatment were all studied as suitable options to provide the biorefining system with feedstock having the suitable properties for the Organosolv.

The main logistical concepts that appear in these descriptions are:

- combination of different biomass feedstock types and quality in one value chain (i.e. residual biomass, energy crops, loose/chipped/pelletized woody biomass);
- tradeoff between the use of residual feedstock and energy crops;
- transportation straight to the biorefinery versus transportation from the farm (after storage) to the biorefinery;
- integrated biomass preprocessing (e.g. wood chipping and pelletization) at industrial facilities already operating in the territory;
- effect of moisture content on the logistics (e.g. seasoning, transport cost) as well as on biomass processing efficiency at the biorefinery;
- combination of different transport modes (e.g. trucks/rail/barges).

3.4 BiomassTradeCentres I and II[3]

The Austrian 'Landwirtschaftskammer Steiermark' has developed the so-called 'Biomass Yard' concept in the BiomassTradeCentre I project (2009-2011) (Loibnegger et al., 2010; Bagley & Parker, 2010). A biomass yard is a regional 'fuel station' for solid biofuels with a high quality, run by a group of farmers (Figure 7). The project aimed at the sustainable supply of woody biomass through centralized marketing of larger bundled quantities of high quality biomass.

In 2011 a follow-up project BiomassTradeCentre II (2011-2014) was started (BiomassTradeCentre II, 2013; Krajnc, 2013). The goal was to achieve approved sustainable utilization of regional forestry biomass in Europe. This second project aimed at the development and implementation of new 'Biomass logistic and trade centres (BLTCs)' in nine countries (Austria, Croatia, Germany, Greece, Ireland, Italy, Romania, Slovenia and Spain). BLTCs are a new and innovative way to organise local biomass supply chains. The project was about optimizing the logistics and promoting quality of wood fuels. A catalogue of wood fuels producers in participating countries (BiomassTradeCentre II, 2015a) and generic guidelines for Biomass trade centres establishment are available (BiomassTradeCentre II, 2015b). In the frame of the project quality control and quality assurance (QA/QC) system that can help to guarantee the solid biofuel quality through the whole supply chain, from the origin to the delivery of the solid biofuel and provide adequate confidence was developed (BiomassTradeCentre II, 2015c).

Figure 7. An example of a regional biomass yard in Austria (Bagley & Parker, 2010).

An example of a wood chips value chain for private forest in Slovenia is given in Table 13 and 14 and Figure 8).

[3] Sources: Loibnegger et al. (2010); Bagley & Parker (2010); BiomassTradeCentre II (2013); BiomassTradeCentres (2012); Krajnc (2013)

Table 13. Wood chips value chain for private forest in Slovenia.

What?	How?	Where?
forest operations	harvesting with chainsaw and skidding with tractor	from forest stand to forest road
transport of logs	semi-truck with trailer and crane for roundwood	from the storage at forest road side to Biomass logistic centre
drying of round wood	uncovered or covered in piles – natural drying	storage at Biomass logistic centre
production of wood chips	chipper mounted on truck with crane	at Biomass logistic centre
storage of wood chips	in the storage house	at Biomass logistic centre
drying of wood chips	drying with hot air	at Biomass logistic centre
selling of high quality wood chips	on spot/via internet/long term contract	at Biomass logistic centre
transport of wood chips to final user	tractor with trailer for bulk loads	from Biomass centre to end user
use of wood chips	biomass heating system	at end user side

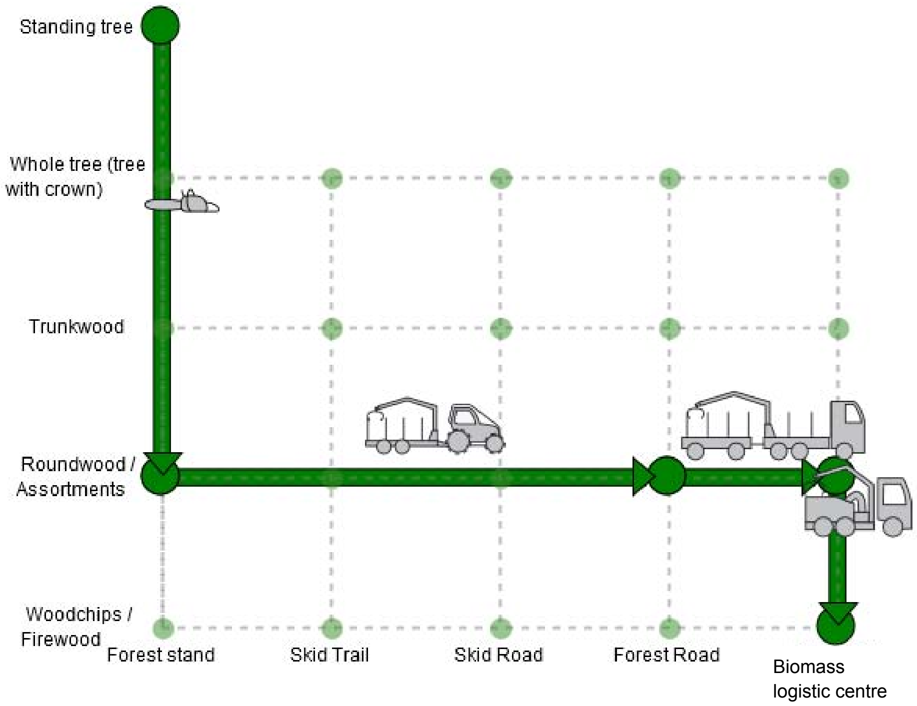


Figure 8. Components in biomass production from private forests to Biomass logistic centres (presented by: WoodChainManager http://wcm.gozdis.si/).

Table 14. Machinery cost of biomass production.

Machine	Fixed costs (€/hour)	Variable cost of fuels and lubricants (€/hour)	Variable costs of maintenance (€/hour)	Total cost of supply chain (€/hour)
Chainsaw (6 kW)	1.85	1.98	1.65	5.48
4WD agricultural tractor (75-94 kW)	11.95	14.04	3.34	29.33
Forest trailer with crane (10 t)	15.96	0.00	9.45	25.41
Semi-truck with trailer and crane for roundwood (300 kW)	29.60	49.57	14.80	93.97
Chipper mounted on truck with crane	87.88	48.11	190.00	235.98

The second value chain (Table 15 and 16, Figure 9) represents a modern way of forest production with the aid of the whole-tree method and cable yarding. Forest worker fells a tree with chainsaw, but does not finish it in full (whole-tree method). This operation is followed by cable crane yarding, which means that a cable device with pivoting, rotating and tilt over tower is mounted to the truck chassis, which enables yarding along the cable line to the forest thoroughfare upwards, downwards or horizontally. Such devices have the carrying capacity of 30-40 kN and are suitable for yarding distances of up to 800 meters. Owing to the need of further treatment of trees, a loading crane equipped with processor aggregate for wood cutting, utilization and sorting is added. Part of the processor head with pickup rollers folds back so as not to impede the gripping of logs. After the hauling, the entire wood mass (roundwood and logging residues) is suitably disposed along the forest road. Further transport of roundwood from forest road to the end user (biomass logistic centre or wood processing industry) takes place in a classical way with different versions of forestry transport compositions. After the completed yarding and transport of roundwood, the logging residues stored along the road are processed into woodchips by a suitable woodchipper. The adequacy of the latter is defined with its economic viability, which depends on several factors (e.g. quantity of raw material, the woodchipper's dimensions, and other production related costs).

Table 15. The most common wood chips value chain in mountain areas in Slovenia.

What?	How?	Where?
forest operations	harvesting with chainsaw and skidding with cable crane mounted on truck with processor	from forest stand to forest road
transport of logs	semi-truck with trailer and crane for roundwood	from the storage at forest road side to Biomass logistic centre
production of green wood chips from forest residues	chipper mounted on truck with crane	at forest road side
drying of round wood	uncovered or covered in piles – natural drying	storage at Biomass logistic centre
production of wood chips	chipper mounted on truck with crane	at Biomass logistic centre
storage of wood chips	in the storage house	at Biomass logistic centre
drying of wood chips	drying with hot air	at Biomass logistic centre
selling of high quality wood chips	on spot/via internet/long term contract	at Biomass logistic centre
transport of wood chips to final user	tractor with trailer for bulk loads	from Biomass centre to end user
use of wood chips	biomass heating system	at end user side

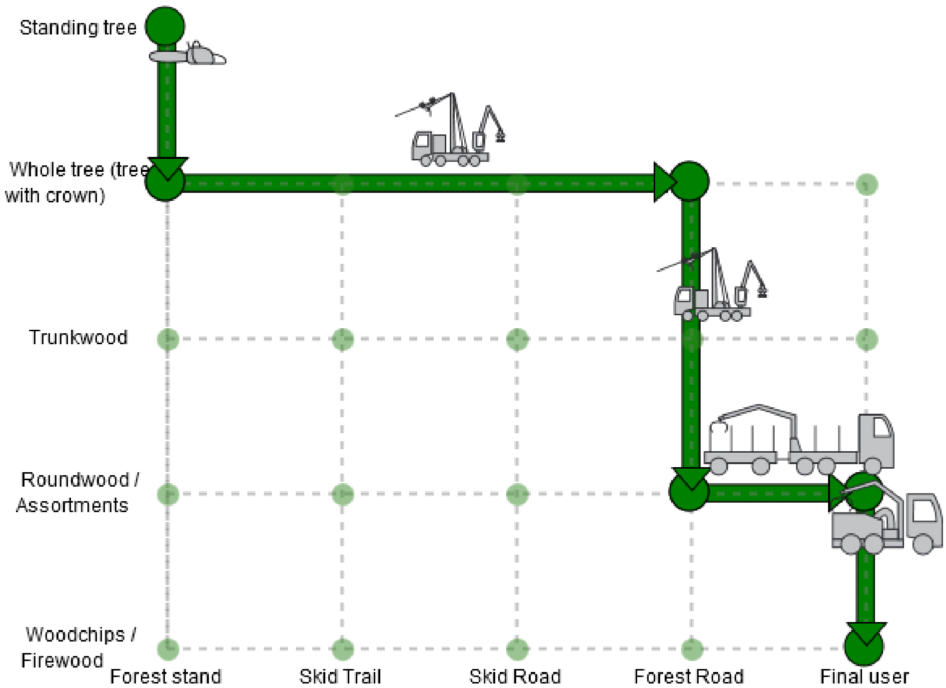


Figure 9. Components in biomass production in mountain areas from forests to Biomass logistic centres (presented by: WoodChainManager http://wcm.gozdis.si/).

Table 16. Machinery cost of biomass production in mountain areas.

Machine	Fixed costs (€/hour)	Variable cost of fuels and lubricants (€/hour)	Variable costs of maintenance (€/hour)	Total cost of supply chain (€/hour)
Chainsaw (6 kW)	1.85	1.98	1.65	5.48
Cable crane mounted on truck with processor head	102.00	48.11	255.00	405.11
Semi-truck with trailer and crane for roundwood (300 kW)	29.60	49.57	14.80	93.97
Chipper mounted on truck with crane	87.88	48.11	190.00	235.98

The main logistical concept that appears in these descriptions is:

- Biomass logistic centre - biomass yards.

3.5 EuroPruning[4]

Biomass value chains from agricultural pruning

EuroPruning carries out a demonstration of value chains for woody biomass from prunings in three EU countries: Germany, France and Spain. These demonstrations aim to reproduce several logistics chains at pilot scale. They are designed to prove two newly built pruning harvesters and a central system for supporting traceability and the organization of the logistics by traders. The case of the chains in Spain are presented here for exemplification of value chains based of agricultural pruning wood.

EuroPruning carried out four different demonstrations based on agricultural pruning wood. The two newly developed machineries (TRL 7) were object of performance tests in every demo site. They are namely the PIMR PRB 1,75 baler (producing round bales of standard dimensions), and the ONG PC50 chipper including relevant improvements in the cutting system (respect usual shredding cutting system). A third commercial machinery, the SERRAT Biomass 150 shredder was utilised in the harvest of olive tree prunings. The pilot chains were implemented with only one harvesting technology per crop site.

The chains implemented at pilot scale were:

- PIMR – PRB 1,75 Baler (Table 17): integrated pick-up and baling of pruning wood into round bales of 1.2 m diameter and 1.2 m width. The pilot chain was implemented for vineyard prunings, as the farmers found the bale format more appealing than bulk chips or chips in big-bags. Bales were left in the field when the bale was ready, or at the head of the row, to subsequently be moved by agricultural tractors with forklift to the field side or to a loading yard.
- ONG - PC50 chipper (Table 18): integrated pick-up and chipping with discharge in individual 1m^3 big-bags, for almond (in Alcañiz) and peach (in Fraga) tree prunings. Farmers preferred the big-bag configuration, instead of the discharge in a 8 m^3 bin mounted on the machinery, which resulted to be heavier and more difficult for maneuvering.
- SERRAT – Biomass 150 shredder (Table 19): commercial unit mounted in front of tractor which conveys pneumatically through a duct the shredded material into a towed trailer. This configuration was suggested by the provider of the external service. The pilot chain was implemented with pruning from traditional and from intensive olive plantations in Escatrón.

[4] Sources: EuroPruning (2013 & 2015); Gebresenbet & Bosona (2015); Pari (2015); Boer et al. (2015)

It must be noted that the pilot scale chains with the PIMR PRB 1,75 baler and the ONG PC50 chipper involved several farmers, who utilized their own tractors and equipment. Therefore it is not possible to describe the specific brand or machinery model utilized.

Table 17. The biomass value chain 'Prunings as bales to bioenergy' in Cariñena and Zaragoza, Spain.

What?	How?	Where?
pruning operation	first a mechanical pre-pruner; secondly a selective manual pruning	on field
Integrated collecting and baling of prunings	tractor towing PIMR PRB 1,75 (agricultural tractors with power > 60kW)	on field
grouping bales	tractor with front forklift	on field to roadside
loading bales	tractor with front forklift	at roadside
transport bales	mobile floor truck. Head truck IVECO. Mobile floor trailer Montull (of 90 m^3 capacity)	from roadside to biomass yard
unloading bales	telehandler (Merlo P40 – 17)	at biomass yard
storage of bales	uncovered in open air storage	at biomass yard
shredding bales into containers (30 m^3)	shredder (mounted on truck)	at biomass yard
loading containers (30 m^3)	multilift truck	at biomass yard
transport containers (30 m^3)	multilift truck	from biomass yard to conversion site
unloading shredded material	multilift (tilting container)	at conversion site
storage shredded wood	hopper	at conversion site
on-site conveying of chips	conveyor belt	at conversion site
bioenergy production	38 MW_{th} alfalfa dehydration facility (*Ejea de los Caballeros*)	at conversion site

Figure 10. Pruning round baler during the performance tests on almond orchard in Alcaniz, Spain and in the pilot experience with vineyard in Carineña, Spain (Pari, 2015).

The shredding of the vineyard pruning bales was proposed to be done at the storage site, even though the transport would have been more efficient with full bales on a platform truck. The limited capacity for treatment by the final consumer, and the fact that part of bales were disassembled during storage, conditioned the decision for the execution of the pilot chains.

Table 18. The biomass value chain 'Prunings as big-bags of chips to bioenergy' in Zaragoza, Spain.

What?	How?	Where?
pruning of almond and peach trees	manual	on field
collecting and chipping of prunings	newly developed mobile chipper (*ONG PC 50*) that drives through the field and blows chips directly in a in big bag (or a temporary container) Chipper was towed by agricultural tractors with power larger than 60kW.	on field
grouping big-bags	tractor with front forklift	on field to roadside
loading big bags with chips	tractor with front forklift	at roadside
transport big bags with chips	mobile floor truck. Head truck IVECO. Mobile floor trailer Montull (90 m^3 of capacity)	from roadside to biomass yard
unloading big bags with chips	telehandler (*Merlo P40 – 17*)	at biomass yard
storage of big bags with chips	uncovered pile	at biomass yard
loading big bags with chips	telehandler (*Merlo P40 – 17*)	at biomass yard
transport big bags with chips	mobile floor truck. Head truck *IVECO*. Mobile floor trailer Montull (90 m^3 of capacity)	from biomass yard to conversion site
unloading big bags with chips	tractor with front forklift	at conversion site
storage of big bags with chips	covered bay	at conversion site
on-site conveying of chips	conveyor belt	at conversion site
bioenergy production	800 kW boiler for farm heating	at conversion site

Figure 11. ONG PC50 chipper, in big bag and in container configuration (Pari, 2015).

The final transport has been considered in big-bags for convenience of in-farm handling of the final user. However the price of a big-bag is considerable respect the 300 kg of biomass contained. Therefore use of big-bags is assumed to be a returnable item. Transport could have been done with bulk chips. For that purpose two options are feasible: use big-bags compatible with auto-discharge (telehandler elevates the big-bag above the truck box and then the discharge rope is pulled). Another option is the discharge on the paved soil and subsequent load with a shovel of large volumetric load capacity. The former system is more compatible with small trucks, since the load and unload time of big-bags is substantial; the latter is more interesting for large volumes. Big-bags are anyway not a system for large scale distribution, but for local consumption, by users preferring to receive big-bags instead bulk material.

Table 19. The biomass value chain 'Prunings as bulk chips to bioenergy' in Zaragoza, Spain.

What?	How?	Where?
pruning of olive trees	manual with electric shears in the intensive olive groves manual with chainsaw in traditional olive groves	on field
collecting and shredding of prunings	commercial shredder *SERRAT Biomass 150* mounted in the rear of tractor (moving backwards). Shredder was towed by Valtra S232 (175 kW).	on field
unloading hog wood at roadside (provisional pile)	regular agricultural tilting trailer	at roadside
loading truck	shovel (4 m^3 loading capacity)	at roadside
transport the hog wood	mobile floor truck. Head truck *IVECO*. mobile floor trailer *Montull* (90 m^3 of capacity)	from roadside to biomass yard
unloading hog wood	mobile floor trailer *Montull* (90 m^3 of capacity)	at biomass yard
handling and building pile	telehandler (*Merlo P40 – 17*) with 1m^3 showel	at biomass yard
storage of hog material	uncovered pile	at biomass yard
loading truck	telehandler (*Merlo P40 – 17*)	at biomass yard
transport hog wood	mobile floor truck. Head truck *IVECO*. mobile floor trailer *Montull* (90 m^3 of capacity)	from biomass yard to conversion site
unloading hog wood	mobile floor trailer Montull (90 m^3 of capacity)	at conversion site
Handling of material	agricultural tractor with showel	at conversion site
on-site conveying of chips	hopper and conveyor belt	at conversion site
bioenergy production	1.7 MW_{th} Uniconfort boiler in feed industry	at conversion site

Figure 12. **ONG PC50 chipper, in big bag and in container configuration (Pari, 2015).**

The system implemented with the SERRAT Biomass 150 showed to be more suitable for large scale in fields where the row width allows the use of machinery requiring high-power tractors. The material produced was not chips but hog wood (usual product obtained by wood shredders).

The main logistical concepts that appear in these descriptions are:

- collecting prunings in bales that will be chipped later on in the value chain versus chipping immediately at the source location;
- producing separate modular units (big-bags or bales) versus bulk material (hog wood);
- biomass size reduction: chipping versus shredding;
- front mounted shredding versus rear towed chipping / baling units (the former avoids tractor to drive over the prunings);
- combination of different transportation types;
- a biomass yard is part of the biomass value chain;
- transport of bulk and packed biomass (big-bags or bales) in moving floor trucks.

Biomass value chain from wood from up-rooted fruit trees

EuroPruning implemented a fifth pilot scale biomass value chain based on the wood of the whole tree, which is removed at the end of the commercial life of a fruit plantation (Table 20 and Figure 13 and 14). The whole tree was cut down with an hydraulic shear mounted either in front of an agricultural tractor or a walking excavator. Trees required a previous preparation prior being fed into a regular forestry chipper with horizontal feed-in system. The preparation consisted in a cut done in the intersection between the main branches with the basal stem to facilitate the feeding in form of a bundle with the claw into the chipper.

Table 20. The biomass value chain 'Woodchips from renovation of fruit tree plantations in Fraga, Spain.

What?	How?	Where?
cutting fruit trees	walking excavator (110 kW) provided with shear mounted in the arm	on field
preparing fruit trees	manual chainsaw with small cuts in the intersection of branches with basal stem	on field
chipping	regular forestry chipper (lateral feeding) powered by agricultural tractor (170 kW)	on field
unloading bulk chips	regular fodder tilting trailer	at roadside
loading truck	showel (4 m^3 loading capacity)	at roadside
transport of bulk chips	mobile floor truck. Head truck *IVECO*. Mobile floor trailer *Montull* (90 m^3 of capacity)	from roadside to biomass yard
unloading bulk chips	mobile floor trailer *Montull* (90 m^3 of capacity)	at biomass yard
handling and building pile	telehandler (*Merlo P40 – 17*) with 1m^3 showel	at biomass yard
storage of chips	uncovered pile	at biomass yard
loading truck	telehandler (*Merlo P40 – 17*)	at biomass yard
transport hog wood	mobile floor truck. Head truck *IVECO*. Mobile floor trailer *Montull* (90 m^3 of capacity)	from biomass yard to conversion site
unloading hog wood	mobile floor trailer *Montull* (90 m^3 of capacity)	at conversion site
handling of material	agricultural tractor with showel	at conversion site
on-site conveying of chips	hopper and screw conveyor	at conversion site
bioenergy production	700 kWt boiler for greenhouse heating	at conversion site

Figure 13. Walking excavator with shear for tree cutting; peach tree field after tree cutting; detail of tree preparation prior feeding into the chipper.

Figure 14. Forestry chipper fed with bundles of fruit tree stems and branches; downloading of the chips in provisional yard at roadside.

The strength of the system is the large amount of material obtained on a site, and the format of the chips, similar to forestry wood chips. The demonstrations showed that the forestry chippers are not fully compatible with agricultural tree forms, and the costs of preparation were substantial. The utilization of large mobile floor trucks was regarded to be convenient.

The main logistical concepts that appear in these descriptions are:

- mechanised felling of fruit trees versus mechanized cut with a shear;
- shear mounted in front of a tractor versus mounted in the arm of a walking excavator;
- on field chipping of trees with mobile train (tractor – chipper – trailer) along the row of felled trees;
- on field utilisation regular agricultural trailers with relevant volumetric capacity 30 m^3);
- manual preparation of trees before chipping.

3.6 Infres[5]

The Infres project (Innovative and effective technology and logistics for forest residual biomass supply in the EU) is dealing especially with biomass from the forestry sector. Five main biomass supply chains have been demonstrated in practice together with the associated IT-systems for fleet and storage management (Infres, 2015). These are:

- supply chains for the integrated biomass extraction chains for mountain forests;
- smart processing chains for residues;
- supply chains for stump wood;
- supply chains for small trees from thinning operations;
- smart large scale forest biomass supply chains for liquid fuel production.

An example of a biomass value chain with a hybrid chipper and large truck in Finland is given in Table 21.

Table 21. The biomass value chain of hybrid chipper and large truck in Finland.

What?	How?	Where?
felling and bunching of thinning wood	with harvester	in forest
forwarding of stems	with forwarder	from forest to roadside
storage & drying of stems	in piles on ground	at roadside
chipping of woody biomass (e.g. pulpwood, logging residues)	newly developed world first full hybrid wood chipper (*Kesla C 860 H hybrid chipper*) blowing chips directly into the chip truck	at the roadside
transportation of wood chips	large truck (Antti Ranta) with high capacity	from roadside to conversion site
unloading chips from vehicle	by tipping	at conversion site
storage of chips	in bunker	at conversion site
on-site conveying of chips to combustion installation	by conveyor belt	at conversion site
bioenergy production	by combustion	at conversion site

The involved research organizations, SMEs, demonstrated innovations and place of demonstrations are given in Table 22.

[5] Sources: Infres (2015); Jessup et al. (2014); Anttila et al. (2014)

Table 22. List with demonstrated innovations within the Infres project.

Involved research organizations, SMEs	Demonstrated innovations	Place of demonstrations
Skogforsk, VTT, Valbo Entreprenad AB	Two-stage grinding	Mackmyra, Sweden
Felis, ALU-FR, Fallert, Pezzolato	Smart chipper truck	Ortenau, Germany
Skogforsk, IVALSA, Pezzolato	Smart chipper truck	Hestra, Sweden
Luke, Kärkimurskaus Oy, UPM Forest, Komptech	Two-stage grinding	Mikkeli and Juva, Finland
IVALSA, SLU, Skogtekniska klustret, Pezzolato	Mini-harwarders	Codroipo, Italy
CTFC, Naarva	Multi-tree harvesting	Central Catalonia, Spain
SLU, Skogtekniska klustret	Multi-tree harvesting	Umea, Sweden
Luke, SLU, IVALSA, Ellettari	Stump drill	Evijärvi, Finland
VTT, JAMK, Poke Metsäkeskus	Chip drying	Jyväskylä, Finland
Skogforsk, SLU, Stockarydsterminalen AB	Terminal logistics	Stockaryd, Sweden
IVALSA, Pezzolato, Valentini	Innovative yarder, smart chipper	Farra d'Alpago, Italy
Luke, Antti Ranta	High mobility truck	Oulu, Finland
BOKU, Naarva	Multi-tree harvesting	Moschendorf, Austria
ALU-FR, IVALSA, Fallert	Chip drying	Vercelli & Bologna, Italy
Skogforsk	Large truck	Södertalje, Sweden
SLU, Skogtekniska Klustret	Fixteri	Holmsund, Sweden
CTFC, CSF	Synthetic rope	Central Catalonia, Spain
CTFC, CSF	Press collector	Central Catalonia, Spain
ALU-FR, Ecomond, Fallert	Logistics optimization software	Freiburg, Germany
BOKU, Schwarz	Semi-automated process analysis	Pilgersdorf, Austria
IVALSA, BOKU, CTFC, Valentini, CSF	Full-suspension carriage	Rumo, Italy
Luke, Kesla, Antti Ranta	Hybrid chipper and large truck	Joensuu, Rauma & Jyväskylä, Finland
Skogforsk, SLU, VTT	Large truck and terminal logistics	Nykvarn, Sweden

The main logistical concepts that appear in these descriptions are:

- integrated harvesting;
- coupled vs. de-coupled logistics for wood chip production;
- terminal logistics;
- logistics optimization;
- multi-tree handling;
- two-stage grinding.

3.7 COST Action FP0902

Many biomass value chains have been described by COST Action FP0902 "Development and harmonization of new operational research and forest assessment procedures for sustainable forest biomass supply", Forest Energy Portal (Forest Energy Portal, 2015; see Table 23 and Annex I). For dominating chains at country level see Díaz-Yáñez (2013).

Table 23. Biomass value chains described by COST Action FP0902, Forest Energy Portal (www.forestenergy.org, 2015).

1. Bundles supply chain for logging residues for energy with chipping at terminal
2. Delimbed stems procurement chain from thinnings, mechanized harvesting and with chipping at the plant
3. Delimbed stems procurement chain from thinnings, mechanized harvesting and chipping at the roadside
4. Forage harvester supply chain in Eucalyptus plantation
5. Forage harvester supply chain in short rotation coppice
6. Full tree mechanized harvesting system with a feller buncher, skidding and processing at the roadside landing to a mill
7. Full tree harvesting system with manual felling, skidding and processing at the roadside landing to a mill
8. Logging residue supply chain with chipping at a terminal & railway transportation
9. Logging residue supply chain with chipping at a terminal & waterway transportation
10. Round wood supply chain with chipping at terminal & railway transportation
11. Round wood supply chain with chipping at terminal & waterway transportation
12. Roundwood harvesting for production of pellets with chipping at terminal (Figure 15)
13. Supply chain for roundwood from motor-manually harvesting
14. Supply chain for roundwood from motor-manually harvesting and with skidder
15. Roundwood supply chain based on cut to length harvesting method to mill
16. Small scale harvesting of whole trees from thinnings with chipping at roadside
17. Steep terrain full tree harvesting system with cable yarding and processing at the roadside landing with a mill
18. Steep terrain supply chain manual harvesting of roundwood with cable yarder with a mill
19. Steep terrain mechanized harvesting of roundwood and cable yarding to the roadside landing, mill
20. Whole tree manual harvesting system from thinnings with terrain chipping in-field and with a plant
21. Tree-length harvesting system with mechanized felling, skidding and loading at the roadside landing
22. Tree-length harvesting system with manual felling & delimbing and skidding to the roadside landing
23. Whole tree supply chain from thinnings with chipping at the roadside with railway transportation
24. Whole tree supply chain from thinnings with chipping at the roadside with waterway transportation
25. Whole tree harvesting procurement chain from thinnings with chipping at roadside
26. Whole tree harvesting procurement chain from thinnings, with forwarding, truck transportation with chipping at the plant

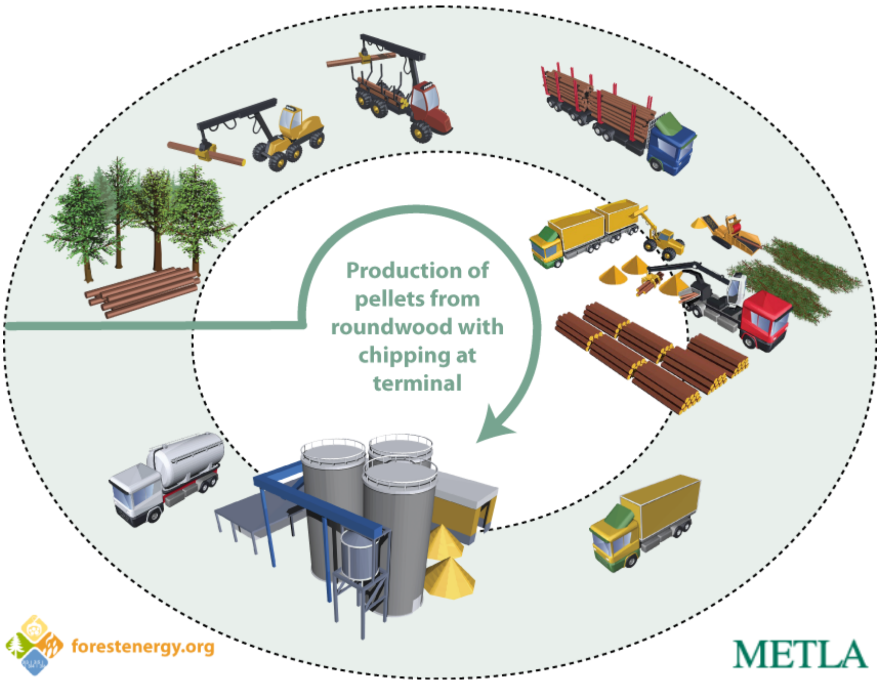


Figure 15. **Example of a biomass value chains in the forestry sector: 12. Roundwood harvesting for production of pellets with chipping at terminal (www.forestenergy.org, 2015).**

Also some integrated harvesting biomass value chains (Table 24) were described, where different types of products (roundwood, residues, stumps, pulpwood & energywood) are delivered at the same time.

Table 24. **Integrated harvesting biomass value chains described by COST Action FP0902, Forest Energy Portal (www.forestenergy.org, 2015).**

27. Integrated harvesting of pulpwood & energywood
28. Integrated harvesting of roundwood & energy wood
29. Integrated harvesting of roundwood & energy wood in steep terrain with manual cutting
30. Integrated harvesting of roundwood & energy wood in steep terrain with mechanized cutting
31. Integrated harvesting of roundwood & residues
32. Integrated harvesting of roundwood, residues & stumps (Figure 16)

Figure 16. **Example of an integrated biomass value chains in the forestry sector: 32. Integrated harvesting of roundwood, residues & stumps (www.forestenergy.org, 2015).**

The main logistical concepts that appear in these descriptions are:

- single product harvesting versus integrated harvesting where a combination of products is obtained;
- integration of different biomass value chains;
- chipping at the roadside versus chipping at a terminal;
- combination of different transportation types: truck transportation versus railway transportation or waterway transportation;
- terminals (biomass yards) included in some value chains.

3.8 LogistEC - French case study Burgundy[6]

The Burgundy case is about the energy crop Miscanthus (Figure 17). The case is about small scale local production of Miscanthus pellets and the logistics are pretty simple: feedstock Miscanthus – harvesting as bales or chips – bales stored at the farm - and then transported to the pellet plant – where they are chipped and pelletized. The current project does not include the further use of the pellets (yet) e.g. in a bioenergy power plant or in other applications (like animal bedding). So it is only about producing intermediate products (pellets) from Miscanthus.

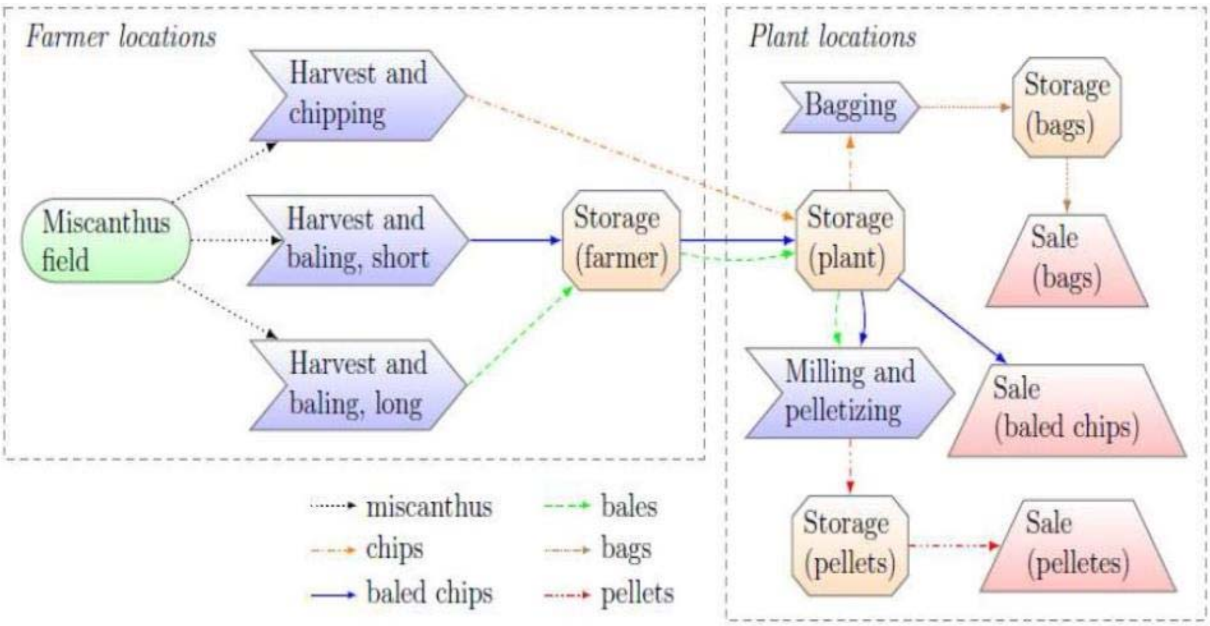


Figure 17. The biomass value chain 'Miscanthus pellet factory' in Burgundy, France (Gabrielle et al., 2015a).

Two option s are described here:

- option 1. Miscanthus bales through farm to pellet factory;
- option 2 - Miscanthus chips straight to pellet factory.

From the task 'on-site conveying of chips' on the Option 2 is exactly the same as Option 1.

The main logistical concept that appear in these descriptions is:

- direct chipping at the roadside versus chipping bales at conversion site.

[6] Sources: Gabrielle et al., 2015a; LogistEC, 2013 & 2015; Nobili, 2015; Bjørkvoll, 2015

Table 25. The biomass value chain ' Option 1 - Miscanthus bales through farm to pellet factory' in Burgundy, France.

What?	How?	Where?
harvesting & baling of Miscanthus	double pass configuration with tractor 240 hp (*Fendt vario 724*) with mower; followed by high density baler 70 (*Krone Big Pack 1270 XC*) or new alternative method: single pass configuration with tractor 325 hp (*Massey Ferguson 8730*) & shredder (*Nobili WS 320 Bio*) combined with high density baler 90 (*KHUN LSB*)	on the field
piling bales	tractor 120 hp (*Fendt vario 312*) with telehandler 106 hp (*LM 430c*)	at roadside
loading of bales	tractor 120 hp (*Fendt vario 312*) with telehandler 106 hp (*LM 430c*)	at roadside
transport bales	tractor 120 hp (*Fendt vario 312*) & double flatbed trailer (*capacity 67* m^3 *or 12 t*)	from roadside to farm
unloading of bales	tractor 120 hp (*Fendt vario 312*) with telehandler 75 hp (*Manitou*)	at farm
storage of bales	in average agricultural shelter on bare ground	at farm
loading of bales	tractor 120 hp (*Fendt vario 312*) with telehandler 75 hp (*Manitou*)	at farm
transport bales	combined truck (*capacity 145* m^3 *or 26 t*)	from farm to pellet factory
unloading of bales	telehandler 75 hp (*Manitou*)	at pellet factory
storage of bales	in storage building	at pellet factory
on-site conveying of bales	conveyor belt	at pellet factory
chipping of bales	shredder	at pellet factory
on-site conveying of chips	conveyor belt	at pellet factory
pelletizing of chips	pelletization	at pellet factory
on-site conveying of pellets	conveyor belt	at pellet factory
storage of pellets	pellet silo	at pellet factory
on-site conveying of pellets	conveyor belt	at pellet factory
package pellets in bags	big bag filling system	at pellet factory
load bags with pellets	telehandler	at pellet factory
transport bags with pellets	truck	from pellet factor to conversion site
unload bags with pellets	telehandler	at conversion site
storage of bags with pellets	storage building	at conversion site
on-site conveying of pellets	conveyor belt	at conversion site
bioenergy production	combustion installation	at conversion site

Table 26. The biomass value chain 'Option 2 - Miscanthus chips straight to pellet factory' in Burgundy, France.

What?	How?	Where?
harvesting & chipping of Miscanthus	tractor 240 hp (*Fendt vario 724*) with mower & chipper blowing chips straight into trailer	on the field

transport chips	tractor 200 hp & trailer (*capacity 50 m^3 or 6.1 t*) Platform truck (*capacity 65 m^3 or 8 t*)	from roadside to pellet factory
unloading of chips	telehandler 75 hp (*Manitou*)	at pellet factory
storage of chips	in storage building	at pellet factory
on-site conveying of chips	conveyor belt	at pellet factory
pelletizing of chips	pelletization	at pellet factory
on-site conveying of pellets	conveyor belt	at pellet factory
storage of pellets	pellet silo	at pellet factory
on-site conveying of pellets	conveyor belt	at pellet factory
package pellets in bags	big bag filling system	at pellet factory
load bags with pellets	telehandler	at pellet factory
transport bags with pellets	truck	from pellet factor to conversion site
unload bags with pellets	telehandler	at conversion site
storage of bags with pellets	storage building	at conversion site
on-site conveying of pellets	conveyor belt	at conversion site
bioenergy production	combustion installation	at conversion site


(a)


(b)


(c)


(d)

Figure 18. Logistical components in the Burgundy biomass value chain: a) mowing (LogistEC, 2013), b) baling (LogistEC, 2013), c) newly developed single pass configuration for Miscanthus harvesting & baling with a tractor 325 hp (Massey Ferguson 8730) & shredder (Nobili WS 320 Bio) combined with high density baler 90 (KHUN LSB) (Nobili, 2015) and d) tractor with telehandler for loading bales (Bjørkvoll, 2015).

3.9 LogistEC - Spanish case study Miajadas[7]

The Miajadas biomass plant, conducted by ACCIONA Company (www.acciona.com), is located in the municipality of Miajadas, between the provinces of Cáceres and Badajoz (Autonomous Community of Extremadura), in the western part of Spain.

Main data of the Miajadas power plant are as follows:

- installed Power Capacity: 16 MW_e;
- forecasted production: 128 GWh/year (equivalent production: 40,000 homes);
- raw material consumed: 110,000 metric tons/year;
- investment: 50 million €;
- jobs created: 25 direct and 75 indirect;
- start-up: November 2010.

In Table 27 the different feedstocks used in the plant, as well as the annual supply volume (2012) of each one are shown.

Table 27. The types and amounts of biomass for the Miajadas power plant.

Herbaceous biomass (53,000 t/year)	Woody biomass (58.000 t/year)
1. herbaceous energy crops (30,000 t/year)	1. forestry crops (46,000 t/year)
2. agricultural residues	2. forestry residues (8,000 t/year)
• winter crops (12,000 t/year)	3. woody agricultural residues (4,000 t/year)
• summer crops (11.000 t/year)	

Within each biomass category is included:

- herbaceous energy crops
  - the whole plant is used to produce electric power (grain + straw)
  - herbaceous crops used: oats, rye, sorghum, wheat, barley, triticale
- agricultural residues
  - residual biomass obtained after the grain has been harvested
  - in this group winter crops (oats, wheat, rye) and summer crops (corn) are included
- forestry energy crops
  - forestry species that are used to produce electric power (logs + branches)
  - black poplar is included in this classification, as well as other forestry species that have been designated by the regional authorities with the energy certification
  - around 60% of this type of biomass is pine, 30% eucalyptus, 9% holm oak, 1% black poplar

[7] Source: Sanchez et al. (2015)

- forestry residues
  - residual biomass obtained after cleaning a forestry area and after the exploitation of wood resources.
  - about 70% of forestry residues come from eucalyptus exploitation, 20% from pine, and 10% from holm oaks and other minor species such other quercus.
- woody agricultural residues
  - residual biomass resulting from fruit trees, vineyards and olive trees pruning
  - about 50% of this biomass comes from peaches, 30% from nectarines, 18% from pear trees, and the last 2% from olive trees

Table 28. The biomass value chain Sorghum bales in Spain.

What?	How?	Where?
harvesting (mowing) fibre sorghum	'Biotrans harvester' which is a modified flail cutter (with hammers) on a tractor (195 CV)	on the field
ranking	rotary rake on a tractor (*Model Krone*)	on the field
baling	case model baler (1.20x0.70x2.40 bales)	on the field
stack pile	telehandler (*Manitu*)	at the roadside (corner of field)
intermediate storage	open field	at the roadside (corner of field)
load	telehandler (*Manitu*)	at the roadside (corner of field)
transport	with truck (Average volume 100 m^3)	from roadside to conversion site
unload	telehandlers (Manitu)	in open field near conversion site
pile up	outdoor storage: A) uncovered from previous year B) covered with geotextile or C) uncovered	in open field near conversion site
load	telehandler (*Manitu*)	in open field near conversion site
transport	truck	to plant storage warehouse at conversion site
unload from the truck to the plant storage warehouse	bridge crane	at the conversion site
load from the feed storage to the feed line	bridge crane	at the conversion site
gridding	just when is coming into the biomass boiler at the plant with a grinder incorporate in the feed line	at conversion site
bioenergy production	(*Miajadas power station*)	at conversion site

(a) (b)

Figure 19. Logistical components of the Sorghum value chain: a) harvester b) storage alternatives on an open field near the power plant (Sanchez et al., 2015).

Within the scope of the LogistEC project, energy crops demonstrations have been developed focus on three crops: triticale and sorghum as annual herbaceous crops and poplar as perennial woody crop.

Regarding sorghum demonstration (Table 28 and Figure 19), during 2014 summer a 29 hectares plot located in Casatejada, Extremadura (Spain) was cultivated under irrigated conditions. In this sorghum cultivation trial, the main objective is to demonstrate new biomass supply chains under real operational conditions. Thus, technological developments activities will be implemented, including:

- improved cultivation practices, related to fibre sorghum crop for energy purposes;
- harvesting practices (cutting, mowing and baling), by adapting currently used machinery, and also checking the best moments for harvesting in relationship with the fibre sorghum crop cycle (yielding either fresher biomass or drier biomass).

The main logistical concepts that appear in these descriptions are:

- get a low enough moisture content by natural drying:
  - o date of the harvesting;
  - o flip the biomass over the field by ranking;
- determinate operational cost under real operation conditions.

4. General logistical concepts

4.1 Introduction

A logistical concept is broader and more general than a specific biomass value chain. A chosen logistical concept always still needs to be further specified and translated in order to obtain a specific biomass value chain (specify all the components). Often several possible biomass value chains fit within that general logistical concept.

Examples of logistical concepts are:

- pre-treatment (e.g. comminution and densification) integrated with harvesting/collecting versus stand-alone pre-treatment later on in the biomass value chain;
- indirect supply to the final conversion location through biomass yards (often in combination with intermediate storage and pre-treatment) versus direct supply from road-side;
- multi-modal transport (combination of different transport types) versus only one transport modality (road, water, rail);
- European/world-wide biomass value chains based on standardized biocommodities (e.g. wood pellets, ethanol or pyrolysis oil) versus regional biomass value chains based on locally sourced ‘raw’ biomass;
- ‘light’ pre-treatments (like comminution, densification, drying, etc.) and/or storage at a de-central (at road site), intermediate (at biomass yard) or central (at conversion site) location;
- ‘intensive’ pre-treatments like (catalytic-) pyrolysis, hydrothermal carbonisation, torrefaction in decentral plants with feedstock capacities up to several 100,000 t/a, efficient energy carrier transport (by railway) to central plants for upgrading to final energy product;
- many small-scale conversion plants versus only one large-scale conversion plant to meet product demand.

New logistical concepts can be applied both to biomass that is already mobilized and to biomass that is not yet mobilized. The logistical concepts that are described below should at least cover the biomass value chains of the case studies of WP9 (see Task 3.3). Important aspects of the description of a logistical concept are:

- characteristics;
- main advantages;
- main disadvantages;
- resulting biomass quality.

4.2 Pre-treatment integrated with harvesting/collecting

In the agricultural sector there is already a long tradition of integrating several operations during the harvesting process. A good example is the development of the combine harvester, where cutting the stem with the grain and threshing it to separate the grain from the straw are combined in one machine. Sometimes this is even combined with baling the straw.

In case of biomass harvest from prunings, the integrated collection concept differs from annual crops. Pruning and fruit/olive/grape harvesting is done in two different moments of the crop cycle, and so, the integration of main product harvesting with the harvest of the residue is not possible. Pruning is carried out usually manually with shears or with mechanically assisted tools (electric shears or chainsaws, e.g.), even though there is a trend to execute non-selective mechanised pre-pruning operations. The pre-pruning takes away important parts of the shoots and branches, in order to reduce the manual work to be carried out later on by workers. Pruning collection can be integrated in next ways:

- Mechanised pre-pruning: by building new machinery able to convey the shredded pieces of wood into a collecting system (instead the default spread of wood pieces on the soil).
- Pick-up and treatment: the current pruning biomass harvest consists in machinery with a pick-up system feeding the branches into the shredder, chipper or baling system. Harvest requires in many cases a previous windrowing operation. Therefore integration can be improved by including windrowers with the harvester, or by adapting the manual pruning work so that the pruning is placed in the centre of rows.

Also in the forestry sector integration of chipping with felling is possible in easy terrain, if the soil bearing capacity is good and yarding distances short. In Finland and Sweden chipping in the forest is no more practised due to logistical challenges and high costs (Routa et al., 2012).

For new non-food biomass feedstocks value chains integration of certain pre-treatments with harvesting or collecting might be advantageous as well. This can already be seen in the three recent EU-projects (EuroPruning, Infres & LogistEC) dealing with new concepts to optimize biomass logistics.

Table 29. Advantages and disadvantages of the logistical concept 'Integrated harvesting/collecting machines'.

Advantages	Disadvantages
• Save one or more extra rides with a machine on the field • Lower overall costs per tonne for the combination of operations • Save extra biomass handling • Better biomass quality (e.g. less contaminated with soil, ...) • Possibility of direct loading in transport vehicle	• More expensive machine for initial investment • More complex machinery including system with multiple purposes • Heavier machine which needs to be compensated (with larger tires) to avoid soil compaction • Slower harvesting rate • Failure in the biomass system may abort the harvest of the main product

4.3 Biomass yards

A biomass yard is a logistical concept (Annevelink et al., 2014b). Several types of biomass supplied by different sectors (e.g. agriculture, forestry, nature management) are collected efficiently on a central location (biomass yard) in a region. There the biomass can be pre-treated into a standardized intermediate product (biocommodity) for further processing by industry. In some cases the biomass is also directly converted into an end-product at the biomass yard. The goal of a biomass yard is to produce a homogeneous output stream with the required specifications based on different inhomogeneous input streams that can be traded as a biocommodity (Sanders et al., 2009). A biomass yard is a spider in the web of collecting biomass. A biomass yard has two main types of tasks: i) technical-operational tasks and ii) management & trade tasks.

A selection of the technical-operational tasks:

- regional collection point for miscellaneous biomass supply;
- storage buffer between supply and demand: bridge seasonal availability effects;
- separate and purify biomass streams;
- bundle biomass streams;
- pre-treat biomass to achieve a uniform quality both in composition and physical appearance (biocommodity);
- supply a constant output stream to buyers;
- take care of transportation;
- facilitate shifts between different modalities (truck, train, ship).

A selection of the management & trade tasks of a biomass yard is:

- manage the streams in the biomass value chain;
- reduce logistical costs by optimization of transport;
- provide service and advice to supplying and buying parties;
- guarantee quality (certification);
- trading biocommodities and developing new markets;
- collect market information (e.g. prices);
- innovate biomass supply chains;
- flexible response to changing markets;
- development of new markets for the produced biocommodities.

Table 30. A SWOT of the biomass yard concept (Annevelink et al., 2014b).

Strengths	Weaknesses
• Production of biocommodities (intermediate products) on specification with a guaranteed quality to supply different buyers. This way it is easier to comply with the requirements of the processing industry that makes final products • Cheaper alternative for agricultural and horticultural companies to get rid of their biomass(residues) • Different types of biomass can be combined, and thus treated more efficiently with the correct technology at a central location • Knowledge of existing organic residues collecting companies can be easily applied and integrated	• 'Theoretical' biomass yard concept still has to prove itself (partially) • Success is only possible when the leading partner is clear • Biomass is an infant industry: only a limited number of buyers and limited price building & competition • Inserting a biomass yard in the existing logistical biomass chain requires extra investment costs • Insufficient experience with license to operate new type of biomass yards (not only woody biomass) • Biomass streams ideally need to remain separated from each other to enable further processing
Opportunities	**Threats**
• Rising demand for biocommodities to supply strong growth of biobased economy • Biomass yard plays role of catalyst when developing business cases • New valorisation opportunities through biorefinery technology • Connection to existing development routes • Taking away the burdens of biomass suppliers and buyers • Connection to circular economy	• Biomass yard concept requires a minimum size to start • There is a 'battle for waste' going on • Success of a biomass yard depends on sufficient valorisation options for all biomass streams • Much competition between existing biomass collecting companies • Relatively high risk (lack of biomass and dependency of buyers) • Competition with cheaper biocommodities from abroad

A SWOT of the biomass yard concept (Table 30) is given by Annevelink et al. (2014). Concepts that resemble a biomass yard are mentioned in several European countries like: Austria, Germany, Sweden and Finland. The concept is also mentioned in the US and Canada. A schematic representation of the biomass yard within a biomass supply chain is given in the Figure 20.

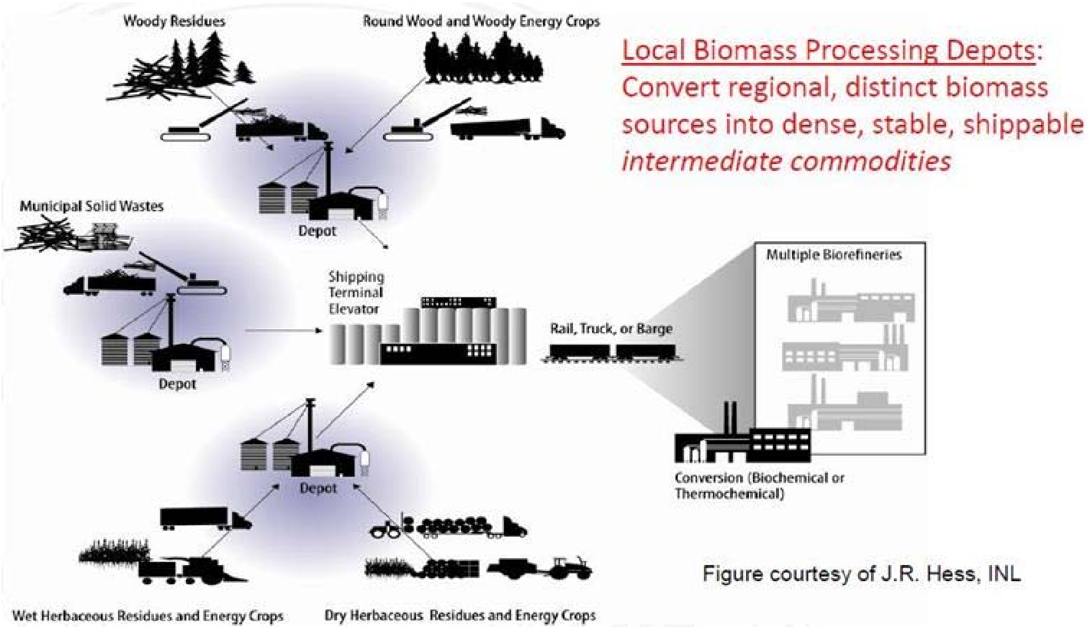


Figure 20. Local biomass processing depot concept in the US (Campbell, 2011).

A biomass yard can play a role in the process of guaranteeing the year-round availability of biomass. The biomass will be stored at the biomass yard until the exact moment when it is needed. The pre-treatment of biomass has to lead to a standardized intermediate product (biocommodity) that can be traded more easily.

4.4 Multi-modality transport

The traditional method for transporting biomass is road transport. However, alternatives could be transport by rail or by waterway. The choice for a certain type of transport is determined by:

- transport distance;
- accessibility.

The feasibility of multi-modality transport increases in combination with the use of a biomass yard and/or with pretreatment. This was the core of the BioBoost project.

Table 31. Advantages and disadvantages of the logistical concept 'Multi-modality transport'.

Advantages	Disadvantages
• enables optimal choice of transport type for each section of the transport route • for longer transport distances cheaper transport modes (ship or train) can be chosen	• more handling during transhipments • higher loading & unloading costs • not all locations can be reached by alternative transport modalities

The average truck transportation distance of timber in Finland in 2014 was 107 km (Strandström 2015). For a train transportation chain the corresponding distance was 322 km including 50 km pre-transport by truck and for a waterway transportation chain 295 km. Energy wood is predominantly transported by trucks. If the transportation distance is less than approximately 50-70 km, the cheapest transport mode is uncomminuted by a truck (Tahvanainen & Anttila 2011). With longer distances transport of comminuted material with a chip truck is more economical. Train transport of energy wood is currently not economically viable in Finland (Nivala et al. 2015).

4.5 Biocommodities

A biocommodity can be seen as a standardised form of biomass. The need for the development of biocommodities was described by Sanders et al. (2009). The main reasons for developing biocommodities are:

- security of supply;
- need for quality standards and quality control and;
- facilitation of trade.

Possible examples of biocommodities that will be further developed are pyrolysis oil, torrefaction pellets, wood pellets and biosyngas. It is not completely clear yet which biocommodities will arise and this will certainly be a stepwise introduction. However, biocommodities will certainly have a number of properties that include:

- transportability;
- stability;
- sufficient market volume;
- year-round availability;
- competitive costs;
- easily standardised in uniform quality characteristics for specific applications;
- easy and quick quality measurements possible.

Biocommodities could be produced e.g. at biomass yards and they will greatly influence the set-up of a biomass value chain. They will enable transportation of the biomass over a much longer distance, thus facilitating international trade.

Table 32. Advantages and disadvantages of the logistical concept 'Biocommodities'.

Advantages	Disadvantages
• standardization • easier to trade (inter)nationally • better transportability • increased storability through stability • better quality that can be measured	• sufficient market volume is needed • higher pre-treatment costs need to be compensated

4.6 Small-scale versus large-scale conversion

The choice for the scale of the conversion leads to either shorter transport distances or longer transport distances.

Table 33. Advantages and disadvantages of the logistical concept 'Small-scale conversion'.

Advantages	Disadvantages
• short transport distance	• higher conversion costs per unit

According to the scale-of-unit-effect, the production costs of an item decrease with the plant capacity. In plant construction each piece of equipment has a scaling exponent, which varies from type to type but 0.7 is a good proxy. Please observe that this is a power function, ^x, not a factor, *x! For example, assume a tube of 1 m length, 1 cm wall thickness and a diameter 0.1 or 1 m (Table 34).

Table 34. Comparison of steel demand per volume of tubes with different diameters.

Tube of 1 m length	0.1 m diameter	1 m diameter
Surface area 2 * pi * r * length	2*3,141*0.05*1 = 0.3141 m²	2*3,141*0.5*1 = 3.141m²
70 kg steel per m² surface	0.3141*70 = 22 kg	3.141*70 = 220 kg
Reactor volume pi r²*length	3.141*0.05² = 7.8 L	3.141*0.5² = 785 L
Steel per L reactor volume	22/7.8 = 2.8 kg	220/785 = 0.28 kg

With regard to the capacity, the larger tube has only 10% of steel compared to the smaller tube. This is similar for plant operation: in a small plant the wood chip feeding is done by a telehandler and one driver, in a larger plan by a wheel loader and one driver. On the other side a large plant needs more biomass than a small one, which increases the transport efforts. An example is shown in the figure below.

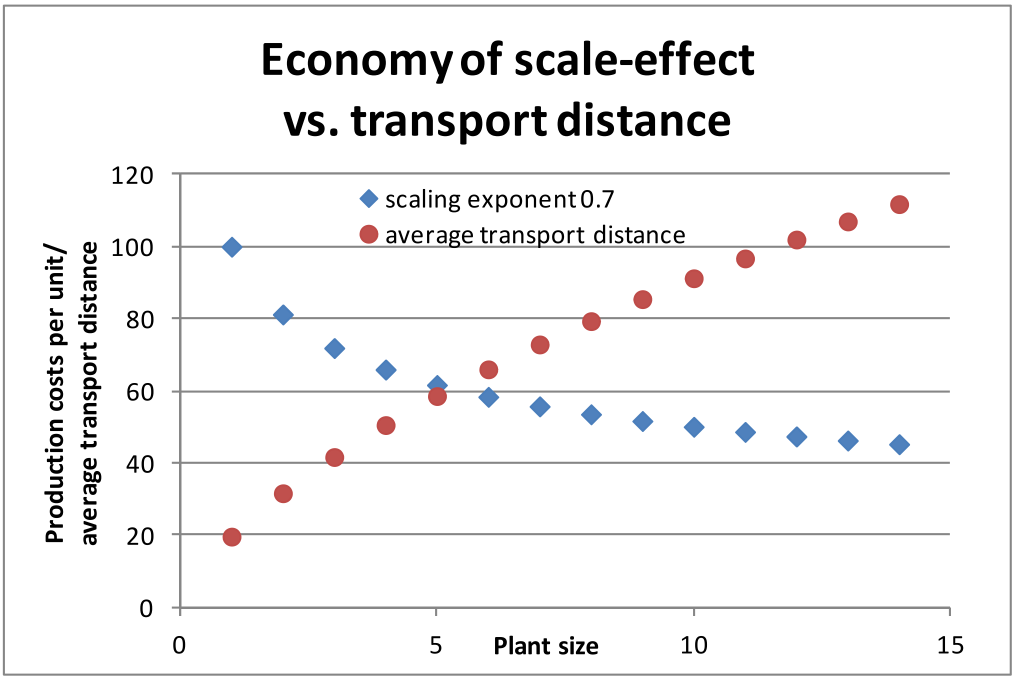


Figure 21. The unit-of-scale-effect: Relation of production costs per unit (blue squares) and average transport distance (red circles) (copyright S. Kühner SYNCOM).

The optimum between transport efforts and production costs depends on the relative importance of the two cost items transport and conversion (Figure 21). If the conversion technology is sophisticated and expensive as for example entrained flow gasification for synfuel production, the high processing costs outrun the wood chip transport costs and the lowest overall costs are at a large plant. In contrast, the processing costs of a pellet mill are relatively low and the wood chip transport has a higher contribution to the overall costs compared to a synfuel plant. So the most economic size of a pellet mill is smaller than that of a synfuel plant.

5. Overview of assessment methods for logistics

5.1 Introduction

Several methods for calculating and sometimes optimizing the logistical costs and greenhouse gas effects of biomass value chains were used in the projects that were described in Chapter 3. Apart from that some other methods were found in literature. All of these methods will be briefly described in this chapter.

The assessment methods that were found are:

- BeWhere - Assessment on an EU- and country-level;
- Bioboost - Holistic Logistics Model;
- Biocore - Supply chain optimization with an MILP model;
- BiomassTradeCentres - Catalogue of wood fuel producers in 9 EU countries;
- COST Action FP0902 - Machine cost calculation model;
- DBFZ method - Calculation transport costs;
- EuroBioRef - Optimizing biomass logistics;
- EuroPruning - support day-to-day logistics operations and economic, environmental and social assessments;
- Infres - Innovative, effective and sustainable technology and logistics for forest residual biomass;
- LOCAgistics - Assessment on a regional level;
- WoodChainManager.

5.2 BeWhere - Assessment on an EU- and country-level

The BeWhere tool was chosen in S2Biom to calculate the logistics on the European level. It was originally developed for the forest sector and for biofuels. Within the S2Biom project it will be extended to agricultural residues. The details of the BeWhere model have been described extensively in several publications (Leduc, 2009; Wetterlund, 2010; IIASA, 2015; ...). The next section only gives a very brief description of BeWhere.

BeWhere identifies places in the EU where there will still be enough space to have extra bioenergy production facilities, based on availability of biomass (corrected for biomass already used) and demand (corrected for already delivered) (Figure 22). BeWhere models the whole biofuel supply chain.

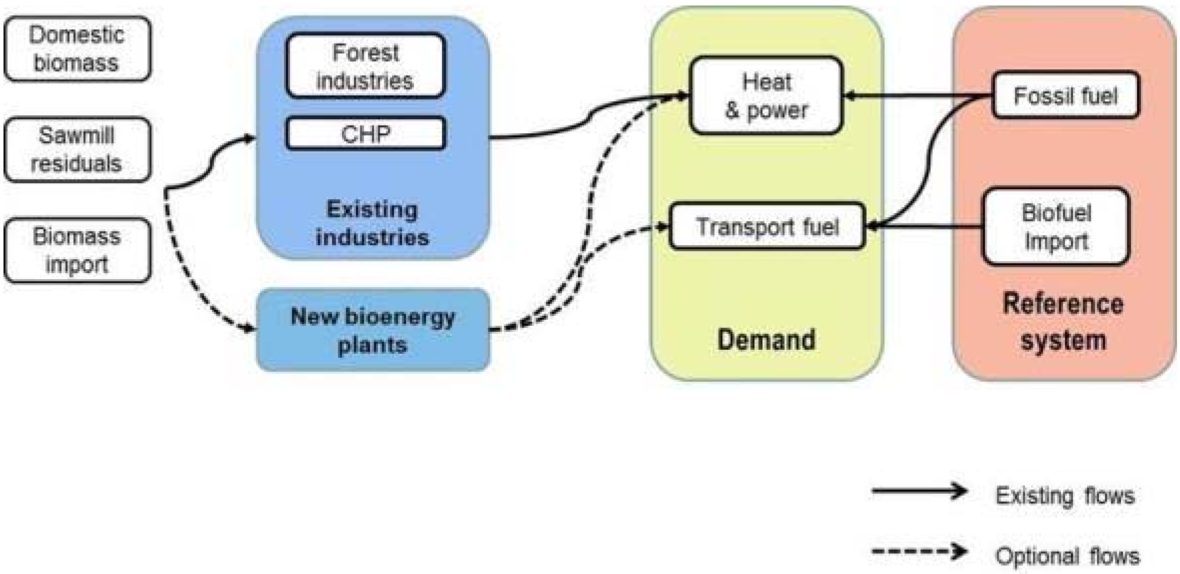


Figure 22. The design problem that needs to be solved by the BeWhere model (IIASA, 2015).

The problem is seen as a facility location problem that is restricted by the amount of (woody) biomass available: local harvested wood per region, sawmill residues and imported biomass. Fixed costs are taken for the biomass after felling and transportation to the side of the nearest road. The whole wood demand is taken into account coming from pulp & paper mills, CHP plants and local district heating (DH) plants (traditional) and possible new bioenergy production plants (e.g. biofuels, or biofuel). The later plants are modelled (with a scaling function). The biofuel demand is estimated by the population data indexed by national transport fuel consumption. The heat demand is estimated from national heat consumption if no better data is available at a fine resolution. And only fossil fuel based energy can be substituted.

The cost for transporting biomass to production plant and for transporting biofuels to gas stations are both taken into account. Transportation can be done by tractor, truck, train and ship. The fixed transportation costs include loading and unloading costs and do not depend on the distance of transport. Variable costs include fuel cost, driver cost, maintenance cost etc. and are dependent on the distance. The most efficient way for transportation in the model are: tractor up to 25 km, truck up to 50 km, train 50–150 km and ship more than 150 km. BeWhere uses a pre-calculated transport matrix, for which any point of the grid is connected to any other points of the same grid. The matrix is generated from a combination of road, railway and shipping line maps based on cost, time or distance minimization. In BeWhere the emissions are defined for each transportation means in gCO_2/km/t (tractor 810, truck 48, train 0.003, boat 22).

The problem is modelled as an Ordinary Mixed Integer Program (MIP). GAMS software is used to develop the model and the solver is CPLEX. When problems are too large they can be divided into smaller ones. Leduc (2009) describes the goal as follows: ‘The model will choose the less costly pathways from one set of biomass supply points to a specific plant and further to a set of biofuel demand points. The final result of the optimization problem would then be a set of plants together with their corresponding biomass and biofuel demand points.'

In the tool one selects the biomass type and conversion technology, and the optimal locations are then selected from the (pre-calculated) database (Figure 23). BeWhere can use detailed roadmaps and calculates 'real' transport distances from source to conversion point. Specific 0.5 x 0.5 degree blocks are being identified where a certain conversion installation can be placed. Costs and GHG emissions are calculated for each segment of the supply chain. BeWhere can refine the input data to make the calculations more specific (e.g. the case studies in Austria are much more detailed in resolution and in input data). Figure 20 presents an example of typical output from the model: left figure shows the robustness of the locations of the production sites under 30 scenarios by their number of occurences, and right side the biomass trades in the EU.

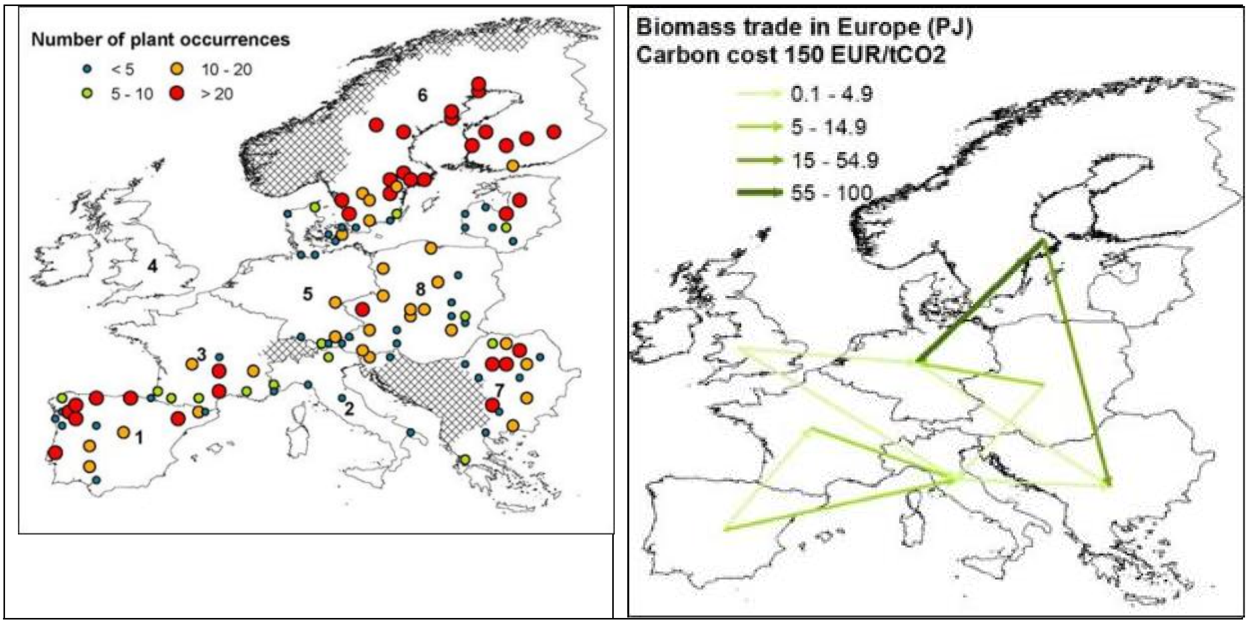


Figure 23. An example of the output of the BeWhere model (IIASA, 2015).

5.3 Bioboost - Holistic Logistics Model[8]

One of the objectives of the FP7-BioBoost project was the optimization of complete value chains from biomass to bioenergy product in the EU-28. This included:

- biomass utilization (price per unit increases with higher utilization rates due to competition);
- biomass logistics from field to decentral plant (based on road network);

[8] Sources: Bioboost, 2013; Pitzer & Rotter, 2012

- size and location of decentral plant (on NUTS 2 resolution);
- energy carrier logistics from decentral to central plant;
- size and location of central plant for upgrading to marketable bioenergy product.

The approach of the University of Applied Sciences Upper Austria (FH OÖ) was to develop a logistic model to identify the most suitable plant locations based on supply and demand. The pathways that were taken into account are:

- straw / fast pyrolysis in decentral plants / gasification to synfuel in central plant (KIT-Bioliq process);
- wood chips / catalytic fast pyrolysis in decentral plants / deoxygenation to transport fuel in central refinery (CERTH, DSM, Neste CatOil-process);
- sorted organic municipal waste / hydrothermal carbonisation in decentral plant / combustion for renewable heat & power in CHP (AVACO2, KIT).

A simulation-based optimization model and a concept for logistics processes feed a Holistic Logistics Model (Figure 24). The objective is the design of cost-efficient and safe transport, handling and storage processes. The approach uses a technical concept, safety concept and cost data.

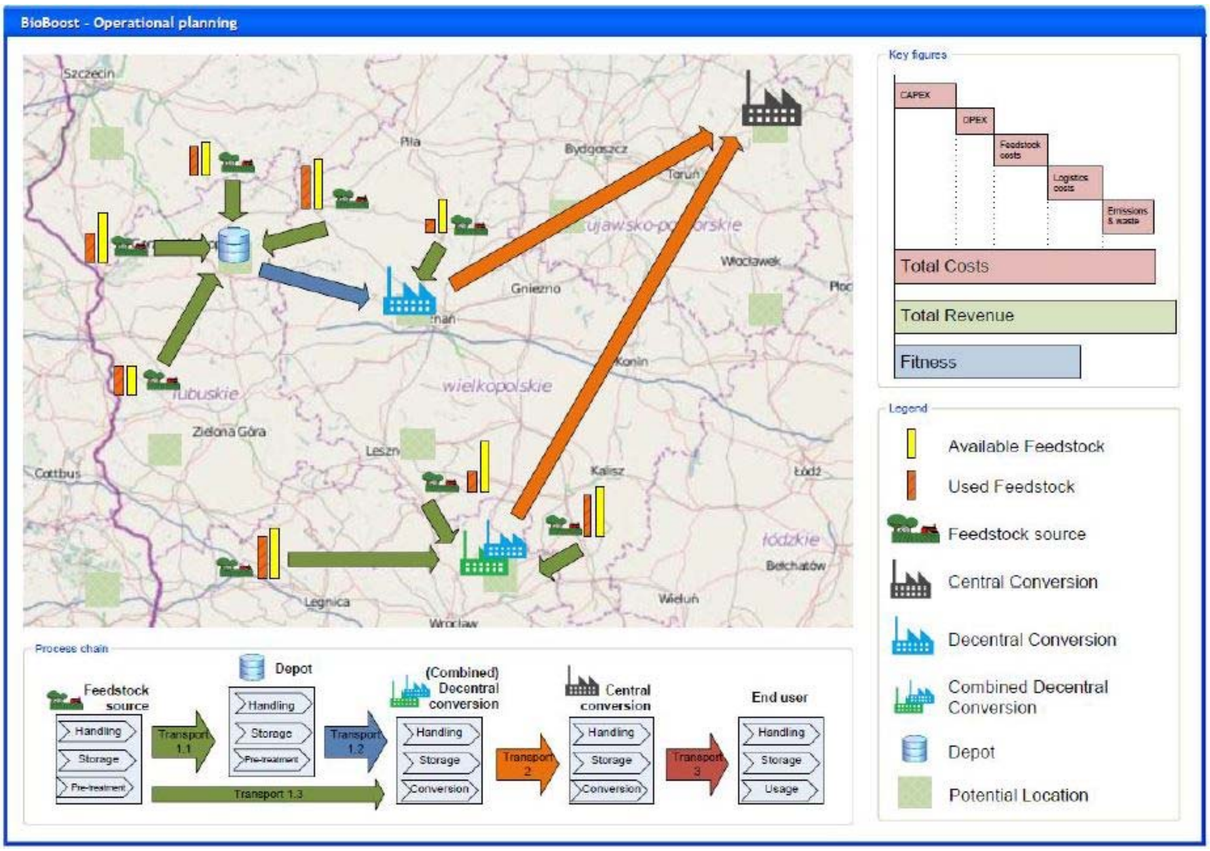


Figure 24. Bioboost Holistic Logistics Model (Copyright: E. Pitzer, G. Kronberger, FHOÖ).

The simulation-based optimization model was developed with the following characteristics:

- separate chain per feedstock;
- uses process information and solution candidates;
- storage sizes & routing can be determined;
- a logistics process is transport, handling, storage or pre-treatment;
- evaluation of costs & emissions for feedstock, transport & handling, storage, conversion & construction and revenue of intermediates;
- optimization overall production costs by feedstock utilization (per region), plant size and transport network.

Figure 25 shows the power and performance of FHOÖ's heuristic optimisation model in an exemplary result for the CP-pathway. In this process, forest fuel is pyrolysed in the presence of a catalyst yielding a high quality bio-oil (15 to 20% oxygen, storable, compatible to equipment for crude oil transport). Upgrading follows a series of extractions and hydrotreatments to remove small acids and phenols, reducing the hydrogen demand in upgrading to transportation fuel. This step is envisaged in refineries profiting of available know-how, infrastructure and co-processing from commercial facilities. The hypothetic scenario below prepared in the BioBoost project shows the extremes, as there is a strong east-west gradient of forest residue availability and upgrading capacity: The Baltic states where the forest residues potential for bio-oil production exceeds the refinery capacity and the Netherlands which are short in biomass residues but a centre of the European refining industry. The first European CFP-plants would be built where feedstock is available in large amounts at low cost as e.g. in the Baltic States. CFP plants (in the coloured regions) attract feedstock from neighbouring regions (blue arrows). The bio-oil of these plants will be transported to refineries with available conversion capacities first nearby, later also further away (red arrows). With increasing implementation, the bio-oil may be transported to refineries with unused capacity or new upgrading capacity would have to be erected. In the Baltic states the forest residue potential for bio-oil production exceeds the locally available refinery capacity, whereas the large Dutch refining capacity is unused because feedstock is scarce. In this example all refineries nearer by the Baltic States have already saturated their surplus capacity with regional-produced bio-oil, which is the reason the CP-oil is transported to Rotterdam refineries in the Netherlands. In regions with low feedstock availability as e.g. the Netherlands bio-oil production costs are relative high due to longer feedstock transport distance and the scale of unit effect. In this model run, the Dutch CFP-plant had a bio-oil production of less than 50.000 t/a while the Baltic had about 150.000 t/a. The bio-oil logistic costs vary between 1 €/t for the CFP at the Lithuanian refinery to about 100 €/t for long distance railway transport to Rotterdam. In the BioBoost project these two refineries were calculated to have production costs of about 1,400 – 1,600 €/t.

Further results for all three pathways and EU-28 can be retrieved under www.bioboost.eu.

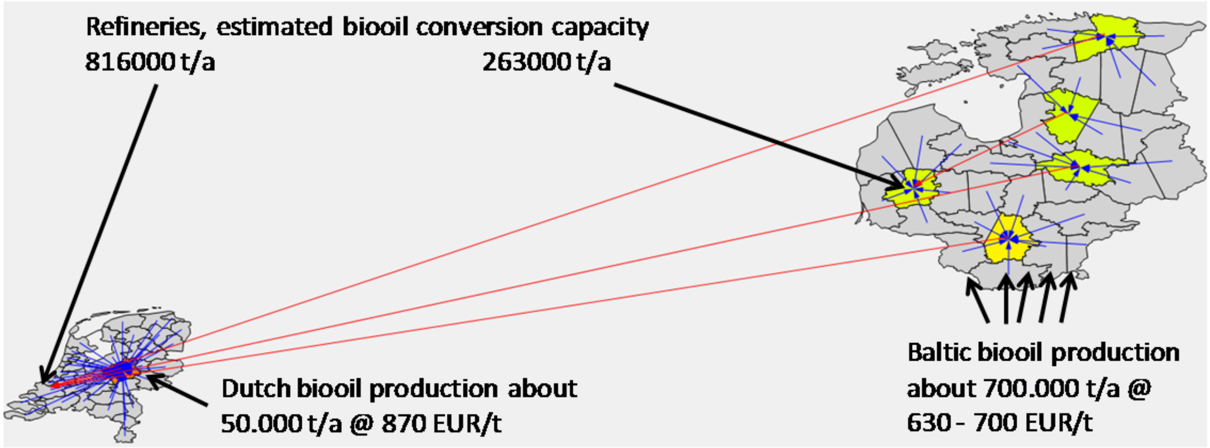


Figure 25. **An exemplary result of the simulation model developed in BioBoost. Areas with CFP-plants are coloured according to the production costs (green – 630; yellow – 700; orange – 870 €/t biooil), NUTS with refineries are indicated by black arrow. CFP-plants would be built where feedstock (here forest residues) are available for low cost as e.g. in the Baltic states. Biomas feedstock transport across NUTS is indicated with blue arrows; red arrows indicate bio-oil transport to refineries with available conversion capacities. Other regions with a more balanced ratio of biooil supply and demand were omitted for sake of simplicity. (Copyright: S. Kühner, SYNCOM)**

5.4 Biocore - Supply chain optimization with an MILP model

Imperial College London used a Mixed Integer Linear Programming (MILP) model in the Biocore project (Patel et al., 2013; Biocore, 2014). The goal of the model was supply chain optimisation. An objective-oriented optimisation procedure was used to select best locations (Figure 26).

The key issues were: feedstocks mix (seasonal/geographical availability, competitive uses), logistics constraint, storage location and size and pre-processing (densification). The time horizon for the optimisation was January 2015 – December 2024. There were two temporal levels (five two-year period discretisation; seasonality). The objective function of the model was: total discounted cost of production + transportation + storage (capital and operations) + technology capital + technology operations + utilities and chemicals. The model takes into account biomass spatial and temporal availability (Figure 27) and existing technologies in the area (sawmills and pelletizing facilities) (Figure 28). The results of the model were: feedstock share and land use and hardwood supplied to the plant.

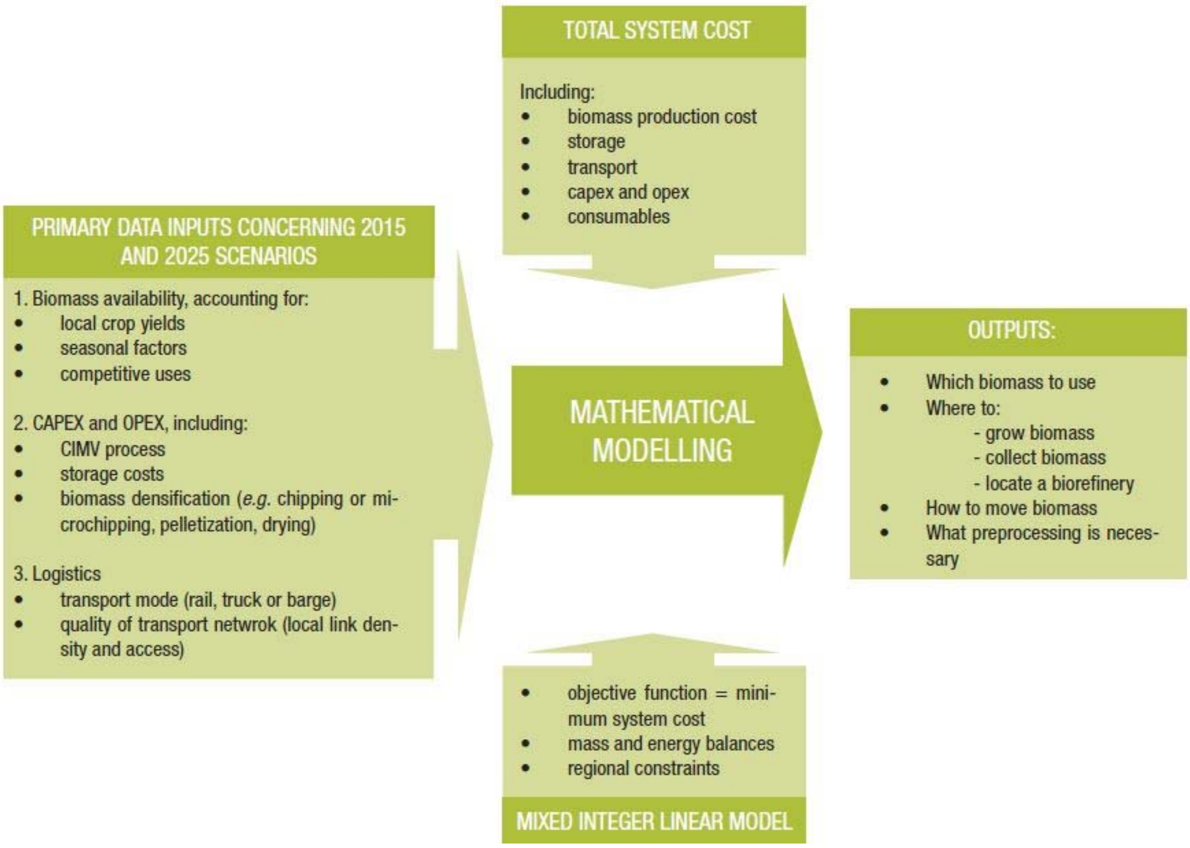


Figure 26. **Objective driven modelling framework used to design the biomass supply chain in Biocore's cases studies (Biocore, 2014).**

In the Biocore project the supply chain logistics were analysed in the framework of the case studies. Current (2015) and future (2025) infrastructure logistics were described, including data on the quality and availability of transport potions and the cost of transportation. The demand of the biorefinery was 150 kt dry matter per year. Transportation costs were taken proportional to the delivery distance and the freight shipped.

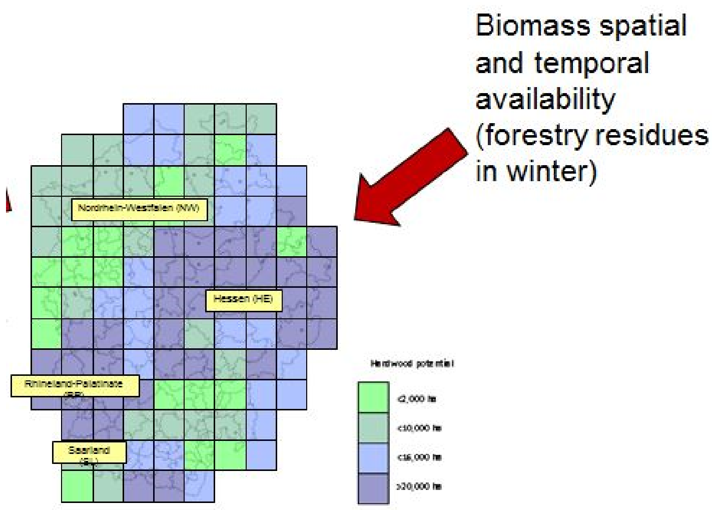


Figure 27. **Biomass spatial and temporal availability (Patel et al., 2013).**

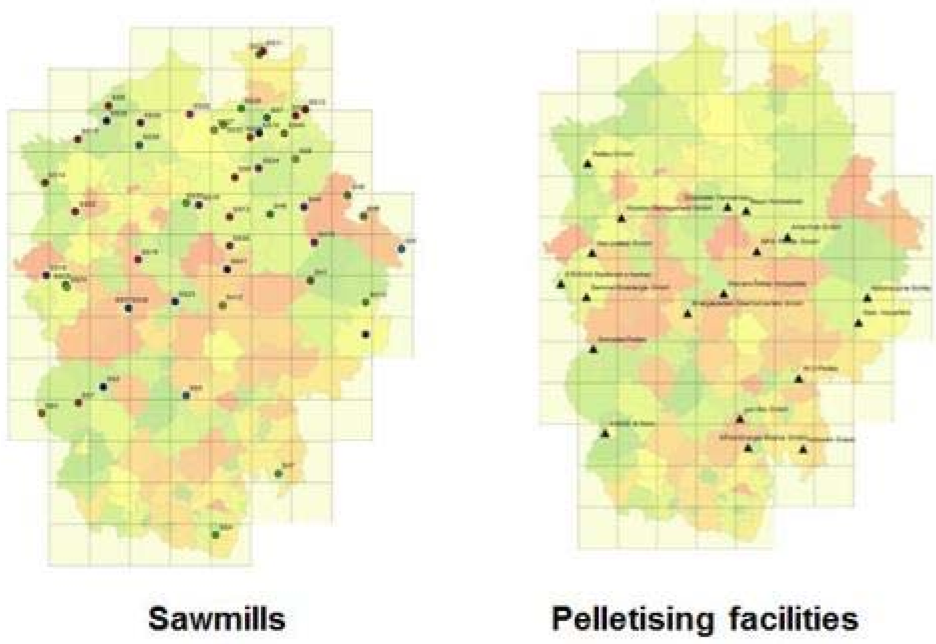


Figure 28. Location of existing technologies in the area (Patel et al., 2013).

In the German case an integration benefit was identified for access to existing hardwood chipping and pelletizing facilities. Also the presence of rail ad fluvial transport options provided cost-effective alternatives to road transport. In the Hungarian case mixed feedstock provided the basis for cost optimized biomass transportation solutions. In the Indian case proximity to the biomass storage facilities is a key factor. However, more efficient straw baling technology will reduce the overall cost of the supply logistics.

Two alternative transport scenarios: 1) uniquely on road and 2) rail transport could also account for part of the supply chain. The use of transport modes such as railways can favorably influence overall costs. In Hungary integration of railways and trucks could produce up to 10% cost reductions. This is more difficult when the biomass production zones are scattered across a territory.

The biorefinery location would benefit from the supply of local biomass to reduce logistics cost.

5.5 BiomassTradeCentres - Catalogue of wood fuel producers in 9 EU countries

One of the important aims in BiomassTradecentre II project was to make the biomass market more transparent and to promote existing biomass producers. To reach this goal a catalogue of wood biomass producers was developed. The international catalogue and internet application (Figure 29 and 30) contains more than 2.100

addresses of service providers (wood chip, firewood, pellet producers, and forest companies but also sawmills) in 9 EU countries (BiomassTradeCentre II, 2015a).

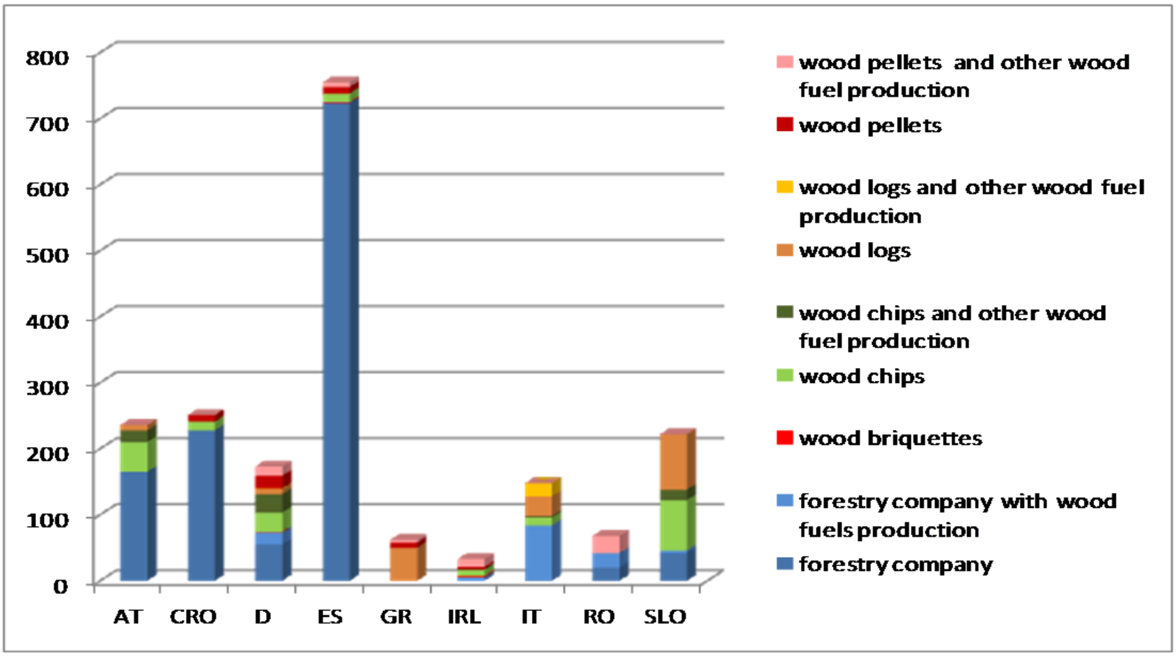


Figure 29. Number of data in online catalogue (status 30.4.2014)by country and type of activity (BiomassTradeCentre II, 2015a).

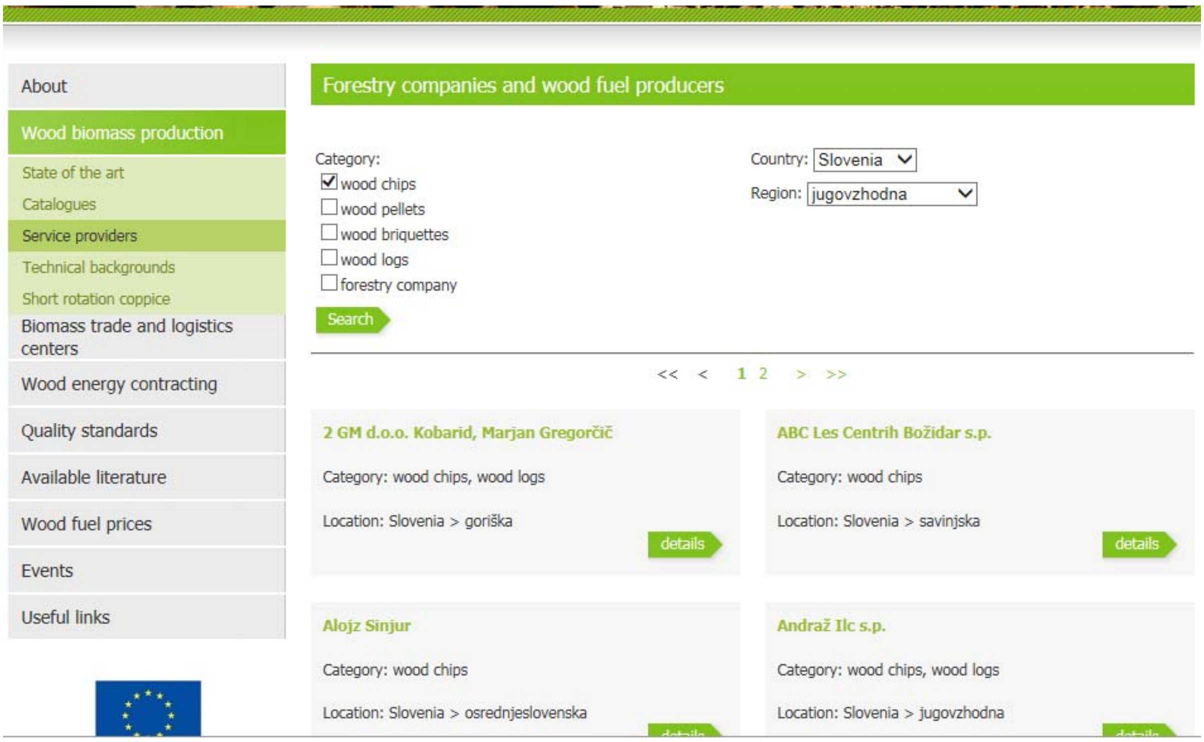


Figure 30. Internet search tool for wood fuels producers.

5.6 COST action FP0902 - Machine Cost Calculation Model

The "Machine Cost Calculation Model" (Ackerman et al., 2014) has been produced by an international group of experts, operating within the framework of COST Action FP0902. The calculation model is specifically designed for cost calculations within biomass harvesting operations, but they also fit for general use and can be applied to many other fields where costing models are needed.

As part of the COST Action FP0902, Stampfer et al. (2013) discussed and presented common modelling methods that have been used by COST FP0902 partners in System Analyses and Modelling in Forest Biomass Supply Chains research, including methods such as:

- productivity models;
- (Multi-Criteria) Decision Support;
- Linear Programming;
- Integer Optimisation (Mixed Integer Programming, MIP and Integer Programming, IP);
- heuristics;
- simulation methods;
- business process mapping.

5.7 DBFZ method - Calculation transport costs

Brosowski (2014) describes a calculation method used by DBFZ for determining country-specific transport costs for different European countries. Three types of country-specific parameters were considered:

i. basic parameters (labour costs, diesel price, lubrication and price level for machinery)
ii. fixed machinery costs (investment, life span, depreciation and operating hours) and
iii. variable machinery costs (repairs, fuel, lubrication).

KTBL data from Germany were taken as a starting point and other countries are calculated using a country-specific price-level index. Calculations were made for the transport costs with trucks in three different supply chains.

5.8 EuroBioRef - Optimizing biomass logistics

Within the EuroBioRef project a comprehensive tool was developed for optimizing biomass logistics by the Danish Technological Institute (Hinge, 2013). The main target was to evaluate different scenarios for supply of multiple biomass to a biorefinery. Data sheets were created about: crop, harvesting, baling, loading, field transport, pretreatment/ insertion, storage (local/central), road transport, sea transport, unloading. The information on the data sheets includes: costs (€/ton $DM_{(out)}$), energy consumption (direct and indirect), CO_2-emissions (direct and indirect), effectivity, input/output ratio, reliability and security of supply, harvest window, use of equipment for other purposes. The calculation of biomass loss is performed as a function of the storage period. The data sheets are processed in supply chains specific for each crop. One chain can have up to a maximum of 15 handling elements, which resulted in about 250 data sheets. A scenario is a unique combination of data sheets. Aspects that might affect the optimization are: moisture content, biological degradation during storage, security of supply, minimum volume for effective handling, energy consumption and CO_2-emission, interdependency between handling operations, build-up and take-out of storages and buffer capacities. The supply chains were fed into a GAMS computing model, which optimizes costs, energy consumption and CO_2-emission. The parameters are weighed.

5.9 EuroPruning - support day-to-day logistics operations and economic, environmental and social assessments[9]

EuroPruning has created and designed a tool to support the logistics operations required for EuroPruning project. It includes a centralized web application and an on-board system (smart box) to be placed into the trucks carrying out the biomass transport. The system is able to provide support for: biomass labelling, prunings quality parameters tracing and monitoring of smart box measures during transportation. The tool can be utilized by a central manager of the whole chain, but also can be utilized as a multi-user platform to facilitate the electronic sale of biomass. The tool allows biomass producers to visualize their biomass lots. Traders and final consumers can place orders by searching and selecting the biomass according to quality and distance. The tools support traders and transporters to choose the best route.

The modeling of costs is not part of the support system for logistics. The economic assessment aims to assess the logistics costs, which includes the next cost items: harvesting, temporary storage, labelling, loads and transport, storage, processing,

[9] Sources: Gebresenbet & Bosona, 2015; Olsson, 2015; Boer et al., 2015

marketing, information and full chain management. The aim of EuroPruning is to minimize total costs including all cost components by identifying costs at all stages of the biomass logistic chain for the agricultural pruning. On the base of this information, to develop a biomass logistics cost model (addressing operational costs) and a Life-Cycle Cost Analysis (LCCA). The assessment will be applied to the cases of the demonstrations carried out. An improvement for the chains in terms of costs will be proposed on the base of the model of costs and LCCA results, by identifying the niches for improvement item by item. The environmental assessment aims to determine the most environmentally friendly paths for agricultural logistics. The method chosen are the Life Cycle Assessment and the methodology set by 2009/28/CE and further implemented by BIOGRACE project and tool (www.biograce.net/). The social assessment will be based on a SROI (Social Return Of Investment) analysis. The analysis measured the economic return of an activity, and in EuroPruning will account the product impact on farmers on energy producers, Greenhouse Gas reductions, job creation and product responsibility.

The three assessments are not integrated with an optimization model. All of them separately will allow the identification of best practices leading to pruning chains of interest because of their performance in terms of economics, environmental and social impacts. The discussion of the results will support the selection of recommended and optimized pruning biomass value chains.

5.10 Infres - Innovative, effective and sustainable technology and logistics for forest residual biomass

Sources: Türkmengil et al., 2014; Alakangas et al. (2015), Erber et al. (2014)

Full supply chain performance estimation and streamlining is one of the tasks of the Infres project (Infres, 2015) that is performed by BOKU University of Natural Resources and Life Sciences in Vienna. Erber et al. (2014) looked at three main objectives for their study:

- bottlenecks in the fuel wood supply chain;
- the structure of current network systems and;
- a dynamic warehouse model should be employed for generating regional wood chip supply networks at optimal cost, considering seasonal fluctuations of supply and demand.

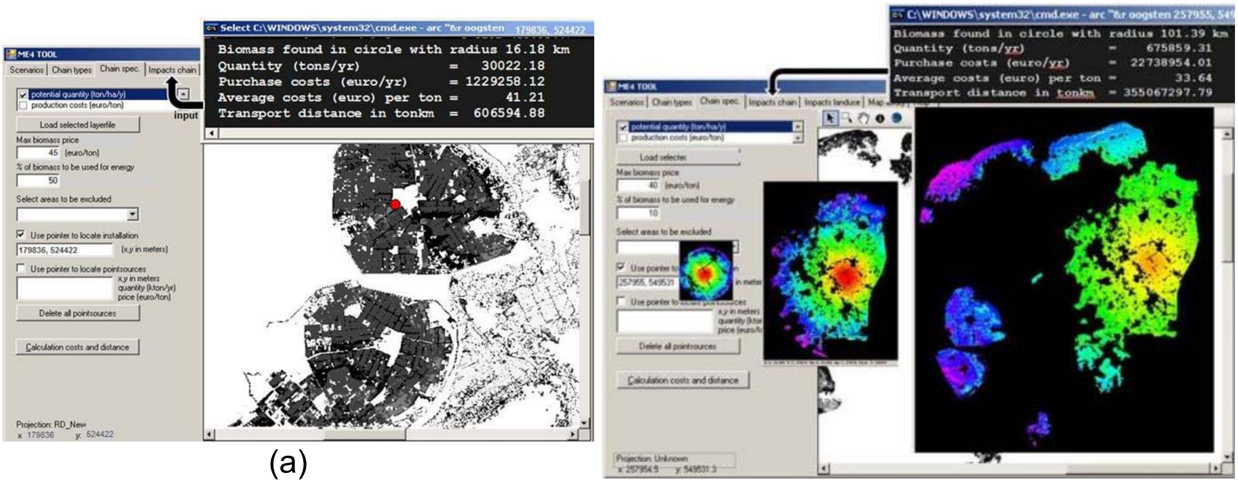
Alakangas et al. (2015) summarized the results of Infres including logistical solutions, forest wood supply networks, innovations in forest wood supply, different supply chains selected for demonstrations and cost estimations of forest fuel procurement in Infres regions.

5.11 LOCAgistics - Assessment on a regional level

The basis for the LOCAgistics tool are i) a GIS tool (Elbersen et al., 2014; Annevelink et al., 2012) developed in the ME4 project 'Integrated framework to assess spatial and related implications of increased implementation of biomass delivery chains' and ii) the Bioloco logistics optimization tool (Annevelink & de Mol, 2014).

GIS-module

This is an interactive tool for the specification and assessment of regional bio-energy chains (Figure 31), where one can specify the position of the conversion technology.



(a) (b)

Figure 31. An example of the interface of the first version of the GIS part of LOCAgistics: a) pin-pointing a location during the chain specification and b) the iterative calculation of costs and distances. (Annevelink et al., 2012).

Bioloco logistics optimization tool

The Bioloco optimisation model (Annevelink & de Mol, 2014) establishes the optimal design of the logistical network (Figure 32) within some broader boundaries e.g. a list of alternative source locations, transport systems, energy plants, etc. Bioloco chooses the best source locations, transport systems, energy plants, etc. It only takes one run of Bioloco to find the optimal network within these specified broader boundaries. Bioloco has the month as time unit. The user of Bioloco has to choose an optimisation criterion at forehand.

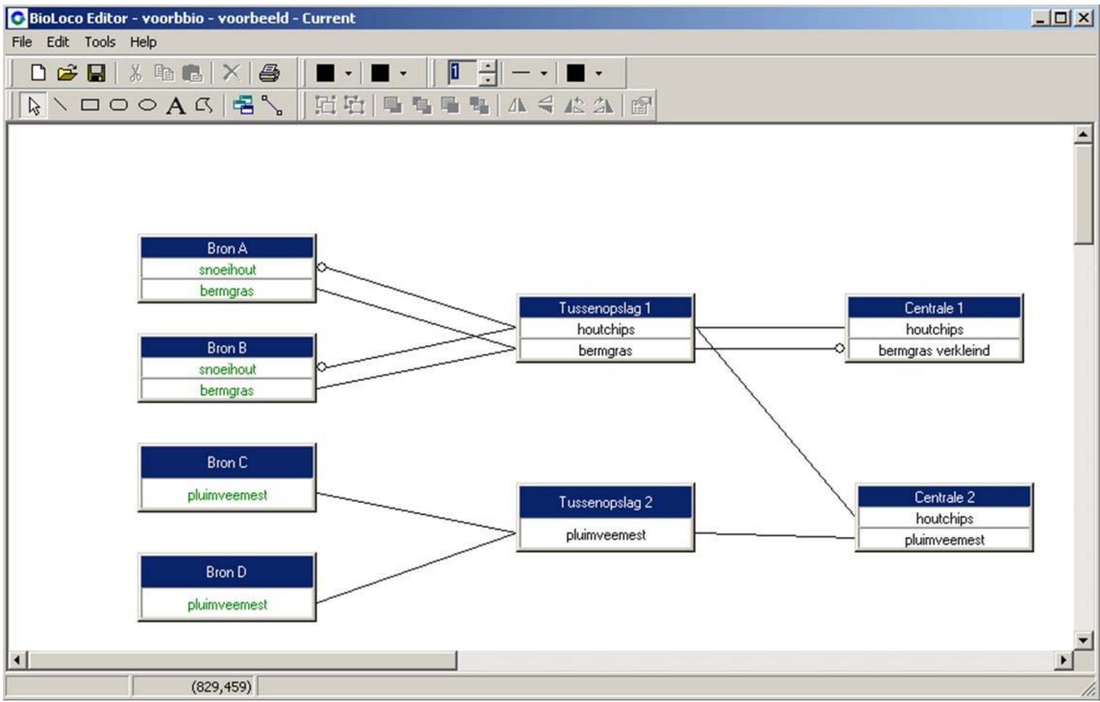


Figure 32. **An example of a simple logistical network within Bioloco (Annevelink & de Mol, 2014).**

Bioloco calculates the optimal bio-energy chain (within certain constraints like biomass types, transport types, storage facilities, pre-treatment methods and conversion techniques) and based on a chosen optimisation criterion (financial, energetic or emission) or combination (goal programming). Bioloco gives insight into the costs, energy consumption and greenhouse gas emission of the biomass supply chain. It takes into account effects that are typical for biomass:

- seasonal fluctuations in supply and demand of biomass;
- losses of water due to drying (positive) and losses of dry matter due to heating (negative).

The type of Bioloco results include:

- total throughput;
- costs and revenues (and profit);
- energy revenues and energy consumption;
- greenhouse gas emissions and greenhouse gas emissions avoided.

5.12 WoodChainManager

Wood process charts (“functiogramms”) can be used as a starting point for cost evaluation and estimation of environmental or ecological impacts. The Slovenian Forestry Institute developed WoodChainManager (WCM) an internet tool for calculation of machinery costs and visualisation of harvesting systems (Triplat et al., 2015). Machinery costs are calculated per scheduled machine hour, where scheduled time is the time during which equipment is scheduled to do productive work. Final selection of harvesting system depends on costs and productivity of selected machinery, especially in cases where soil conditions as well as terrain enable more than one option. Comparison of machinery costs along different harvesting systems facilitate the selection of suitable harvesting systems.

Web portal WoodChainManager (http://wcm.gozdis.si) offers following interactive tools suitable for the organization and optimization of forestry works:

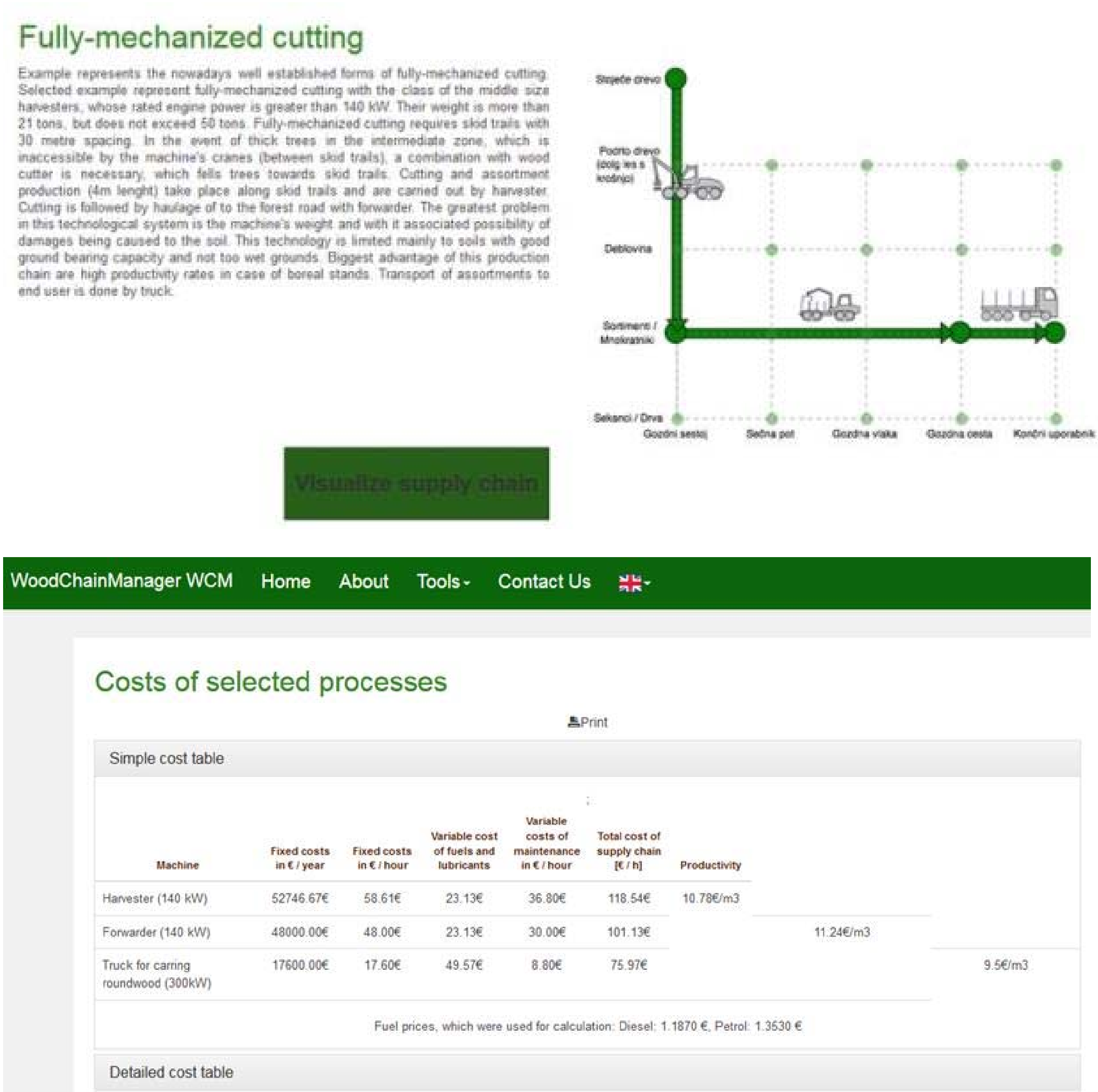
- creation of interactive and transparent descriptions of forestry wood chains;
- creation of transparent calculations of forestry mechanization costs;
- stipulation of forestry production norms;
- converting between volume, weight and energy units.

For easier understanding and comparison of different tailor maid production chains WoodChainManager contains detail description of six most common production chains:

1. Traditional production of roundwood;
2. Non-professional production of firewood for own use;
3. Non-professional production of wood chips for own use;
4. Production of green wood chips;
5. Fully-mechanized harvesting (Figure 33);
6. Cable crane yarding.

Each production chain has a short description, Wood process charts (“functiogramms”) for visualization of the process and table of machinery costs.

WoodChainManager (WCM) is still in development next phase of development will contain also the calculation of operator costs (personal costs).



Fully-mechanized cutting

Example represents the nowadays well established forms of fully-mechanized cutting. Selected example represent fully-mechanized cutting with the class of the middle size harvesters, whose rated engine power is greater than 140 kW. Their weight is more than 21 tons, but does not exceed 50 tons. Fully-mechanized cutting requires skid trails with 30 metre spacing. In the event of thick trees in the intermediate zone, which is inaccessible by the machine's cranes (between skid trails), a combination with wood cutter is necessary, which fells trees towards skid trails. Cutting and assortment production (4m lenght) take place along skid trails and are carried out by harvester. Cutting is followed by haulage of to the forest road with forwarder. The greatest problem in this technological system is the machine's weight and with it associated possibility of damages being caused to the soil. This technology is limited mainly to soils with good ground bearing capacity and not too wet grounds. Biggest advantage of this production chain are high productivity rates in case of boreal stands. Transport of assortments to end user is done by truck.

Visualize supply chain

WoodChainManager WCM Home About Tools Contact Us

Costs of selected processes

Print

Simple cost table

Machine	Fixed costs in € / year	Fixed costs in € / hour	Variable cost of fuels and lubricants	Variable costs of maintenance in € / hour	Total cost of supply chain [€ / h]	Productivity		
Harvester (140 kW)	52746.67€	58.61€	23.13€	36.80€	118.54€	10.78€/m3		
Forwarder (140 kW)	48000.00€	48.00€	23.13€	30.00€	101.13€		11.24€/m3	
Truck for carring roundwood (300kW)	17600.00€	17.60€	49.57€	8.80€	75.97€			9.5€/m3

Fuel prices, which were used for calculation: Diesel: 1.1870 €, Petrol: 1.3530 €

Detailed cost table

Figure 33. **Example of supply chain description and cost calculation in WCM (Triplat et al., 2015).**

6. Assessment of logistical concepts

6.1 Introduction

In the description in the DOW of Task 3.2 it is mentioned that the logistical concepts will already be assessed immediately after their description. However, the problem of this task is that it depends on data of the advanced case studies (both regional and on the EU-level). And these advanced case studies will not be started officially before Month 24 and they will last until Month 34, so most of the data were not be available yet while writing this current deliverable D3.2 that needed to be delivered at the end of Month 24. Therefore only a general, qualitative assessment of the logistical concepts was made in Chapter 4 of this deliverable D3.2. So a further assessment of a selection of the logistical concepts will be performed in the third stage of the S2Biom project and this will be described in Deliverable D3.3. For these assessments the advanced case studies will be used, combined with data from literature.

6.2 Choice of methods for further assessment in S2Biom

Although the details still need to be further discussed at this stage two methods have been chosen for further assessments in the S2Biom project viz.:

- BeWhere – for the European & national level
- LOCAgistics (partly combined with the DBFZ calculation method) – for the regional and local level.

These two methods will be closely interlinked so that LOCAgistics can further refine and detail the outcomes of the BeWhere model and that the BeWhere model can use the outcome of the LOCAgistics model to modify their calculations if needed. The relationship between BeWhere and LOCAgistics in the S2Biom project is given in Figure 34. More details of the assessment approach will be described in Deliverable D3.3.

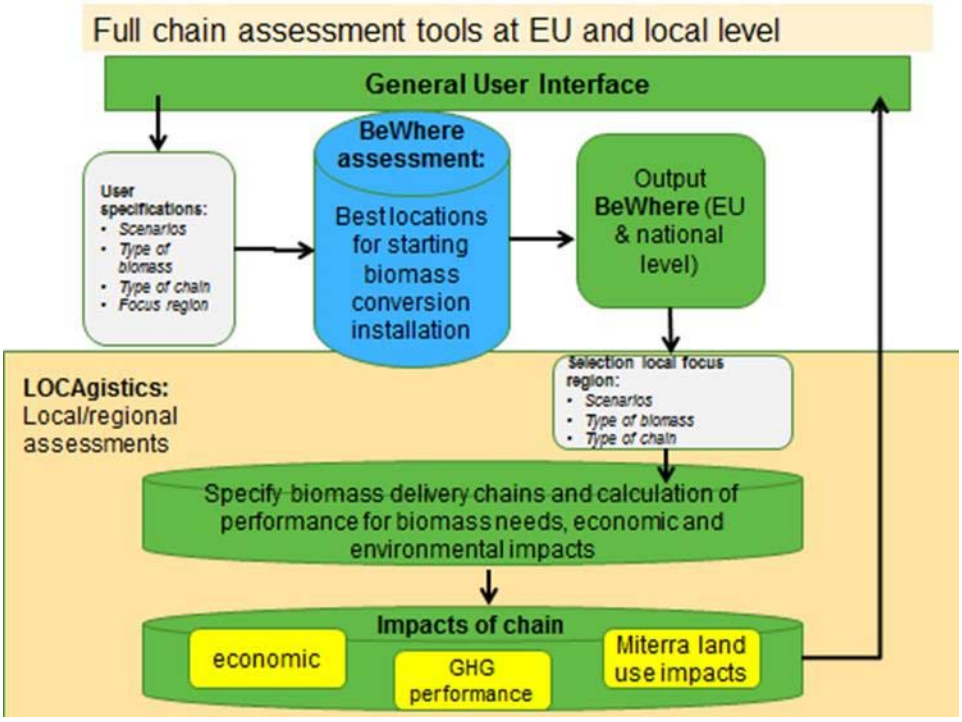


Figure 34. Relation between BeWhere and LOCAgistics.

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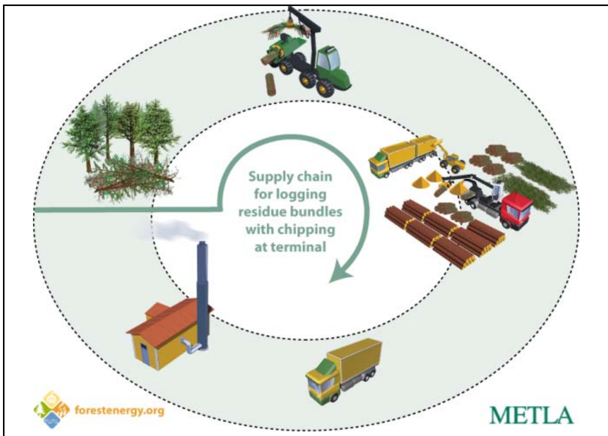
Annex I. Biomass value chains in the forestry sector (COST FP0902)

The numbers of these biomass value chains (Forest Energy, 2015) refer to Table 23 in Chapter 3. Furthermore each figure has the title of the chain in the center.



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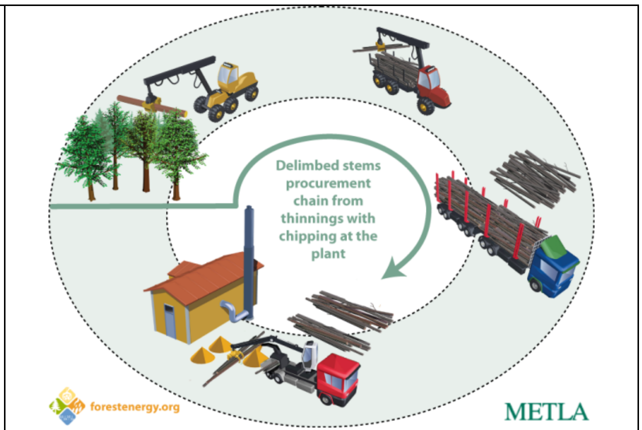

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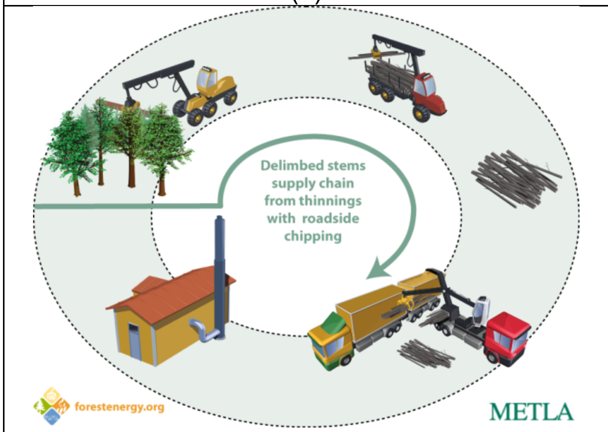

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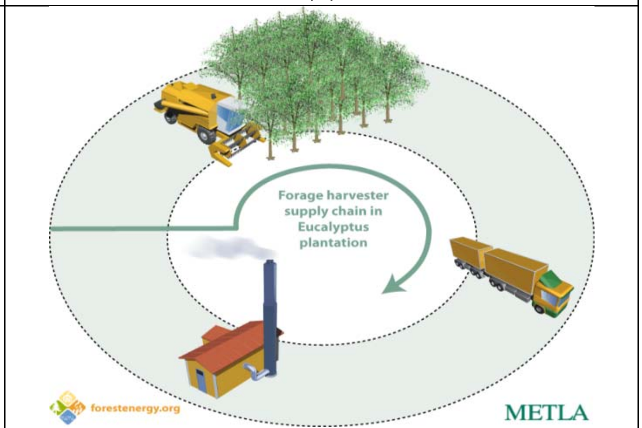

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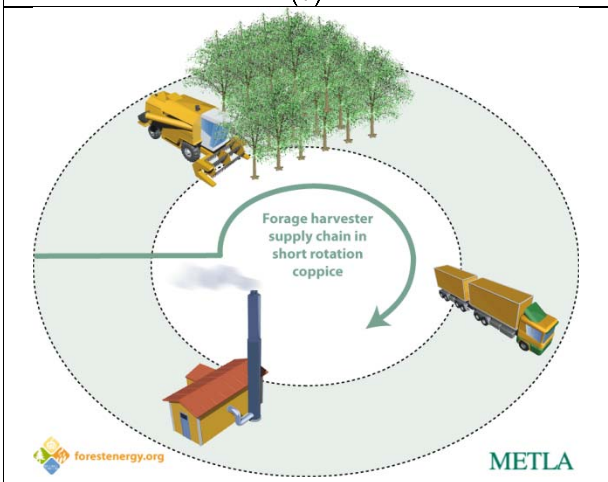

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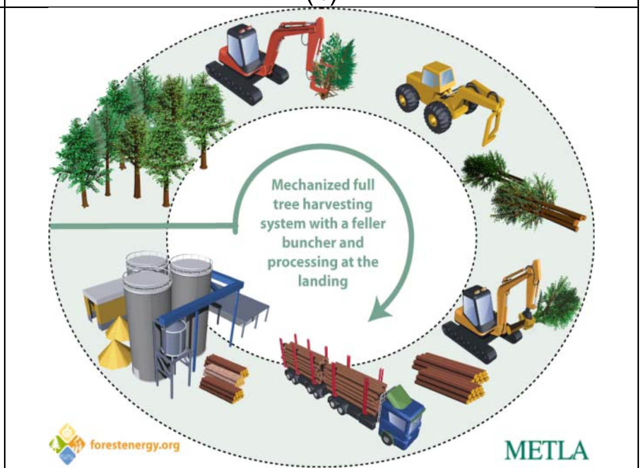

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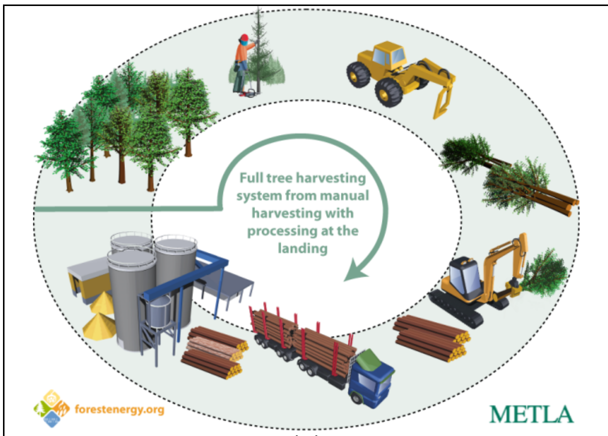

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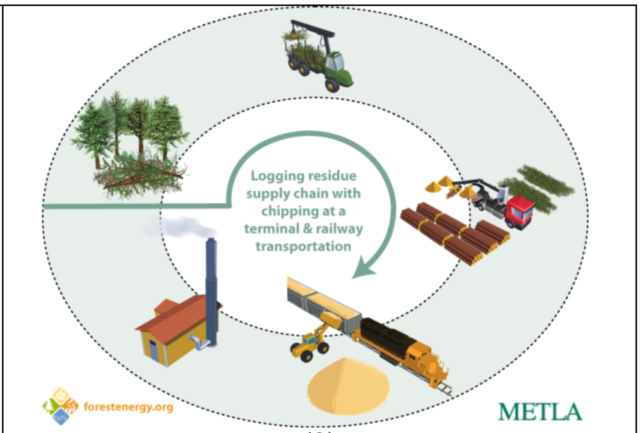

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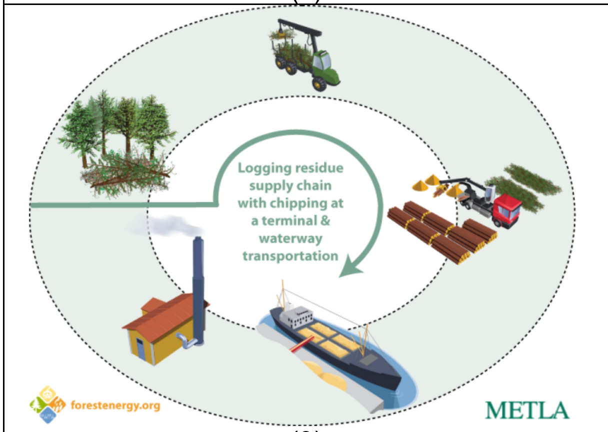

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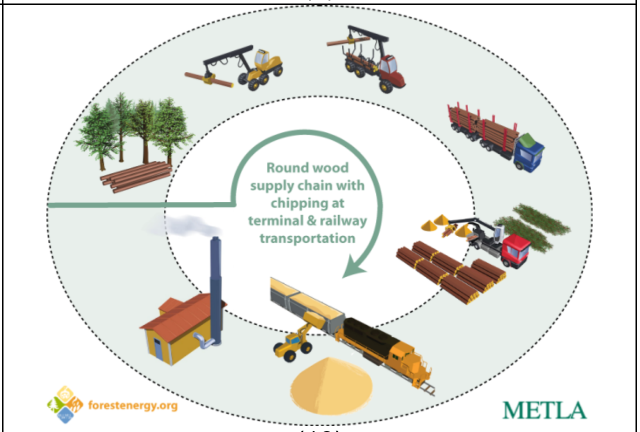

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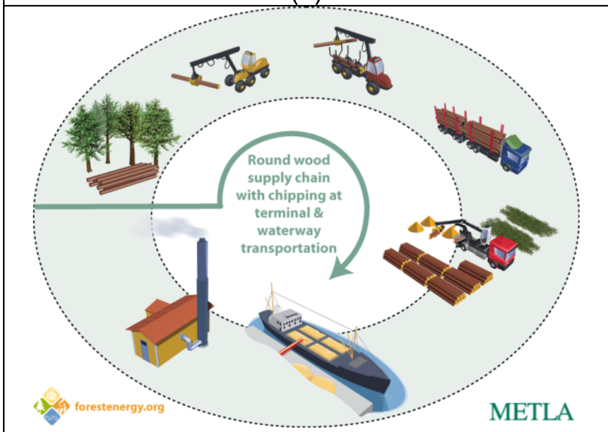

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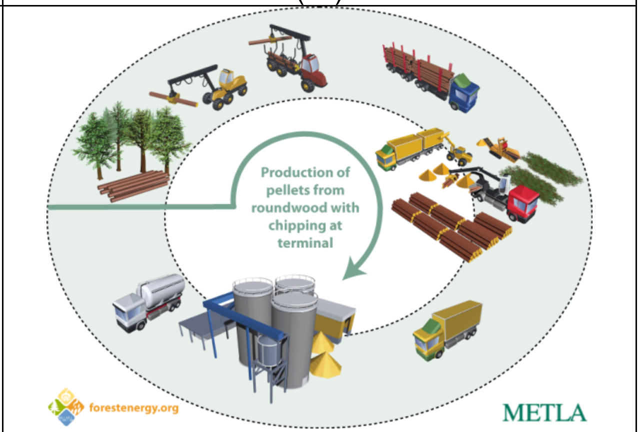

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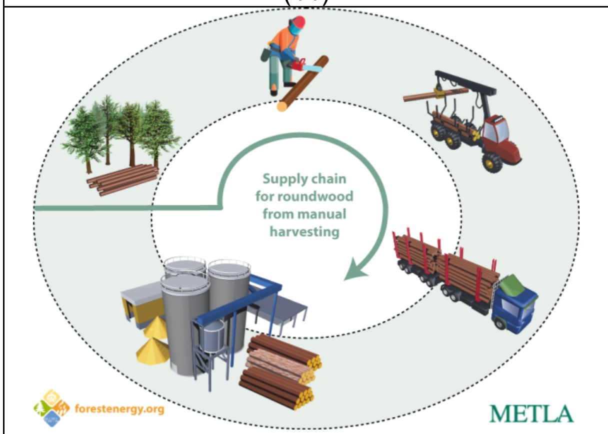

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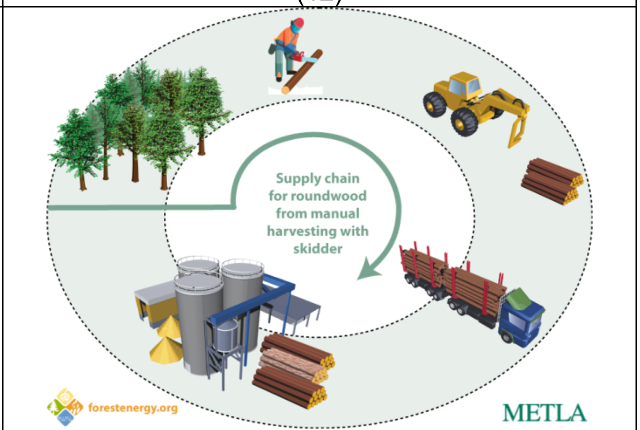

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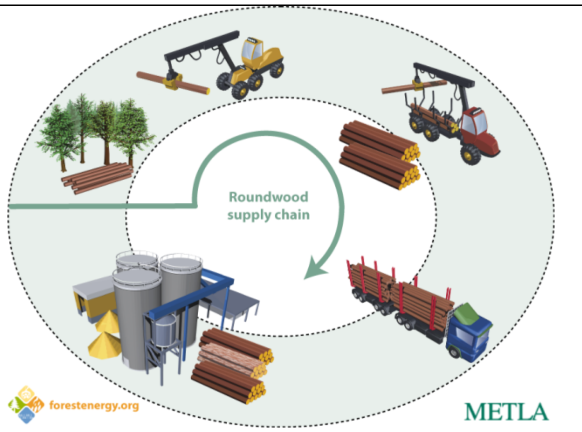

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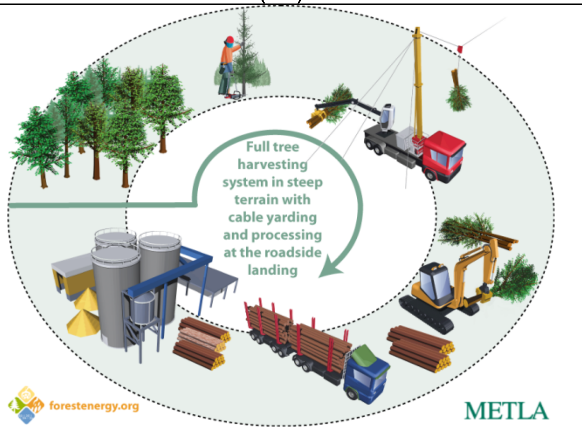

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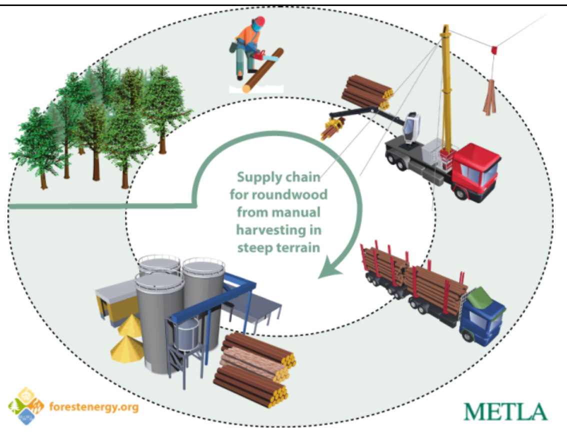

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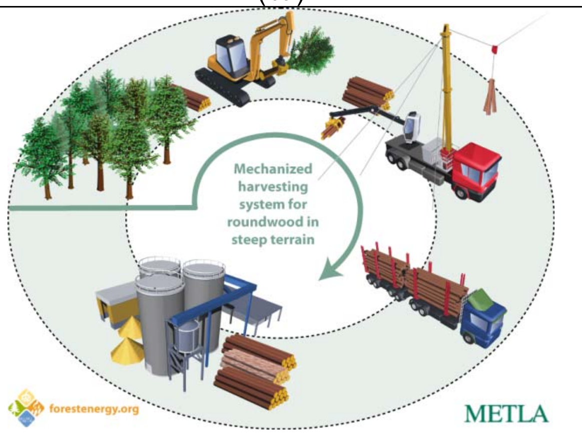

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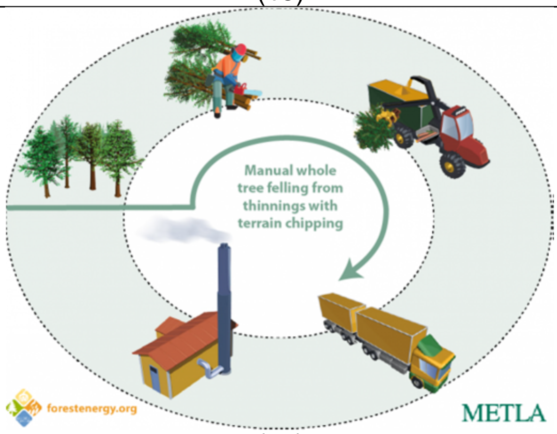

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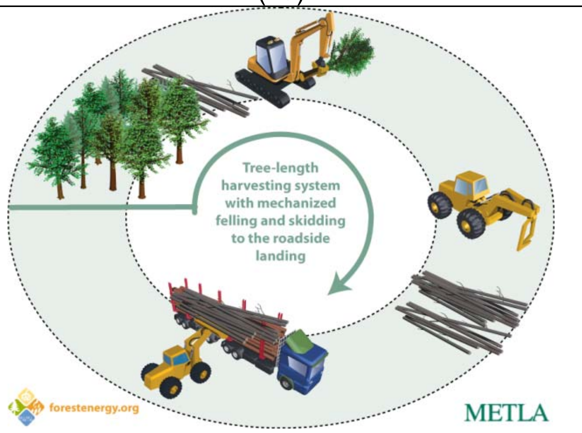

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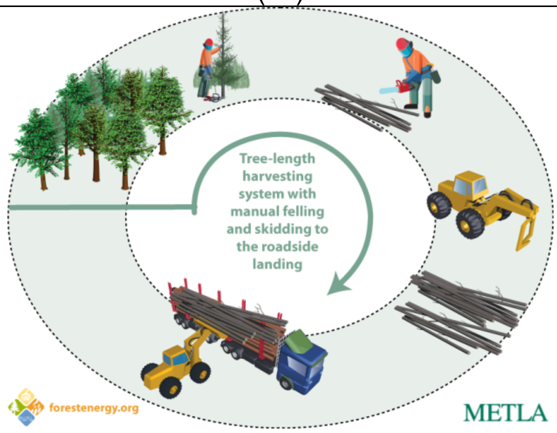

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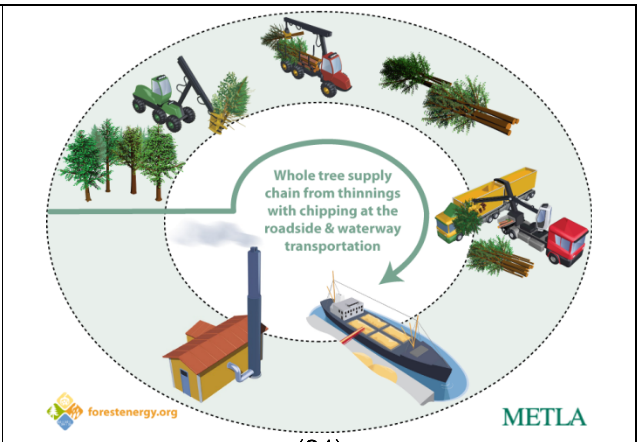

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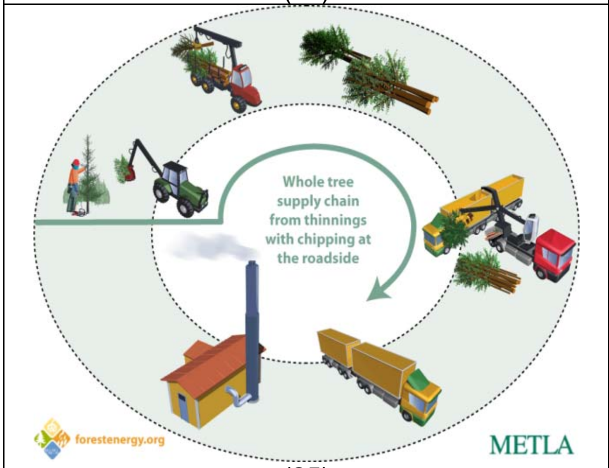

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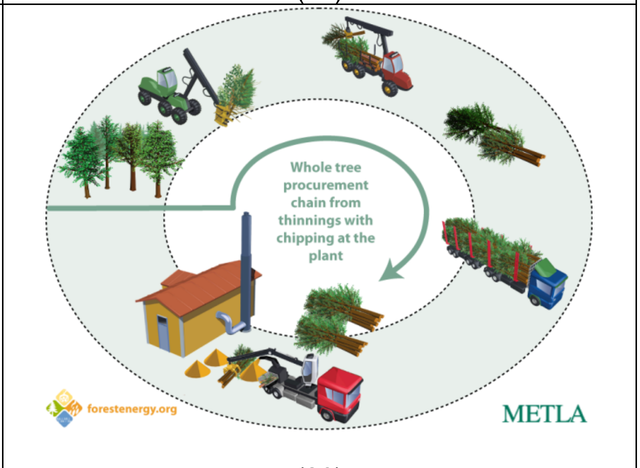

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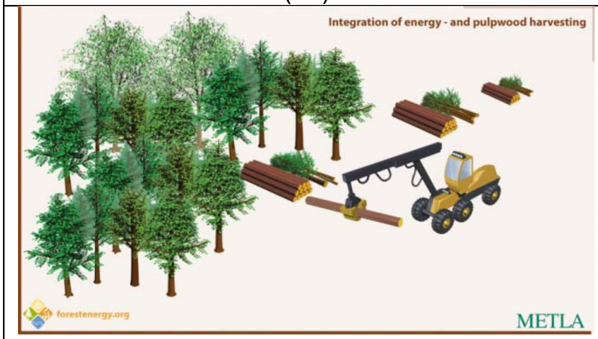

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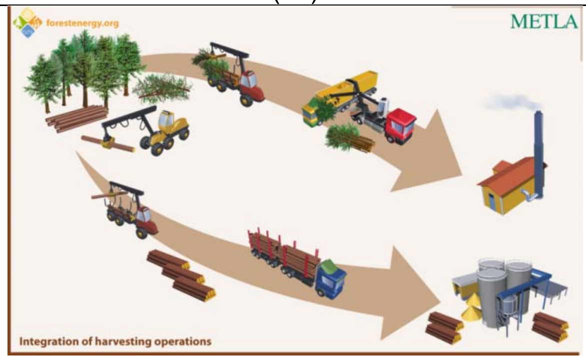

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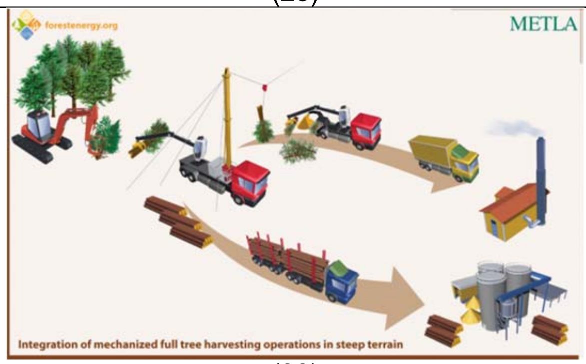

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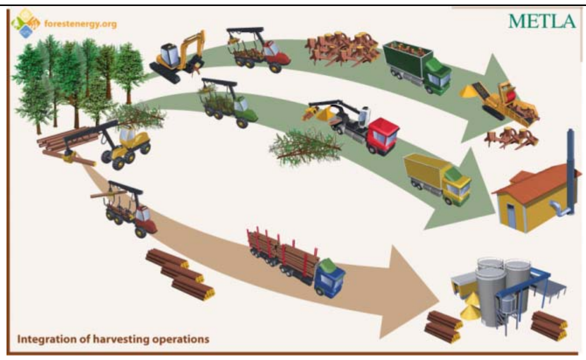
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