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Biomass based energy intermediates boosting biofuel production

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Deliverable

D1.4 Biomass Logistics

Report on logistics processes for transport, handling and storage of biomass residues from feedstock sources to decentral conversion plants

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Glossary

BD	bulk density
CP	catalytic pyrolysis
CCP	central conversion plant
DCP	decentral conversion plant
DFC	distance fixed costs
DM	dry matter
DVC	distance variable costs
Feedstock type	biogenic residue examined
FM	fresh mass
FP	fast pyrolysis
FTL	full truck loads
Intermediate	energy carrier produced in DCPs
LR	logging residues
MC	moisture content
ÖKL	*Österreichisches Kuratorium für Landtechnik und Landentwicklung*
SC	supply chain
SCM	supply chain management
SKU	stock keeping unit
TIA	traffic impact assessment
TUL	*Transport, Umschlag und Lagerung*
WP	work package
wt%	weight percentage

Abstract

This report deals with the BioBoost supply chain considering core logistics processes: transport, storage and handling. The main objective is to design and evaluate these processes for biogenic residues. Hereby, existing literature as well as implicit, practical know-how are consolidated and analysed in order to receive inferences to the research questions posed.

First, assets used within logistics processes are specified for each reference feedstock. Second, cost calculations are made by means of specified assets in order to determine target metrics, i.e. EUR/tkm and EUR/t. Third, additional analyses related to biomass logistics are conducted.

With respect to biomass logistics, farm tractors are inferior to trucks in terms of transport costs. This could be ascribed to lower average vehicle speeds of farm tractors and, thus, resulting in lower annual mileage rates. Vehicle-trailer combinations using roll-off containers (primarily used for wood chips) seem to be unattractive due to higher transport cost rates. However, in case of also considering handling costs, these transport means may outperform others. With respect to handling square bales, gantry cranes represent the most efficient handling asset. Moreover, additional advantages of deploying gantry cranes are identified.

Implementing an intermediate depot between feedstock sources and a decentral conversion plant implies additional storage and handling costs. A case study shows that these extra storage fixed costs will only pay off at a certain transport distance. In such a 4-echelon supply chain setting, cost advantages of trucks can be exploited for transports between the intermediate depot and the conversion plant to a greater extent. A final traffic impact assessment provides insights into trips attracted and produced through locating a conversion plant from a social point of view.

These findings represent essential input data for the Data Model (D4.4) in BioBoost. Furthermore, the second part of the BioBoost supply chain, energy carrier logistics, will be elaborated within the next months and finalized in D4.1 Logistics Concept.

1 Introduction

Based on an increasing relevance of physical distribution within the marketing context, a new discipline, called *TUL Logistik*[1] has evolved in the 1970s. Basically, TUL deals with three transfer functions as depicted in Table 1 *(Danzas Lotse, 2004, p. 9)*. Correspondingly, plenty of authors have dedicated their focus to these core logistics processes *(Weber, 2012, p.93ff)*. Recently, the attention has been directed towards Supply Chain Management (SCM) that represents the latest discipline of logistics. However, the importance of transporting, handling and storing is omnipresent since the 1970s. Therefore, these logistics processes also set the study area in this report.

Table 1: Basic logistics processes

Transfer function	Transport	Handling	Storage
Based on	Spatial distribution	Material distribution	Temporal distribution
Demand for transfer function	Divergent locations of value creation (globalized production networks)	Divergent lot sizes in production, inventory, transportation, etc.	Divergent points in time of production and consumption

Within the BioBoost project, the main materials that are manipulated along the supply chain are classified into biomass residues (a.k.a. feedstock types) and energy carrier (a.k.a. intermediates). Because of divergent requirements of those materials for designing logistics processes, the supply chain is analysed separately: (i) *biomass logistics* and (ii) *energy carrier logistics*. The former further specifies the study area of this report, whereas the latter will be described in D4.1.

[1] The acronym *TUL* stands for the German terms for transport, handling and storage and has emerged from the German-speaking area.

The biomass logistics is aligned to the following reference feedstock types as agreed within the reference pathways:

- Straw as an agricultural residue (cereal, oilseeds and maize straw)
- Wood chips as forestry residue (logging residues, thinning wood, root biomass, wood balance)
- Organic municipal waste (garden/park waste, food waste and kitchen waste)

A major starting point for analysing logistics processes is given by reference pathways. The BioBoost project investigates three different conversion technologies: (i) fast pyrolysis, (ii) catalytic pyrolysis and (iii) hydrothermal carbonization. Each of these technologies deals with different feedstock types, production capacities, energy carrier applications of different scales, and side products. In order to reduce complexity at an early stage of the project, the project consortium agreed upon a fixed reference pathway for each conversion technology. Besides data related to energy carriers, these reference pathways also characterize the reference types of biomass (straw, wood chips and organic municipal waste) which are required for a decentralized conversion.

The report aims at designing and evaluating transport, handling and storage processes for biomass logistics. In doing so, logistics processes at feedstock sources, intermediate depots as well as decentral conversion plants (inbound logistics[2]) are analysed. To start with, logistics requirements for each biogenic residue are collected. Based on that, a technical concept for each logistics process is set up. This implies specification of assets used for transport, handling and storage. Thereafter, performance and cost data for the selected assets are determined. Then, cost calculations and further analyses are made.

[2] The outbound logistics, i.e. logistics processes from the gate of the decentral conversion plant is explained within the energy carrier logistics (D4.1).

Based on the objective of this report quoted above, the following research questions arise:

(1) Which assets are used for biomass logistics?

(2) Which costs do arise for each logistics process (transport, handling, storage)?

(3) When does an intermediate depot pay off?

(4) How can logistics process costs be allocated to other European countries?

(5) What is the traffic impact resulted from setting up a decentral conversion plant?

The report is structured as follows. After presenting introductive information, the methodological approach is described in Chapter 2. The third chapter is dedicated to a review on existing literature and practical knowledge related to biomass logistics. In chapter 4, data on designing and evaluating logistics processes are presented. Thereafter, different analyses are conducted in order to answer the remaining research questions as mentioned above. Finally, chapter 6 provides conclusions and an outlook. Key implications for biomass logistics are summarized and links to other tasks in WP 4 and WP6 are stated.

2 Methodological Approach

2.1 General Approach

Biomass logistics represents not an untapped object of investigation. Several project reports, scientific papers as well as ample knowledge in practice are available today. This existing knowledge base has been analysed in a first step through conducting expert interviews and reviewing literature. In alignment to the before mentioned research questions, data were consolidated in an MS Excel file in order to receive proper inferences. By answering the research question, data are prepared for subsequent tasks (Figure 1).

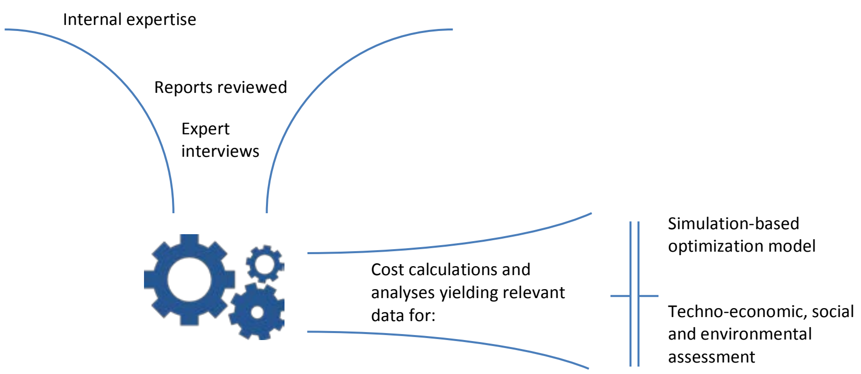


Figure 1: Methodological Approach

First of all, a desktop study is conducted by screening existing (project) reports related to biomass logistics. In addition, plenty of internet documents provided by companies engaged in biomass logistics are reviewed. Further, internally available expertise and experiences in the field of transportation are incorporated. Based on this desktop study, some authors of reports reviewed are contacted. The expert interviews not only provide valuable information for the analyses, but also enable validity checks of final results. A list of experts interviewed can be retrieved from the annex. The BioBoost project consortium further provides valuable information upon feedstock potential, relevant feedstock types and conversion processes for this report.

2.2 System Boundary

Derived from the supply network representation (Figure 1), respective logistics processes are broken down to a linear supply chain representation which enables a business process view. The considered supply chain involves basically five echelons: feedstock sources (pile, roadside), intermediate depots, decentral conversion plants, central conversion plants as well as end users. In order to reduce complexity in terms of the optimization and simulation (Task 4.3) and because of already existing well-established energy supply networks, the final consumers are neglected. Due to the fact that feedstock types investigated in this report represent residues/by-products, the production process (cultivation, harvesting, pressing and field transport, or forwarding and roadside chipping etc.) is also neglected. Consequently, the system boundary for the holistic logistics model is determined as illustrated in Figure 3.

An initial overview about the system boundary of the holistic logistics model is given in Figure 2.

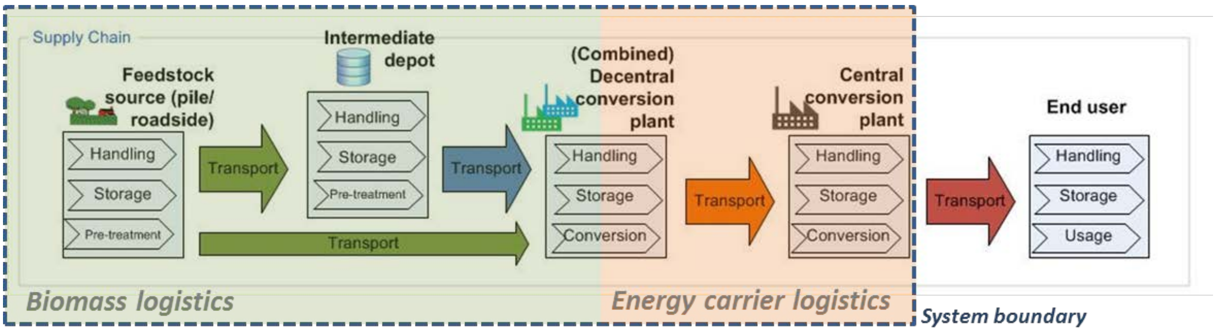


Figure 2: Overall system boundary

As already mentioned before, this report deals with biomass logistics (left part of Figure 2), which includes all transport, handling and storage processes arising from pile/roadside towards feeding reactors at decentral conversion plants with respective feedstock types.

2.3 Asset Specification

By evaluating costs for transport, handling and storage, required assets need to be specified in the forefront. A hierarchical classification of transport assets, originating from product characteristics and converging to transport modes, supports the specification of handling and storage assets (Figure 3). For instance, wheat straw is pressed into square bales, which constitute loading units. In contrast, bulky material, e.g. wood chips, can be manipulated more efficiently through applying loading devices, e.g. roll-off containers. A loading unit further impacts the required handling asset. A telescopic handler needs different equipment when loading square bales than manipulating wood chips. With respect to the storage process, even transport means and modes influences assets required for storing. Transporting biomass via barges or rail cars conditions different infrastructure that would be needed in case of only using road as a transport mode.

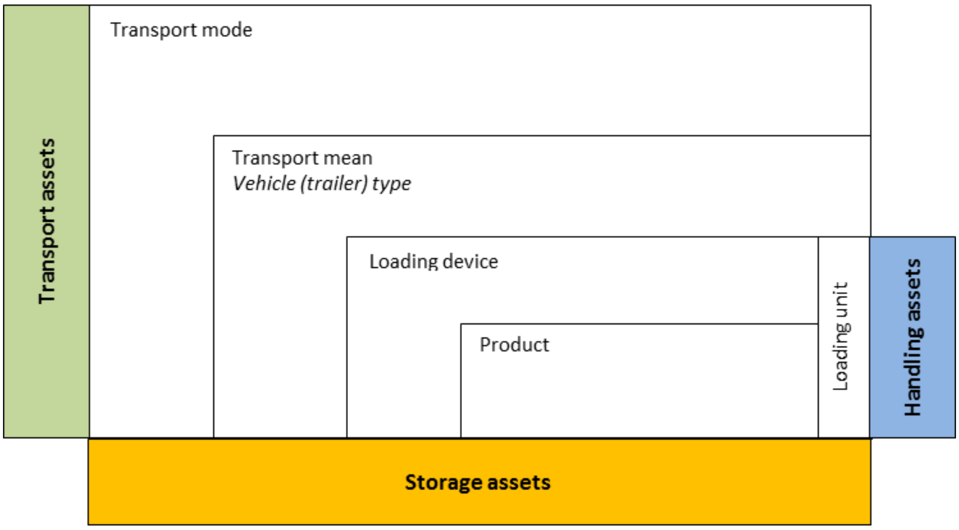


Figure 3: Overview about asset to be specified for logistics processes

In order to design biomass logistics, FHOÖ defined reference assets that are used in practice. For instance, the *Steyr CVT 6130 (Case New Holland)* is used as a reference asset for farm tractors. Correspondingly, cost and performance data are indicated.

2.4 Cost Calculations

A crucial part in the BioBoost project represents the profitability analysis. Accordingly, a major aspect of this report is to analyse the structure of logistics costs as well as main cost drivers. In virtue of assets specified, relevant costs, e.g. costs for depreciation, maintenance, capital, fuel, labour, etc., are evaluated following standards of direct costing. More specifically, distance variable costs (DVC) and distance fixed costs (DFC) are determined.

Besides cost evaluation, also performance data (e.g. payload, average vehicle speed, fuel consumption, annual operating hours and milages, etc.) are determined in order to derive desired target metrics as given in Table 2. Dealing with biomass logistics, the dry matter (DM) content represents a crucial issue. Due to high and valueless proportion of water contained in biogenic residues (indicated as moisture content MC wt%), logistics processes need to be evaluated on the basis of dry matter content.

Table 2: Target metrics

Logistics process	Target metrics
Transport	*EUR / t (DM)*km or EUR / t*
Handling	*EUR / t (DM)*
Storage	*EUR / t (DM)*

Initially, cost data are surveyed only for Austria. In order to transfer and allocate these data to the geographical study area in BioBoost (EU 25 + Switzerland), major cost drivers are identified through the cost calculations. Then, indices for these major cost drivers (e.g. labour costs, fuel costs) are generated by applying statistics available for Europe. Finally, all cost data are verified by reviewing existing reports dedicated to biomass logistics.

The cost calculations prepared in this report feature a static behaviour. Here, no assumptions are made for future development of costs. This prevailing limitation will not exclude considerations about including cost dynamics in subsequent analyses and reports within the BioBoost project.

3 Review on Existing Literature and Practical Knowledge

In the course of the previous decades a rethinking in terms of alternative energy sources has taken place. Renewable energy sources, e.g. biomass, came to the fore and induced plenty of projects on a national as well as international level. Also the scientific community put emphasize on this topic. When it comes to how generating energy out of biomass in an efficient way, logistics play a decisive role. As a matter of fact, plenty of reports dedicated to biomass logistics have been published recently. The following represents not an exhaustive but selective abstract of existing literature.

3.1 Literature on Biomass Logistics

The *RENEW project (2008)*, which was run prior to BioBoost, has also dealt with biomass logistics. More specifically, a concept for biomass provision is evaluated (EUR/GJ) for agricultural and forestry residues as well as for energy crops. The respective costs are not only evaluated for a current state (base case), but also for two future scenarios assuming different levels of feedstock utilization. The overall supply chain is subdivided into two parts: (1) biomass provision up to the first gathering point and (2) biomass provision from the first gathering point. Basically, all costs are defined for six regions in Europe.

The *BioLog I project (2007)* aims at optimizing a supply chain for woody biomass by minimizing transports in Austria. Based on both an evaluation of disposal feedstock potential for woody biomass and an existing supply network of biomass conversion plants (BMK[3]) and the evaluated feedstock potential, transport costs are minimized through applying a linear programming (LP) model. In terms of allocating feedstock potential to BMKs, three types of heuristics are applied: (i) total cost minimum, (ii) market power and (iii) attraction of regions. By designing an optimal supply network, different types of terminals (agricultural, regional and industrial) are located through using the mathematical model and assumed logistics data.

[3] BMK = Biomassekraftwerk.

A further project called *Optimierung der regionalen Warenströme (Qualitäten, Transport, Aufkommen, etc.) über Biomasse-Logistikzentren (2008)* puts a strong focus on biomass logistics centres. More specifically, a location and allocation model that aims at minimizing transport and preparation costs in Styria (Austria) is set. With respect to the solution process, a mixed-integer programing (MIP) model and a geographic information system are used. Among further issues, processes for storage and handling in biomass logistics centres are designed and evaluated more in detail.

Another, quite recent project *Basisinformationen für eine nachhaltige Nutzung von landwirtschaftlichen Reststoffen zur Bioenergiebereitstellung (2012)* deals with straw as an agricultural residue associated with high potential in Germany for energy generating purposes. Among others, this project also dedicated its attention towards biomass logistics. In particular, supply chains are investigated in more detail by determining also logistics assets. Similar to this report, different options of configuring logistics costs (e.g. type of vehicle-trailer combination applied) are analysed and evaluated.

In 2005, the *Institute for Technology Assessment and Systems Analysis (ITAS)* published a study called *Entwicklungen von Szenarien über die Bereitstellung von land- und forstwirtschaftlicher Biomasse in zwei baden-württembergischen Regionen zur Herstellung von synthetischen Kraftstoffen (2005)*. Here, also the feedstock potential for biogenic residues is evaluated for Germany. Furthermore, supply costs (EUR/Mg DM) for straw, hay, maize and forest residues are calculated for different transport distance intervals.

The study *Leitfaden Bioenergie – Planung, Betrieb und Wirtschaftlichkeit von Bioenergieanlagen (2005)* indicates also valuable information on biomass logistics. Especially, technical specifications regarding biomass storage, e.g. quality losses of different feedstock types, storage techniques etc., are mentioned.

Practical insights into processes within biomass logistics provide the final report from the project *Optimierung der Beschaffungs- und Distributionslogistik bei großen Biogasanlagen (2007).* This project deals with both inbound as well as outbound logistics of biogas plants in Austria. Especially, technical specification of used assets and work time studies for different processes are presented in this report.

Further practical insights into converting straw into energy provide the study *Straw to Energy - Status, Technologies and Innovation in Denmark (2011).* Especially, types of bales and assets, e.g. telescopic handler, forklift trucks or gantry cranes, used for handling straw are specified. The *Wood Fuels Handbook (2008)* gives insights into main characteristics of log wood and wood chips. Additionally, this handbook indicated key figures (costs, productivity, etc.) for assets used along the supply chain.

Regarding the specification of storage assets, the report on *Biomass Logistics & Trade Centers (2010)* offers an implementation guide for such BLTCs. More precisely, three steps are described for a successful project implementation for future BLTC operators. Cost figures are also incorporated in this report.

With respect to biomass transports, several studies and scientific papers are reviewed. The *Biogas Forum Bayern (2010)* published several studies referring to biomass transports. The *BTL Wieselburg (2009)* also engages in biomass transportation. Several scientific papers are available *(Handler, 2009 and 2010).* Further papers related to biomass transports are published by Searcy et al. (2007), Singh et al. (2010) as well as Hamelinck et al. (2005).

Besides the projects mentioned above, further scientific work in the field of supply network planning for bioenergy generation is done. *Gold and Seuring (2011)* provide a recent literature review regarding supply chain and logistics issues for biomass-based energy production. Basically, literature with respect to both (i) operational issues regarding harvesting and collection, storage, transport and pre-treatment techniques as well as (ii) strategic issues referring supply system design are reviewed. *Moser (2012)* engages in location and capacity planning for *Biomass-to-Liquid (BtL)* plants in Austria. This thesis validates a production network for BtL characterized by a decentral pyrolysis and a central synthesis as an optimal supply network. *Freppaz et al. (2004)*, *Rentizelas et al. (2009)*, *Velazquez-Marti, Fernandez-Gonzalez (2010),* deals with mathematical models as decision support tools. *Perpiñá et al. (2009)* apply Geographic Information Systems (GIS) for optimizing biomass logistics.

Another interesting paper reviewed is given by *Lourdes Bravo (2011)*. Key barriers along a biofuel supply chain are investigated by applying a comprehensive literature review. This paper pinpoints variables that may hamper biomass-to-energy development. For instance, facility location and capacity are variables identified in the context of storage. Storage is a major cost driver in biomass logistics.

In addition to the reports reviewed, several books have been screened with respect to (biomass) logistics processes *(Gleissner, 2009; Kaltschmitt, 2009; Martin, 2009; Pfohl, 2010; Weber 2012).*

3.2 Practical Knowledge on Biomass Logistics

Besides the reports reviewed, practitioners have been contacted and interviewed in order to receive and verify data. This is because most of the before mentioned reports make assumptions in terms of cost data and do not verify the same in a transparent way. The interviews have been mainly conducted with Austrian organizations that are engaged in biomass logistics. From governmental agencies and educational and research institutions via transport, storage as well as biomass power plant operators to motor vehicle/trailer manufacturers are consulted (a comprehensive list of all experts interviewed can be retrieved from the annex). The gathered information has a major impact on the validity of logistics costs, because cost calculations are based upon practical data sets.

4 Biomass Logistics – Designing and Evaluating Logistics Processes

This chapter aims at examining the design and evaluation of biomass logistics processes. For this purpose, an MS Excel file, LogisticsProcesses.xlsx, is generated, which incorporates major computations.

4.1 Biomass Supply Chain in Detail

First of all, the overall supply chain depicted in Figure 4 need to be analysed in more detail. As already mentioned above, the biomass production process (cultivation, harvest, etc.) is neglected. The holistic logistics model assumes that respective biogenic residues are provided at pile or at roadside. The biomass supply chain starts with the storage process at feedstock source and ends at the decentral conversion plant (DCP) when feeding the reactors (Figure 4). Correspondingly, the logistics costs are evaluated for this scope.

The respective supply chain exhibits either two or three echelons, that is, biomass residues are transported directly from the feedstock source to the DCP or biomass residues are first transported to an intermediate depot (pre-carriage) before further transported to the DCP (on-carriage). Basically, each echelon features storage and handling processes (loading and unloading). The transport process occurs between echelons.

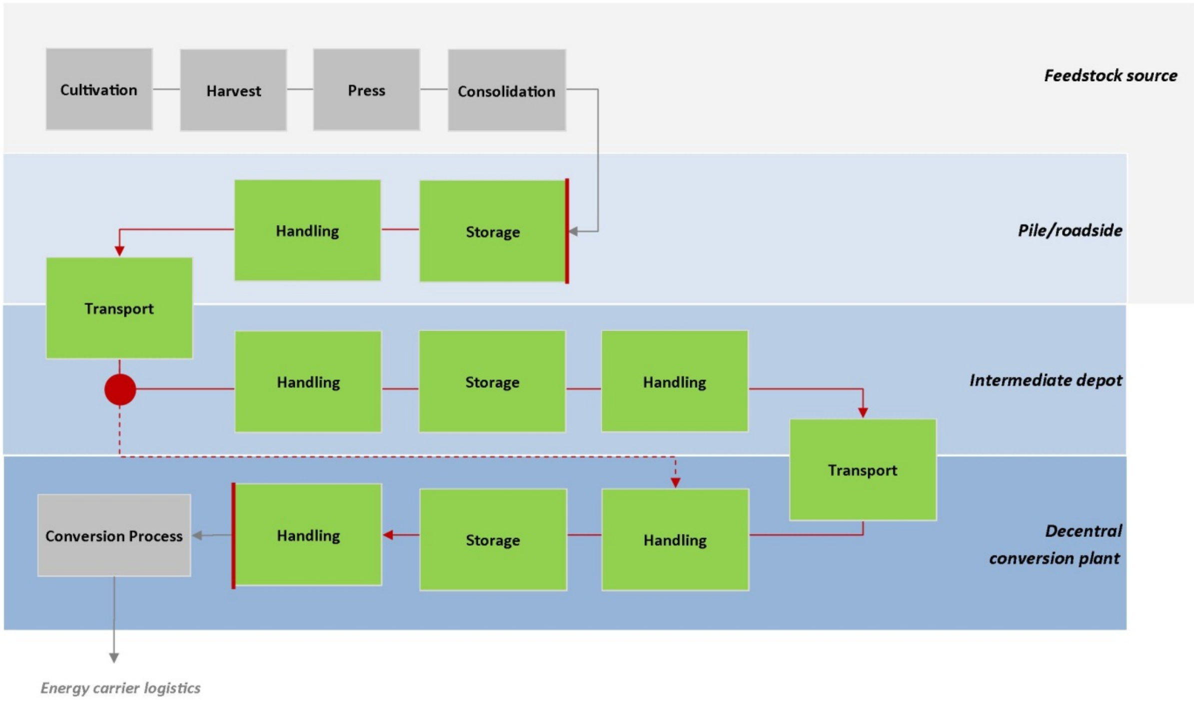


Figure 4: Biomass supply chain in detail

4.2 Specification of Reference Feedstock Types

In the BioBoost project three conversion technologies are examined: (i) fast pyrolysis (FP), (ii) catalytic pyrolysis (CP) and (iii) hydrothermal carbonization (HTC). As already explained above, reference feedstock types are defined for each technology.

Table 3: Conversion technology and defined reference feedstock types

Conversion technology	Reference feedstock type
Fast pyrolysis (FP)	Wheat straw
Catalytic pyrolysis (CP)	Wood chips from logging residues
Hydrothermal carbonization (HTC)	Organic municipal waste

These types of biogenic residues constitute the main starting point for biomass logistics analyses. Therein, all processes and required assets are aligned according to the product specifications.

Kaltschmitt et al. (2009, p. 173 ff) provides an overview about selected product specifications and their implications for modelling biomass supply chains. An extract of this overview is displayed in Table 4.

Table 4: Overview about product specification of biomass fuels

Product specification of biomass fuels	*Main effects on*
Moisture content (MC)	*Storability, caloric value, dry matter loss, self-heating, transportability*
Degradation	*Dry matter loss (technical and biological)*
Bulk density (BC)	*Transport- and storage costs, logistics concept*
Particle size	*Pourability, drying properties, dry matter loss*
Viscosity	*Handling, ability to blend*

A major factor of transporting biomass fuels efficiently is given by the moisture content (MC). This parameter indicates the amount of water contained in biomass and may vary considerable. Biomass excluding the moisture content is denoted as dry matter (DM). Generally, the MC has an essential impact on transport and storage process. Technical assets, e.g. drying machines, etc. or transport and storage capacities are determined by this product specification. Storing biomass leads to dry matter losses due to biological degradation and technical inefficiencies. Therefore, dry matter losses need to be defined for each feedstock type as well as storage location *(DBFZ, 2012, p. 67)*. The moisture content is also a crucial figure for conversion technologies in order to work properly. Furthermore, this parameter may cause an additional pre-treatment process, i.e. drying.

A key figure with respect to product specifications represents the bulk density (BD), because this parameter influences the efficiency of transport and storage processes substantially *(BOKU, 2007, p. 9).* Especially, transporting straw is restricted by available cargo space. In case of increasing the BD, more square bales can be transported which increase the utilization of transport means *(KRONE, 2012, p. 37)*. The bulk density represents a measurement that expresses the weight/volume ratio of materials. In addition to the mass density, bulk density also considers voids which arise in terms of creating piles of materials and is determined as kg per m³ *(Francescato, V. et al., 2007, p. 8)*. That is, this ratio provides information concerning volume and weight of a material, which need to be transported, handled and stored. With respect to biomass logistics, transports of feedstock types associated with a low bulk density faces volume restrictions, whereas high density feedstock types reach payload restrictions *(Kaltschmitt et al., 2009, p. 278).* In general, the bulk density of biomass is influenced mainly by (i) moisture content, (ii) type of biomass and (iii) particle size *(Expert interview 4, 2012).*

4.2.1 Straw for Fast Pyrolysis

Within the BioBoost project, the *Karlsruhe Institute of Technology (KIT)* applies wheat straw as a reference feedstock type for fast pyrolysis. The conversion process requires the following feedstock properties: The MC should come below 15 wt% and the particle size amounts to 10 mm. Further required technical specifications are depicted in Table 5.

Within the BioBoost project, the following supply scenario of wheat straw is defined. Square bales associated with a dimension of 2.4 x 1.2 x 0.9 m (length x width x height) and a weight of 500 kg FM are assumed *(Bernard KRONE GmbH (2012)*. Thereof, a bulk density of 193 kg/m³ (MC 14 wt%) is calculated. Due to the fact that all cost rates are calculated on the basis of dry matter (DM) which excludes the moisture content the bulk density is reduced to 166 kg/m³ DM. The square bales are stored in the form of covered piles directly on the field. On average, the bales are stored 6.5 months (assumption). The particle size of pressed wheat straw is assumed to account for 21 mm. Before feeding the straw to the fast pyrolysis reactor, the feedstock type needs to be comminuted. Correspondingly, assets at the decentral conversion plant need to be considered. All data collected for the reference feedstock wheat straw are summarized in Table 5.

Table 5: Reference feedstock type for fast pyrolysis: wheat straw

	Conversion technology	Fast Pyrolysis	Unit	References
Required specifications	Moisture content (MC)	15	wt%	*TNO, 2012*
	Particle size (length)	10	mm	*TNO, 2012*
	Impurity	-		*KIT, 2012*
	Ash content	6	wt%	*TNO, 2012*
	Net caloric value	13.44	MJ/kg	*TNO, 2012*
	Volume-based energy density	2.59	GJ/m³	*KIT, 2012*
	Feedstock costs	150	EUR/t FM	*Syncom, 2013*
Provided specifications	Provided product	Square bales		
	Storage form (assumed)	Covered piles		
	Storage placement (assumed)	On-field		
	Storage time (assumed)	6.5	months	*Average storage time over a year*
	Bulk density (fresh mass)	193	kg/m³ FM	*KRONE, 2012*
	Bulk density (dry matter)	166	kg/m³ DM	
	Moisture content (MC)	14	wt%	*Scott, 2011, p. 8*
	Dry matter loss (open storage)	8	wt%	*DBFZ, 2012, p.67*
	Dry matter loss (closed stoage)	2	wt%	*DBFZ, 2012, p.67*
	Particle size (length)	21	mm	*Expert interviews, 2012*
Further specifications	Associated risks	None known		
	Required pre-treatment process	Comminution		*KIT, 2012*

4.2.2 Wood Chips for Catalytic Pyrolysis

The *Centre for Research and Technology Hellas (CERTH)* investigates catalytic pyrolysis within the BioBoost project. As a reference feedstock type for this conversion technology, wood chips based on logging residues (soft and hardwood) are defined. More precisely, the following required specifications are indicated. Wood chips to be converted need to exhibit a moisture content level of smaller than 10 %. Furthermore, the maximum particle size is given by 5 mm. Besides these parameters, further specifications are made as depicted in Table 6. Again, there is a divergence between required features for conversion and provided product characteristics provided at feedstock source.

The following specifications for wood chips from full tree logging residues at roadside landing are assumed. Simultaneously, these parameters serve as input variables for the analyses in subsequent chapters.

Logging residues (LR) are defined "*as the unmerchantable above ground biomass left behind in a cutover area and consist of branches and unmerchantable tops (logging slash) and trees ignored because of their species, small size or inferior quality*" *(Pettersson, 2007, p. 782).*

In general, residues from full tree logging operations feature a rather low bulk density (BD) as well as high moisture content (MC). Accordingly, this situation poses a major challenge for the logistics operations. For instance, the form, duration and placement of storage as well as weather conditions affect the feedstock quality essentially *(Shuva, 2012, p.44).* As already mentioned above, bulk density influence efficiency transportation and handling.

The most common way of supplying LR in Finland, Sweden and Austria is to forward the residues towards roadside landings and store them as slash piles. Determining the fuel quality (caloric factor and ash content), the moisture content represents the most important property that further affects storage and transport costs. At the so-called "green state", logging residues feature a MC of between 55 wt% (Scots pine) and 45 wt% (Norway spruce). During summer season logging residues stored at piles (windrows) at roadside landing; MC can decrease to approximately 25 wt% within one month of storage duration (uncovered storage). In case of storing loose LR uncovered for about 9 months, the MC increases again to wt40 % - due to contamination with snow and rain[4] *(Pettersson, 2007, p. 782f)*. Therefore, logging residues are assumed to be comminuted within one month before transportation on roads.

Further parameters, e.g. ash content and caloric value, are also altered during storage process, but will not be elaborated here. Instead, the focus is put on the impact of moisture content on logistics processes. MC influences considerably *bulk density* and *dry matter loss* which represents two important parameters for transport, handling and storage. The former has already been described above.

"Dry matter losses can be caused either by microbial activity, most commonly fungal attacks (biological), or spillage of material during handling and storage (technical)." (Pettersson, 2007, p. 785). The dry matter loss for loose logging residues at roadside landing is indicated by 11 % for the respective storage time. Consequently, this parameter reduces the available feedstock quantity at the feedstock source.

The underlying supply scenario involves comminution of the before-mentioned logging residues at roadside landing through applying mobile chippers. This is because of the motivation of increasing efficiency in road transportation by enhancing bulk density of logging residues. Here, a bulk density of 276 kg/m³ (MC 30 wt%)[5] is assumed. Again as a matter of the calculation basis, the bulk density is reduced to 193 kg/m³ DM.

Further specifications for wood chips concern associated risks of manipulating this feestock type as well as required pre-treatment processes. The latter results from the discrepancy of the above-mentioned required and provided properties. That is, particle sizes (5 mm vs. 30 mm) and moisture content (30 wt% vs. 10 wt%) diverge. Additional comminution and drying at the decentral conversion plant are necessary and need to be considered in planning the facilities. The risks affect the logistics processes per se, for instance, security installations due

[4] Logging residues can also be stored as compacted residues logs (bundles) produced at roadside landing. This concept implies lower MC rates in case of longer storage times. However, this system is still less well-developed and not broadly applied.

[5] A blend of softwood (spruce: 223 kg/m³) and hardwood (beech: 328 kg/m³) is defined as per Francescato, 2008, p.27.

to self-heating of wood chips. This issue is elaborated separately within the BioBoost project. All specifications are summarized in Table 6.

Table 6: Reference feedstock type for catalytic pyrolysis: wood chips

	Conversion technology	Catalytic Pyrolysis	Unit	References
Required specifications	Moisture content (MC)	8	wt%	*TNO, 2012*
	Particle size (length)	5	mm	*TNO, 2012*
	Impurity	-		
	Ash content	0.54	wt%	*TNO, 2012*
	Net caloric value	16.0	MJ/kg	*Wood fuels handbook, 2008, p. 27*
	Volume-based energy density	4.41	GJ/m³	*TNO, 2012*
	Feedstock costs	80	EUR/t	*Syncom, 2013*
Provided specifications	Provided product 1	Logging residues (loose)		
	Moisture content (MC)	55	wt%	*Shuva, 2012. "green state"*
	Storage form (assumed)	Covered windrows (slash piles)		*Specified within storage process*
	Storage placement (assumed)	Roadside landing		
	Storage time (assumed)	1	month	*Pettersson, 2007, p.789*
	Moisture content (MC) reduced	28	wt%	*Pettersson, 2007, p.783*
	Dry matter loss at roadside landing	0.9	wt%	*Pettersson, 2007, p.791*
	Provided product 2	Wood chips		
	Bulk density (fresh mass)	276	kg/m³ FM	*Annex (Average of Beech and Spruce)*
	Bulk density (dry matter)	193	kg/m³ DM	
	Moisture content (MC)	30	wt%	*Francescato, 2008, p. 11*
	Dry matter loss (closed storage)	3	wt% (p.a.)	*Francescato, 2008, p.46*
	Particle size (length)	30	mm	*ÖNORM M 7133 (G30)*
Furhter specifications	Associated risks	Self-heating > 100°C		*Francescato, 2008, p.44*
	Required pre-treatment process	Comminution & drying		

4.2.3 Organic municipal waste for Hydrothermal Carbonization

A third reference pathway has been defined for hydrothermal carbonization (HTC), which is examined by *AVA-CO2*. Here, organic municipal waste is defined as reference feedstock type. Principally, the moisture content does not play a role for this conversion technology. Instead, problems are encountered with respect to impurities, e.g. glass, metal, etc. detected in the waste. This challenge in processing also induces a pre-treatment process prior to the conversion process: Presorting

Within the BioBoost project it is assumed that organic municipal waste is available at a certain collection point (e.g. composting plants). Therefore, the waste collection process is not analysed here. In general, HTC plants are small-dimensioned in relation to FP and CP plants. Correspondingly, these plants are designed to be located next to major organic waste collection places. This fact also implies that no logistics processes are examined for this conversion technology. It is assumed that reactors are fed fully automated through screw-conveyor. For the sake of completeness, specifications are made also for organic municipal waste as indicated in Table 7.

Table 7: Reference feedstock type for HTC: organic municipal waste

	Conversion technology	HTC	Unit	Reference
Required specifications	Moisture content (MC)	70	wt%	*TNO, 2013*
	Particle size (length)	50-500	mm	*TNO, 2013*
	Impurity	Problems encountered		
	Ash content	15	wt%	*TNO, 2013*
	Net caloric value (LHV)	16.9	MJ/kg	*TNO, 2013*
	Volume-based energy density	2.96	GJ/m³	*TNO, 2013*
	Feedstock costs	-60	EUR/t	*TNO, 2013*
Provided specifications	Provided product	Compacted organic waste		
	Bulk density (fresh mass)	175	kg/m³ DM	*TNO, 2013 (150-200 kg/m³ DM)*
	Moisture content (MC)	30	wt%	*TNO, 2013*
	Particle size (length)	50-500	mm	*TNO, 2013*
	Storage placement (assumed)	Organic waste collection point		
Further specifications	Associated risks	None known		
	Required pre-treatment process	Presorting		

Besides these reference feedstock types for the conversion technologies investigated in the BioBoost Project, other biogenic residues (as quoted in the minutes of the telephone conference from October 24th, 2012) might be further analysed in terms of logistics process design (Table 8).

Table 8: Potential feedstock types for further investigation

Conversion technology	Potential feedstock types for further investigation
Fast pyrolysis	Scrap wood A2, Miscanthus, Flour production residue middle fraction
Catalytic pyrolysis	Miscanthus
Hydrothermal carbonization	Spent grains from brewery

4.3 Specification of Assets and Infrastructure used for Biomass Logistics

Based on the feedstock properties, assets and infrastructure used for transport, handling and storage are defined in the following. Simultaneously, this set constitutes the basis for subsequent analyses. Referring back to Figure 3, a dependency of transport assets on storage and handling process exist. Especially, this subordination controls the costs for handling, as will be shown afterwards. Accordingly, assets applied for transporting are defined in a first step.

4.3.1 Transport Assets

Based on the product specifications, loading devices applied for manipulating biogenic residues in practice are identified. Principally, loading devices aims at increasing efficiency during handling, and thus, reduces logistics costs.

The combination of the product and loading device is defined as loading unit. For instance, a 40 m³ roll-off container loaded with wood chips represents a loading unit. A loading device is mainly characterized by its dimensions (metre), payload (ton) and cargo space (cubic metre).

A square bale also embodies a type of loading device. The assumed reference square bale has the following dimensions: 2.4 x 1.2 x 0.9 m (length x width x height). According to *Krone*, a well-known producer of agricultural machinery, square bales associated with a total weight of 500 kg are feasible *(KRONE, 2012, p. 31)*. Retrieving the product data as introduced above, a bulk density of 193 kg/m³ FM and 166 kg/m³ DM, respectively, can be calculated.

With respect to transporting wood chips, roll-off containers are broadly applied in practice. Especially for communition at road side landing using a mobile chipper, despite the dependency between chipper and transport mean, roll-off containers enables high utilization rates for both and, thus, reduce total costs. This is due to reduced waiting times for both assets. However, applying roll-off containers requires enough space to manoeuver these containers at roadside landing. Basically, roll-off devices are defined for both farm tractor transports (40 m³) and truck transports (30 m³). All specifications are displayed in Table 9.

Table 9: Loading devices as transport asset

Loading device					
Square bales			Unit		*Ref.: Krone BiG Pack 1290 HDP, Skott (2012)*
	Length	2.40	m		*Round bales features a lower bulk density than square bales (Kaltschmitt, 2009, p.280)*
	Width	1.20	m		
	Height	0.90	m		
	Volume	2.59	m³		
	Weight	500	kg (MC: 14 %)		
	Weight	430	kg DM		
	Bulk density	193	kg/m³ FM		
	Bulk density	166	kg/m³ DM		
Roll-off container 40 m³			Unit		*Ref.: AVE Behältertyp (large size)*
	Length	7	m		Link
	Width	2.4	m		
	Height	2.4	m		
	cargo space	40	m³		
	Payload	13	t		
Roll-off container 30 m³			Unit		*Ref.: AVE Behältertyp (medium size)*
	Length	5	m		Link
	Width	2.4	m		
	Height	2.6	m		
	cargo space	30	m³		
	Payload	13	t		

These loading devices are used in combination with transport means. Generally, transport means can be categorized according the transport modes road, rail, waterway, air and pipeline. Within the BioBoost project, only road and rail transportation are examined. Subordinately, transport means are compose of different vehicle and trailer types. For biomass logistics, only road transport and the following vehicle-trailer combinations are analysed for the selected feedstock types (Table 10).

Table 10: Vehicle-trailer combinations considered

Vehicle-trailer combination		Feedstock type	Max. cargo space / payload
Farm tractor and (two) tippers		Wheat straw and wood chips	70 m³ / 21.4 t
Farm tractor and platform trailer		Wheat straw	89 m³ / 18 t
Farm tractor and hook lift trailer for roll-off containers		Wood chips	40 m³ / 23 t
Truck and drawbar trailer		Wheat straw and wood chips	115 m³ / 25 t
Truck and drawbar/hook lift trailer for roll-off containers		Wood chips	60 m³ / 26 t

By virtue of expert interviews and existing literature, biomass residues are mainly transported on road networks. In general, transport distances in the biomass collection process need to be kept down, because of low energy as well as bulk density, and high moisture content of biogenic residues. Besides that, rail and waterway transportation rely on restricted handling locations (ports, stations and terminals) which require proper infrastructure and induce additional handling costs. These extra costs impose a considerable competitive disadvantage compared to road transportation *(Expert interview 6, 2012).*

As can be seen from Table 10, farm tractors and trucks are analysed for biomass transportation. In the following tables, tractor vehicles are specified:

Table 11: Vehicle properties: farm tractor

Vehicle properties: farm tractor	
Engine power	Four-wheel drive, 130 kW
Fuel consumption rate[6]	54.5 l/100 km *(Handler, 2012)*
Operating life	8 years
Operating hours	1,500 h/p.a.[7]
Mileage	12,500 km[8]
Average vehicle speed	32.5 km/h *(Handler, 2009)*
Investment costs	120,000 EUR
Residual value	15,000 EUR

Table 12: Vehicle properties: truck tractor

Vehicle properties: truck tractor	
Engine power	315 kW
Fuel consumption rate	32.5 l/100 km *(Handler, 2012)*
Operating life	8 years
Operating hours	2,000 h/p.a.[9]
Mileage	75,000 km[10]
Average vehicle speed	55 km/h *(Handler, 2009)*
Investment costs[11]	115,000 EUR
Residual value	30,000 EUR

Truck tractors are dedicated for transport operations, whereas farm tractors are primarily used for arable farming. This fact is reflected particularly in fuel consumption rates, annual mileages and average vehicle speeds (Table 11 and Table 12). This specifications impacts logistics costs considerably as introduced later.

Besides the tractor vehicle, also respective trailer types are specified. Principally, the dimensions (length, width, and height) are determined in order to derive the available cargo

[6] Fuel consumption is indicated for transport purposes.
[7] Assumption: Days of operation per year: 250 d; hours of operation per day: 6 h.
[8] Assumption: Days of operation per year: 250 d; mileage per day: 50 km.
[9] Assumption: Days of operation per year: 250 d; hours of operation per day: 8 h.
[10] Assumption: Days of operation per year: 250 d; mileage per day: 300 km; 30 % thereof on tolled roads.
[11] Including truck type mounting (*Expert interview 12, 2012*).

space and the maximum payload are indicated. In doing so, reference trailer types applied in practice are characterized as follows (Table 13).

Table 13: Example for trailer type specification

Farm tractor and tippers (wheat straw)					
	1st Trailer	Length	5.0	m	
		Width	2.5	m	
		Height[1]	2.8	m	
		cargo space	35.0	m³	
		Max. payload	10.7	t	
		Square bales	13.0	units	
	2nd trailer	Length	5.0	m	*Ref.: Steyr CVT 6130*
		Width	2.5	m	*Link*
		Height[1]	2.8	m	*Ref.: HB Brantner PW 13000*
		cargo space	35.0	m³	*Link*
		Max. payload	10.7	t	[1] *Height of cargo space*
		Square bales	13.0	units	

With respect of transporting square bales, stacking plans (Figure 5) are designed in order to deduce the maximum number of square bales to be manipulated. Here, the specifications made in Table 9 are applied. A first analysis shows that traditional tippers as indicated in Table 13 only enable transporting 26 square bales, whereas platform trailers allows for 33 square bales (+ 27%).

Stacking plan - square bales (wheat straw) on platform trailer

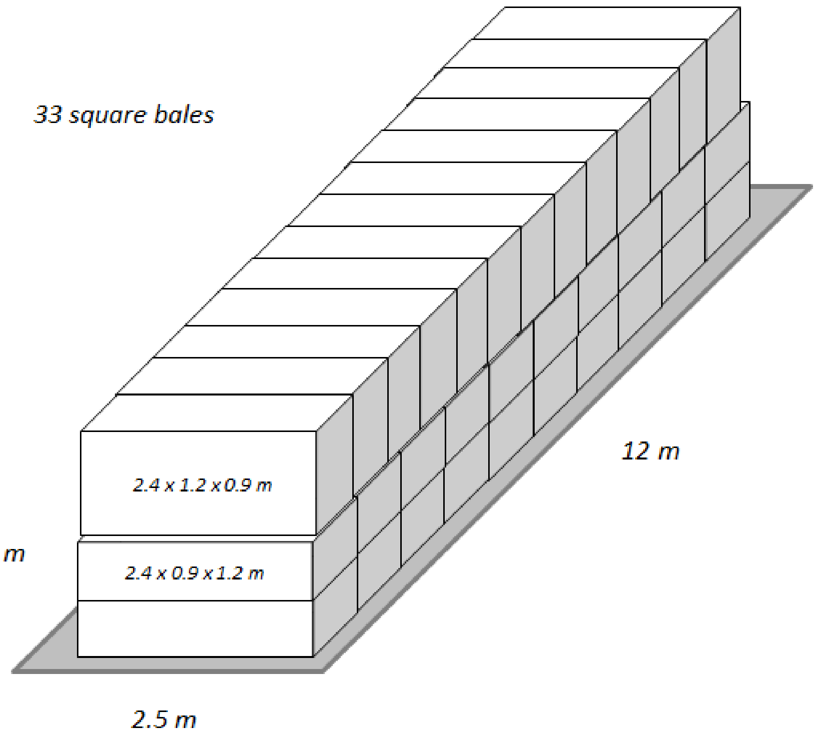


Figure 5: Stacking plan for square bales on a platform trailer

A platform trailer features an available cargo space of 88.5 m³ and a maximum payload of 18 tons. In a next step, the utilization capacity of each vehicle-trailer combination is calculated. In general, full truck loads (FTL) are assumed for road transportation. This implies that either the cargo space or payload is fully utilized for haulage. Facing biomass transports, it is expected that there are no back hauls, that is, either vehicle-trailer combination is collecting a full truck load from one feedstock source and transporting to a decentral conversion plant. After unloading cargo, the transport vehicle drives back empty. This situation reduces the transport utilization rates substantially. In order to calculate the real utilization rate, the following formula is applied *(Blauwens et al., 2008, p. 46):*

$$Real\ utilization\ of\ transport\ capacity = \frac{Payload\ utilized_{(Source \rightarrow Sink)} + Payload\ utilized_{(Sink \rightarrow Source)}}{PayloadPayload\ available_{(Source \rightarrow Sink)} + Payload\ available_{(Sink \rightarrow Source)}}$$

The same holds true for computing cargo space utilized. Accordingly, the transport capacity figures are adapted. Table 14 gives an overview about the specifications made for farm tractors and platform trailers and the calculated utilization rate.

Table 14: Selected vehicle-trailer combination as transport asset

Farm tractor and platform trailer (wheat straw)						
	Trailer	Length	12.0	m		
		Width	2.5	m		
		Height[1]	3.0	m		
		cargo space	88.5	m³		
		Max. payload	18.0	t		
		Square bales	33.0	units		
		Utilization of transport capacity	100%	46%		
		Total square bales	33	15	units	
		Total payload available	18.0		t	*Ref.: Fliegl DPW 180 Dolly*
		Total payload utilized	16.5		t FM	*Link*
		Total payload utilized	14.2	6.5	t DM	*[1] Height of cargo space*
		Total cargo space available	89		m³	
		Total cargo space utilized	74		m³ FM	

Considering fresh matter (FM) quantities, platform trailers exhibit rather high utilization rate of 46 % (compared to tippers: 25 %). In case of also incorporating dry matter content, the payload utilized is decreased to 6.5 t DM. Among others, this figure represents the basis for the subsequent logistics costs calculations in Chapter 4.4.1.

4.3.2 Handling Assets

Similar to the transport asset specification, different handling equipment for manipulating biomass used in practice are analysed (Table 15).

Table 15: Handling equipment considered

Handling equipment	
Front-end loaders (farm tractor)	
Telescopic handler	
Forklift truck	
Gantry crane	

In practice, different handling equipment is applied at different nodes within the BioBoost supply network. Key properties of biomass handling assets are given by lifting height and capacity. For instance, the height of the pile at the field in regard of storing square bales is restricted to the lifting height of front-end loaders, which are broadly used in practice. Moreover, the lifting capacity, that is the number of tons or cubic metre that can be manipulated by one single lifting, limits handling performance essentially. In general, telescopic handlers are best suited for handling biomass, although this represents the second most expansive equipment. Front-end loaders imply the highest fuel consumption rates: 18.5 l/h are indicated for a 140 kW farm tractor at middle utilization *(OEKL, 2012)*. However, gantry cranes are assumed to be electrified. Table 16 provides an overview about the specifications made.

Table 16: Handling equipment properties

Handling equipment	Lifting height (m)	Lifting capacity (t/m³)		Annual operating time (h/p.a.)	Fuel consumption rate (l/h)	Investment costs (EUR)
Front-end loaders	3.7	2.0	2.3	1,500	18.5	6,900
Telescopic handler	8.6	5.5	4.0	2,000	7.0	90,000
Forklift truck	3.7	3.5	1.5	2,000	2.5	32,000
Gantry crane	8.0	4.0	4.0	5,000	--	330,000

Gantry cranes represent a particular type of handling equipment. Despite having a high performance rate (ability to load 8-12 square bales at once *(DBFZ, 2012, p.68; Skøtt, 2011, p.13)*, gantry cranes are stationary and, hence, require infrastructure (building, tracks, etc.). Moreover, the investment costs are significant compared to the other handling options. Table 17 finally shows major differences between transportable and stationary handling equipment.

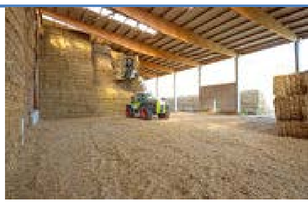
Table 17: Comparison between stationary and transportable handling equipment

Transportable handling equipment		Stationary handling equipment	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Flexible in application	Installation of required transport lanes (increased costs)	During unloading/loading process, moisture content and weight can be measured	High investment costs (crane and associated infra- and superstructure)
Comparatively low investment costs	Increased risk of accidents, e.g. risky handling in great lifting heights; further: need for safety installations, e.g. crash barriers)	Unloading/loading capacity up to 12 square bales at a time *(Skøtt, 2012)*	Bounded to tracks (limited options to manipulate material)
	Unloading/loading capacity: 1-2 square bales at a time *(Skøtt, 2012)*	Unloading/loading process can be fully automated, reduced hourly costs *(Voith Kransysteme, 2012)*,	
	Longer process lead times due to additional measurements (moisture content); up to 50 % additional time *(Skøtt, 2012)*	Better lifting height and capacity (t and m³)	

4.3.3 Storage Assets

Storage represents a major element in logistics. The process results from the time span between point of production and consumption. Within a supply network, each network node represents a potential storage location. The BioBoost project considers three storage locations for biomass logistics, in which square bales and wood chips can be stored: (1) pile/roadside landing (feedstock source), (2) intermediate depot and (3) decentral conversion plant (Table 18).

Table 18: Storage locations considered

Storage locations (biomass logistics)		Square bales	Wood chips
1	Piles/roadside landing		
2	Intermediate depot		
3	Decentral conversion plant		

Storage assets are basically aligned with the characteristics of products to be stored. In Chapter 4.2, reference feedstock types are already introduced. Therein, types of stock keeping units (SKU) are also defined: wheat straw is compacted as square bales and wood chips are stored as loose piles. For each SKU a supply scenario is defined in alignment with specification made in work package 1.

With respect to wheat straw, square bales are produced and consolidated at the field in the form of piles. Principally, bales can be stored uncovered – contamination with rain and snow increases moisture content – or tarpaulins are used for covered storage. In BioBoost, it is assumed that tarpaulins are used in order to partly reduce the risk of remoistening. Due to the fact that square bales are only produced in late summer, these units need to be stored for the whole year. Hence, a square bale is stored on average 6.5 months before being processed. For square bales two locations for storage exists: either wheat straw is stored at the field or it is forwarded towards an intermediate depot after production. In any case, square bales are further transported to the decentral conversion plant. There a safety stock of a five-day plant throughput is assumed. This figure can be reasoned by means of several publications, e.g. *Trippe et al, 2010, DBFZ, 2012 and FNR, 2005* and can be applied for both fast and catalytic pyrolysis.

Wood chips are produced from logging residues (soft and hard wood). Initially, logging residues are stored as slash piles at roadside landing. This type of feedstock already features high moisture content (MC 55 wt%). Especially for wet biogenic residues, e.g. logging residues, the process of storing poses high challenges on the product quality as well as on safety requirements. Associated risks are as follows *(FNR, 2005, p.79):*

- Dry matter loss through biological and technical processes (risk of loss)
- Self-heating through biological processes (hazard risk)
- Remoistening through uncovered storage (quality risk)
- Odour nuisance (environmental risk)
- Fungi and sporulation (health risk)

All of these risks will be intensively discussed in a subsequent risk assessment conducted also in the BioBoost project. However, dry matter loss, self-heating and remoistening have a fundamental impact on storage costs and, thus, are considered already in this report. In order to reduce these storage risks, the biological activity of biomass need to be prevented. This can be achieved by keeping moisture content low during storage through covered storage, reducing storage time, optimal filling height, sufficient air access or active ventilation.

In BioBoost it is assumed that logging residues are chopped shortly after harvesting at roadside landing. Then, wood chips are forwarded towards an intermediate depot in order to ensure optimal conditions for decreasing moisture content. After storing wood chips for 3 months at the intermediate depot, it is transported to the decentral conversion plant. There, a safety stock of a five-day plant throughput is hold, too.

Storage locations are primarily characterized by its infrastructural capacity. This includes dimensions of the storage yard and warehouse as well as utilities, e.g. weigh-bridge, office container, etc. First of all, dimensions (storage capacities) of the storage yard and warehouses are specified for each storage location. In doing so, several assumptions are made. In general, the feasible storage capacity (cargo space) is reduced by (i) spaces between square bales and the angle of repose of slash or wood chips piles. Figure 6 provides an overview about deductions assumed for realistic storage capacities for both open and closed storages.

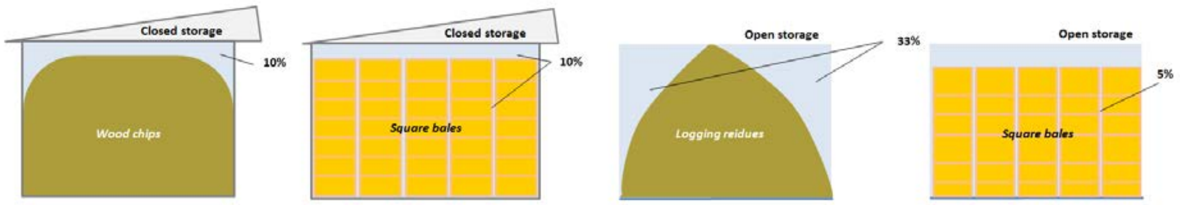


Figure 6: Reduced storage capacity

Based on input data from other BioBoost work packages and an existing study conducted by the *Waldverband Steiermark GmbH (2008)*, the following specifications are made for each storage location.

Table 19: Storage building specification

Storage building specifications	Piles / roadside landing		Intermediate depot (closed)		Intermediate depot (open)		Decentral conversion plant	
	Square bales	Logging residues	Square bales	Wood chips	Square bales	Wood chips	Square bales	Wood chips
Filling height (m)	6.3	5	7	7	6.3	5	10	10
Reduced storage capacity (%; Figure 6)	5	33	10		5	33	10	
Dimensions of storage yard / warehouse (length x width x height; m)	-[12]		40 x 25 x 7		100 x 30 x 6.3	100 x 30 x 5	80 x 35 x 10	60 x 35 x 10
Storage capacity (m³)			12,600		22,800	10,050	18,000[13]	12,960
Storage capacity (t DM)[14]			2,090	2,430	3,782	1,938	2,986	2,499

Besides defining storage capacity, also sealed area for transport and handling activities are incorporated at intermediate depots as well as at the decentral conversion. For instance, Figure 7 shows a draft layout plan for storage at a fast pyrolysis plant. Approximately 300 m² are dedicated for an unloading area, where square bales can be manipulated by a gantry crane within a closed warehouse.

[12] This figure depends individually on the feedstock potential within a specific area (e.g. t/km²) evaluated in WP1. Taking into account the feedstock potential, filling height as well as deductions assumed in Figure 7, the storage capacity (m³) can be calculated. Generally, it is assumed that the storage capacity at storage location 1 is not restricted to footprint.

[13] The width and height at the decentral conversion plant are given by specifications of a gantry crane. Furthermore, the dimensions are aligned to cover the required five-day plant throughput. Bulk density is based on dry matter.

[14] For calculating the storage capacity in tons, the bulk density (dry matter) is applied.

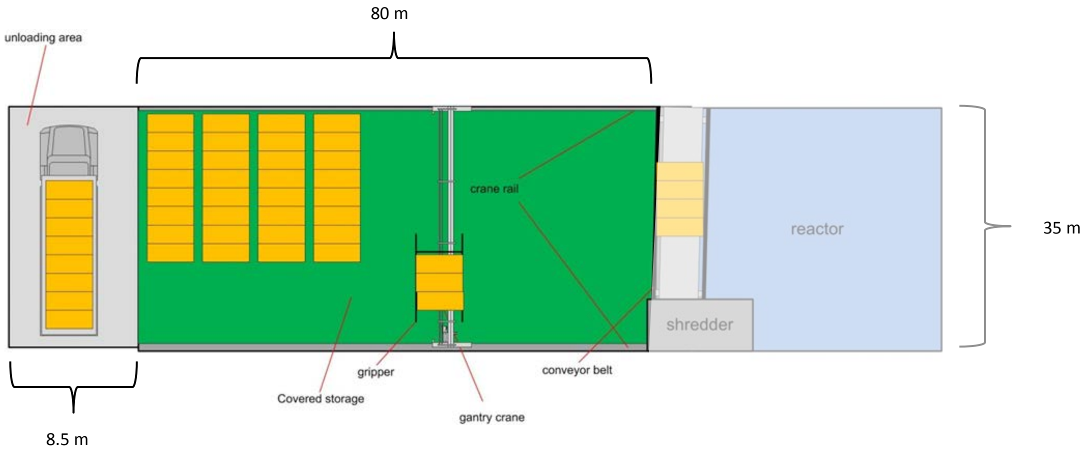


Figure 7: Draft layout plan for storage at DCP (FP)

Referring back to the question of whether to implement an intermediate depot or not depends on several factors. The following table provides a first overview about pros and cons of each individual supply path.

Table 20: Pros and cons of storage at pile/roadside landing and intermediate depot

Factor	Storage at	
	Pile / roadside landing *(square bales/ logging residues)*	**Intermediate depot** *(square bales/wood chips)*
Dry matter loss	High	Medium
Risk of remoistening	High	Low
Risk of self-heating	Low	High
Storage and handling costs	Low	High
Transport costs	High	Medium
Local weather conditions *Suitable for*	Dry climate zones *Southern Europe*	Humid climate zones *Central and Northern Europe*
Security of supply	Medium	High

As already mentioned above dry matter losses occur due to microbial activities on the one hand side and spillage during handling and storage processes on the other hand side. For instance, bottom parts of logging residues are left at roadside landing due to soil contamination. Biogenic residues associated with high moisture content, e.g. logging residues, generally imply a higher dry matter loss. This can mainly be ascribed to metabolic activities. However, dry matter loss increases by decreasing particle size, that is, wood chips are prone to dry matter loss, too. This is because of three major aspects *(Ashton et al, 2007):*

1) Chopped biomass exhibit an increased area of exposed surfaces on which microbial activity can occur,
2) the small the particle size is, the less air flows through piles and, thus, prevents heat dissipation, and
3) chipping releases the soluble contents of plant cells providing microbes with nutrients

The risk of remoistening is higher at piles and roadside landing due to insufficient shelter against weather, whereas closed storage enables higher drying rates. Further, microbial activities generate heat inside the piles. Again, the higher moisture content is, the higher the risk of self-heating.

On a cost level, additional storage and handling costs in case of implementing an intermediate depot are confronted with higher transport costs that arise due to an increased number of trips towards a decentral conversion plant. This research question is examined in detail later within the cost analyses.

Local weather conditions also influence the decision on whether to store at field or at an intermediate depot. Dry climate zones, e.g. Southern Europe, clearly favour storage at pile/roadside landing, whereas humid climate zones account for considering intermediate depots.

Finally, the security supply constitutes a further aspect which favours the implementation of intermediate depots. Risk pooling is a concept of addressing variability in supply chains. This approach suggests that demand variability is reduced if demand is aggregated across locations. In general, this reduction in volatility accounts for a decrease in safety stock and therefore reduces average inventory levels *(Simchi-Levi, 2008, p.48).*

Based on all assets defined for transporting, handling and storing square bales and logging residues/wood chips, cost rates are investigated for each logistics process in the following.

4.4 Cost Calculations for Biomass Logistics Processes

As a crucial input for the holistic logistics model, costs for transport, handling and storage are calculate. The target metrics are already indicated in Table 2. The following assumptions hold:

- Direct costing (including variable and fixed costs) is applied
- All costs are given on a net basis (excluding value added taxes)
- Annual interest rate is given by 4 % p.a.
- Fuel costs (diesel) amounts to 1.27 EUR/l
- Maintenance rate are as per VDI 2067
- Labour costs (gross wage) are given by 22.53 EUR/h or 35,820 EUR/p.a.
  (details see Annex)
- No subsidies are considered

As already indicated in Table 2 the target metrics are EUR/t (DM)*km (transport process) and EUR/t (DM) (handling and storage process). These cost rates are calculated on a dry matter basis, because no one would pay for water.

4.4.1 Transport Costs

Based on the specifications made above concerning transport assets, all vehicle-trailer combinations are evaluated according to their direct costs. Specifically, variable, i.e. distance variable costs (DVC), as well as fixed costs, i.e. distance fixed costs (DFC) are identified. Table 21 shows cost elements considered for transport costs evaluation. Usually, costs for transporting biomass are defined as EUR/t DM, provided that a fixed catchment area is given *(DBFZ, 2012, p.75; Leible, 2005, p.32).* As already mentioned, dry matter basis represents a meaningful basis for biomass logistics cost calculation. Because of applying a real routing network for Europe within the BioBoost project, transport costs need to be aligned with the holistic logistics model. Therefore, transport costs are calculated in the form of EUR/t (DM)*km.

Table 21: Cost elements considered for transport process

Cost elements	Distant fixed costs *DFC*	Distant variable costs *DVC*
Depreciation	x	
Maintenance	x	
Interest on investment	x	
Insurance	x	
Labour	x	
Tyres		x
Fuel		x
Lubricants		x
Road charges		x[15]

First of all, total annual direct costs are computed for each vehicle-trailer combination by means of the cost elements depicted above. Most of these costs are determined through consulting practitioners (see list of interviewed expert in Chapter 8.1) and standard values published by the Austrian Council for Agricultural Engineering and Rural Development (*Österreichisches Kuratorium für Landtechnik und Landentwicklung – ÖKL*). Basically, costs for both vehicle (tractor unit) and trailer are surveyed.

Besides the annual cost rates, also performance-related data of each individual vehicle-trailer combination need to be specified. The following data are indicated (Table 22):

[15] Road charges arise only for truck transports. Here, it is assumed that 30 % of annual mileage concern tolled roads.

Table 22: Performance-related data for transport process

Performance-related data	Unit
Days of operating per year	d/yr
Operating hours per day	h/d
Operating hours per year	h/yr
Daily mileage	km/d
Mileage per year	km/yr
Mileage per year on tolled roads	%
Payload utilized	t (DM)
Fuel consumption rate	l/100 km[16]
Average vehicle speed	km/h

These data are required to break down the total annual direct costs towards (i) daily cost rates, (ii) hourly cost rates, (iii) kilometre cost rates and finally (iv) tonne-kilometre cost rates.

The prepared calculation template (Table 23) is introduced using the example of calculating transport costs for a farm tractor and a platform trailer. First, performance-related data as illustrated in Table 22 (orange-coloured cells) are defined according to both specifications made before (i.e. payload utilized) and experiences from practitioners. Farm tractors are primarily dedicated to agricultural applications. Therefore, daily operating hours are reduced to 6 hours (truck: 8 hours). Provided that farm tractors are operated 250 days each year, total operating hours per year amounts to 1,500 h. Moreover, practical experiences reports that farm tractors exhibit a daily mileage of 50 km. In contrast, trucks are assumed to cover 300 km each day or 75,000 km each year (annual operating days: 250). This figure, of course, is indicated for transporting biomass with trucks and cannot be compared to mileage of logistics service provides which is considerable higher.

In total, a farm tractor and platform trailer induces annual costs of 89,108 EUR. Basically, cost elements as displayed in Table 21 are considered. Breaking total annual costs down to costs per ton-kilometre, it is assumed that a farm tractor is able to transport 6.5 tons (DM)

[16] Fuel consumption rates represents average values which also takes into account empty runs

of square bales for 32.5 km per hour. Finally, costs for using a farm tractor and platform trailer amounts to 0.28 EUR/t (DM) km

Table 23: Calculation scheme for transport costs

Farm tractor and platform trailer (wheat straw)				
Interest rate	%	4	Link	*Status: October 2012*
Days of operating per year	d/yr	250	250	*Expert interview*
Operating hours per day	h/d	6	Link	*Expert interview*
Operating hours per year	h/yr	1,500	Link	
Daily mileage	km/d	50	50	*Expert interview*
Mileage per year	km/yr	12,500	12,500	
Mileage per year on tolled roads	%	0	0	
Fuel cost	EUR/l	1	Link	*Status: October 2012, net price*
	Unit	Motor vehicle	Platform trailer	
Max. payload	t	0.0	18.0	
Capacity utilization	%		46%	
Payload utilized	t DM	0.0	6.5	
EU emission classification	class	IV	0	
Fuel consumption	l/100 km	54.50	0	*Handler, 2012*
Number of axles		2	2	
Number of tyres needed		4	12	
Service operating life	years	8	6 Link	
Average vehicle speed	km/h	32.5	32.5	*Handler, 2009*
Investment costs with tyres	EUR	120,000	20,000	*net price, expert interview*
Residual value	EUR	15,000	10,000	*ÖKL, 2012*
Depreciation	EUR/yr	13,125	1,667	
Maintenance costs	EUR/yr	14,400	6,000	*ÖKL, 2012*
Interests on investment	EUR/yr	2,400	400	
Insurance costs	EUR/yr	200	20	*Expert interview*
Labor costs	EUR/yr	35,820	0	*see Annex*
Price per tire	EUR/ unit	7,000	400	*net price; expert interview*
Running distance of tyres	h	4,000	4,000	*Expert interview*
Cost for tyres	EUR/yr	2,625	1,800	
Fuel costs	EUR/yr	8,652	0	
Lubricant costs	EUR/yr	2,000	0	*Expert interview*
Road charges	EUR/yr	0	0	
Annual costs	EUR/yr	79,222	9,887	
Total annual direct costs	**EUR/yr**	**89,108**		*net for transport combination*
Daily rate	EUR/d	356.43		
Hourly rate	EUR/h	59.41		
Kilometer rate	EUR/km	1.83		
Ton-kilometer rate	EUR/tkm	0.28		

Similarly, transport costs are evaluated for all other vehicle-trailer combinations. Table 24 provides an overview of all other transport cost rates.

Table 24: Transport cost rates

Transport Asset	Unit (tons dry matter)	Biomass logistics costs for Wheat straw	Biomass logistics costs for Wood chips
Farm tractor and tippers	EUR/tkm	0.58	0.32
Farm tractor and hook lift trailer	EUR/tkm		1.11
Farm tractor and platform trailer	EUR/tkm	0.28	
Truck and drawbar/hook lift trailer	EUR/tkm		0.29
Truck (and drawbar trailer)	EUR/tkm	0.15	0.11

Farm tractors and tippers represent a prevailing vehicle-trailer combination for biomass transports. The Austrian Council for Agricultural Engineering and Rural Development publishes an estimate for transport cost rate of 0.56 EUR/tkm[17]. Therefore, it can be assumed that the above-calculated transport cost rates constitute practical cost rates for Austria. Allocating these costs to BioBoost's study area (EU27 + Switzerland) will be presented later.

In order to receive insights into the composition of total annual direct costs of all other vehicle-trailer combinations, an overview is provided in (Table 25). Regarding wheat straw transports, the farm tractor combined with a platform trailer yields the lowest total annual costs (89,108 EUR/yr).In terms of transporting wood chips a farm tractor and two tippers features the lowest total annual costs (95,342 EUR/yr.). Fundamental differences between farm tractor and truck transports arise at maintenance costs, insurance costs and, especially fuel costs.

Fuel costs are basically determined by annual mileage. Although, farm tractors feature a higher average fuel consumption rate of 54.5 l/100 km (trucks: 32.5 l/100 km), trucks are assumed to cover 75,000 km p.a., whereas farm tractors only travel 12,500 km each year. In turn, this difference can be reasoned by different average vehicle speeds assumed: farm tractor 32.5 km/h and trucks 55 km/h *(Handler, 2009 & 2012).*

[17] Source: http://oekl.at/oekl-richtwerte/berechnungsgrundlagen-2/.

Table 25: Overview about total annual direct costs of all vehicle-trailer combinations

Breakdown of total annual direct costs	Unit	Farm tractor and tippers (wheat straw, wood chips)	Farm tractor and platform trailer (wheat straw)	Farm tractor and hook lift trailer for roll-off container (wood chips)	Truck and drawbar trailer (wheat straw, wood chips)	Truck and drawbar/hook lift trailer for roll-off-container (wood chips)
Depreciation	EUR/yr	17,125	14,792	17,875	14,625	18,250
Maintenance costs	EUR/yr	24,600	20,400	28,200	10,000	14,000
Interests on investment	EUR/yr	3,080	2,800	3,360	3,240	3,720
Insurance costs	EUR/yr	240	220	240	2,600	2,600
Labour costs	EUR/yr	35,820	35,820	35,820	35,820	35,820
Cost for tyres	EUR/yr	3,825	4,425	3,525	3,600	3,600
Fuel costs	EUR/yr	8,652	8,652	8,652	30,956	30,956
Lubricant costs	EUR/yr	2,000	2,000	2,000	2,477	2,477
Road charges	EUR/yr	0	0	0	7,277	7,277
Total annual direct costs	EUR/yr	95,342	89,108	99,672	110,594	118,699

Taking the mean values of each cost element introduced in Table 25, the following major cost drivers can be identified: depreciation, maintenance costs, labour costs and fuel costs. More specifically, these costs types represent 87 % of total annual direct costs (mean values). Accordingly, this set of cost elements are further used to allocate transport costs to the study area.

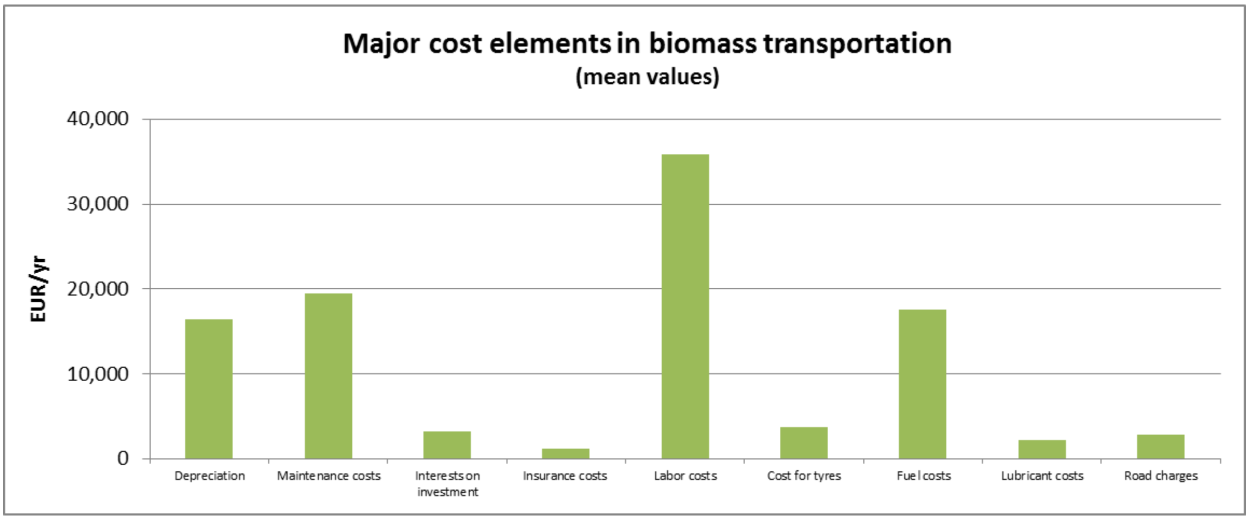


Table 26: Major cost elements in biomass transportation

4.4.2 Handling Costs

Four different handling assets are investigated in this report: (i) front-end loader (farm tractor), (ii) telescopic handler, (iii) forklift truck, and (iv) gantry crane. In order to evaluate this equipment, hourly cost rates (EUR/h) are calculated. Table 27 provides an insight into the calculation scheme.

Handling assets are evaluated based on fixed and variable costs. Figures are primarily taken from existing studies. For instance, a telescopic handler costs 34.85 EUR each hour. Besides that costs also idle times (waiting costs) of vehicle-trailer combination need to be considered. In general, hourly distance fixed costs (DFC) are taken for waiting costs. Then, performance-related data determined for wheat straw and wood chips, respectively. Generally, all four handling assets feature a lead time per handling process of 1.5 minutes. The handling capacity (indicated as tons dry matter) which can be transferred within this lead time complies with assumed number of loaded square bales or lifting capacity (m^3) of the shovel. Similar to transport assets, handling capacity of handling equipment is restricted rather by cargo space (m^3) than by cargo weight.

Subsequently, two lead times are calculated: lead time I and lead time II. The former implies the time needed to load or unload a vehicle-trailer combination (min/vehicle), whereas the latter indicates the time required for transferring one ton (DM) of biogenic residues (min/t DM). Lead time II also represents the key figure for determining the handling costs (EUR/t (DM)).

Starting from a fully utilized payload of each investigated transport asset (Table 14, t DM (100%)), productivity (t DM/h) for each handling asset can be determined. Taking both hourly cost rates as already described and productivity rates, handling costs (EUR/t DM) can be defined for each handling equipment and vehicle-trailer combination. Furthermore, simple stock transfers, which do not consider a waiting vehicle-trailer combination, are evaluated.

In addition to the four handling assets, tipping process as well as handling roll-off containers are evaluated. Here, a lead time per handling process of 2.5 minutes is assumed.

Table 27: Calculation scheme for handling costs

Telescopic handler					
Investment costs	EUR	90,000	*Schnedl, 2008*		
Operating hours	h/yr	2,000	*DBFZ, 2012, p.67*		
Fixed costs	EUR/h	9.15	*DBFZ, 2012, p.67*		
Variable costs	EUR/h	25.70	*DBFZ, 2012, p.67*	*including labour costs*	
Hourly rate	EUR/h	34.85			
Handling equipment - total hourly rate	EUR/h	34.85	*including labour costs*		
Farm tractor and tippers	EUR/h	53.91	Cost for idle times (waiting)		
Farm tractor and platform trailer	EUR/h	49.35			
Truck and drawbar trailer	EUR/h	33.14			
Wheat straw					
Assumed lead time per handling process	1.5	min			
Handling capacity	1.29	t (DM)	*equals handling 3 square bales per lifting*		
Lead time II	1.2	min/t DM			
Performance data	Payload utilized (t DM)	Lead time I (min/vehicle)	Lead time II (min/t DM)	Productivity (t DM/h)	Handling cost (EUR/t DM)
Farm tractor and tippers	11.2	13	1.2	52	1.72
Farm tractor and platform trailer	14.2	17	1.2	52	1.63
Truck and drawbar trailer	17.2	20	1.2	52	1.32
Stock transfer			1.2	52	0.68
Wood chips					
Assumed lead time per handling process	1.5	min			
Handling capacity	0.8	t (DM)			
Lead time II	1.9	min/t			
Performance data	Payload utilized (t DM)	Lead time I (min/vehicle)	Lead time II (min/t DM)	Productivity (t DM/h)	Handling cost (EUR/t DM)
Farm tractor and tippers	11.2	22	1.9	31	2.88
Farm tractor and platform trailer	14.2	28	1.9	31	2.73
Truck and drawbar trailer	17.2	33	1.9	31	2.20
Stock transfer			1.9	31	1.13

Table 28 provides an overview about all calculated handling cost rates.

Table 28: Handling cost rates

		Biomass logistics costs for		
Transport Asset	*Handling Asset*	*Unit (tons dry matter)*	Wheat straw	Wood chips
Farm tractor and tippers	Front-end loaders (farm tractor)	*EUR/t*	3.66	7.23
Farm tractor and platform trailer		*EUR/t*	3.53	6.97
Truck and drawbar trailer		*EUR/t*	3.06	6.04
Stock transfer		*EUR/t*	2.10	4.14
Farm tractor and tippers	Telescopic handler	*EUR/t*	1.72	2.88
Farm tractor and platform trailer		*EUR/t*	1.63	2.73
Truck and drawbar trailer		*EUR/t*	1.32	2.20
Stock transfer		*EUR/t*	0.68	1.13
Farm tractor and tippers	Gantry crane	*EUR/t*	1.04	4.65
Farm tractor and platform trailer		*EUR/t*	1.01	4.50
Truck and drawbar trailer		*EUR/t*	0.89	3.98
Stock transfer		*EUR/t*	0.65	2.91
Farm tractor and tippers	Forklift truck	*EUR/t*	2.52	7.50
Farm tractor and platform trailer		*EUR/t*	2.39	7.11
Truck and drawbar trailer		*EUR/t*	1.92	5.71
Stock transfer		*EUR/t*	0.96	2.84
Farm tractor and tippers	Tipping (unloading)	*EUR/t*		0.20
Truck and drawbar trailer		*EUR/t*		0.08
Farm tractor and hook lift trailer	Handling roll-off container	*EUR/t*		0.31
Truck and drawbar/hook lift trailer		*EUR/t*		0.26

In search of most appropriate handling asset for each reference feedstock type, the following inferences can be concluded. Gantry cranes indicate the lowest costs for handling wheat straw (square bales). This type of crane is able to simultaneously handle up to 12 bales per lifting (*Skøtt, 2011, p. 13).* However, in this analysis the handling capacity is restricted to 8 square bales according to the assumed lifting capacity of the gantry crane (4 ton). This figure corresponds to assumption made in *DBFZ, 2012, p. 68*. Furthermore, transferring square bales within the storage, gantry cranes seem to be the most efficient option. Facing different storage locations, gantry cranes are primarily applied at decentral conversion plants because of high investment costs. Front-end loaders (farm tractor), which represents the most expensive way of handling square bales, are mostly used at the feedstock source (pile at field), whereas telescopic handler are deployed at intermediate depots.

With respect to wood chips, handling cost rates are principally higher than for square bales. This disparity can be reasoned by looking at provided feedstock specifications. Logging residues as well as wood chips are provided as loose products. Contrary to square bales, no compaction takes place. Consequently, the capacity (tons dry matter) of handling assets is considerably lower for wood chips than for square bales (see Table 27).

Front-end loaders and fork lift trucks seem to be highly inappropriate due to restricted lifting capacity. Although telescopic handler and gantry cranes exhibits the same lifting capacity (4 m³), gantry cranes seems to be unattractive, too. This is caused by high hourly costs of this handling asset (89.64 EUR/h) compared to the hourly cost for a telescopic handler (34.85 EUR/h). This same holds true for simple stock transfers.

However, the lowest handling costs for wood chips feature the manipulation by means of roll-off containers and the tipping process. This can be traced back to the ability to load and unload a vast amount of biogenic residues within a short period of time without required additional handling equipment. Therefore, the following conclusion can be drawn.

Considering transport cost rates as shown in Table 24 vehicles with hook lift trailers for roll-off containers have a major disadvantage compared to other vehicle-trailer combination in terms of transport costs. However, this perceived drawback may be compensated by also incorporating handling costs. This situation clearly shows an increased efficiency and cost advantage through applying roll-off containers. A further advantage of using roll-off container for handling is given by higher utilization rates of mobile choppers at roadside landing *(Expert interview 15, 2012)*.

4.4.3 Storage Costs

In general, inventory holding costs include variable costs (i.e. capital costs[18]) and fixed costs, e.g. warehousing, depreciation, insurance, etc. Here, fixed costs are referred to storage costs and are determined by specifications made in Chapter 4.3.3. Storage costs (EUR/t DM) are examined for wheat straw (square bales) as well as logging residues/wood chips and for each storage location. Organic municipal waste is not regarded, because HTC plants are supposed to be located right next to waste collection yard.

[18] Capital costs represent opportunity costs for the capital that is tied up in inventory.

On the basis of predefined supply scenarios for wheat straw and logging residues/wood chips, data on average storage periods and dry matter loss are provided. Regarding wheat straw, an average storage period for storage location 1 and 2 of 6.5 months[19] is assumed. At the decentral conversion plant a five-day plant throughput is stored. This figure corresponds to 0.2 months. Logging residues are stored for one month *(Pettersson, 2007, p.789)*, whereas wood chips are assumed to remain three months at an intermediate depot *(Expert interview 15, 2012)*.

Data on dry matter losses are taken from different existing studies and are adapted according to the storage periods. *DBFZ (2012, p. 67)* determines dry matter loss rates for square bales stored at different locations, while *Pettersson (2007, p. 791)* and *Francescato (2008, p. 46)* defines loss rates for logging residues and wood chips, respectively. Dry matter loss at decentral conversion plants are broken down linearly based on the given data for intermediate depots (Table 29).

Table 29: Storage periods and dry matter losses assumed for storage locations

			Feedstock types	
Storage periods	*Storage location*	*Unit*	Wheat straw	Logging residues/ wood chips
Pile/roadside landing	1	months	6.5	6.0
Intermediate depot	2	months	6.5	3.0
Decentral conversion plant	3	months	0.2	0.2
			Feedstock types	
Dry matter loss	*Storage location*	*Unit*	Wheat straw	Logging residues/ wood chips
Pile/roadside landing	1	wt%	8%	5%
Intermediate depot	2	wt%	2%	3%
Decentral conversion plant	3	wt%	0.05%	0.17%

The calculation scheme is introduced using the example of an intermediate depot (Table 30). Based on the specifications made for an intermediate depot, investment costs are defined in an initial step. Each storage location is assessed according to its total annual fixed costs including (i) depreciation, (ii) interests on investments, (iii) maintenance and (iv) labour. For this purpose, costs are primarily taken from *Waldverband Steiermark GmbH, 2012, p. 209f*. Costs for real estate are disregarded due to major regional differences. Regarding labour

[19] Due to the fact that wheat straw is harvested once a year, storage periods of square bales can range from 1 month to 12 months. Here, the average value of 6.5 months is assumed.

costs, practitioners stated that one full-time and one part-time worker are required for operating an intermediate depot *(Expert interview 15, 2012)*. In total, the calculation yields storage fixed costs of 108,930 EUR for an intermediate depot.

Table 30: Calculation scheme for storage costs

Storage location2:	***Intermediate depot***			
Interest rate	%	4		
		Investment	Depreciation	Maintenance
Plot area paved	EUR	300,000	12,000	3,000
Sealed area for transport	EUR	75,000	3,000	750
Sealed area for closed storage	EUR	30,000	1,200	300
Sealed area for open storage	EUR	45,000	1,800	450
Warehouse	EUR	300,000	12,000	3,000
Weigh-bridge	EUR	30,000	1,500	600
Office container and equipment	EUR	10,000	2,000	100
Total costs	EUR	780,000	31,500	8,100
Annual fixed costs				
Depreciation	EUR/yr	31,500		
Interests on investment	EUR/yr	15,600		
Maintenance	EUR/yr	8,100		
Labour	EUR/yr	53,730		
Total annual fixed costs	EUR/yr	108,930		
		Wheat straw	Wood chips	
Annual throughput quantity	t (DM)/yr	10,842	17,472	
Storage costs per ton	EUR/t (DM)	10.05	6.23	

The above defined average storage periods fix annual inventory turnovers. Therefore, the annual throughput quantity of each storage location can be defined by multiplying storage capacity (t/DM)[20] by annual inventory turnovers. Finally, storage costs per ton (EUR/t (DM) are calculated for wheat straw and wood chips. Table 31 illustrates storage cost rates.

Table 31: Storage cost rates

			Feedstock types	
Storage costs	*Storage location*	*Unit (tons dry matter)*	Wheat straw	Logging residues/ wood chips
Pile/roadside landing	1	EUR/t	1.99	1.99
Intermediate depot	2	EUR/t	10.05	6.23
Decentral conversion plant	3	EUR/t	0.63	0.56

[20] The storage capacity (t (DM) includes both open and closed storages (Table 26).

As already indicated in Table 19, storage costs at pile/roadside landing are not subject to plot areas. Thus, only costs for tarpaulins of 1.99 EUR/t are quoted for both wheat straw and logging residues/wood chips *(DBFZ, 2012, p. 67)*. The storage costs per ton (DM) computed in Table 30 amounts to 10.05 EUR/t (DM) for wheat straw and 6.23 EUR/t (DM) for wood chips. In comparison to *DBFZ (2012, p. 67)* storage cost of 13.89 EUR/t (DM) are estimated. Because of higher inventory turns of wood chips (4 inventory turns per year), storage costs are lower.

Facing rather small safety stocks compared to annual throughput rates at decentral conversion plants (FP: 175,000 t (DM)/yr; CP: 180,000 t (DM)/yr) implicates high inventory turnovers. Total annual storage fixed costs can be allocated to a higher throughput quantity, which reduces storage costs per unit considerably. Storing wheat straw at DCP costs 0.63 EUR/t (DM), whereas wood chips amounts to 0.56 EUR/t (DM).

5 Practical Implications

Based on insights gained in preceding chapters, practical implications are drawn in this chapter. Besides determining input data for the holistic logistics model, also remaining research questions are answered. Based on the cost calculations conduced in previous chapters, further practical implications are drawn. More specifically the following, remaining research questions should be answered:

- In which scenario does an intermediate depot pay off?
- What is the traffic impact resulted from setting up a decentral conversion plant?
- How can logistics process costs be allocated to other European countries?

5.1 Implementing an Intermediate Depot

As already sketched, basically a 3-echelon supply chain is considered in the BioBoost project: (1) feedstock source, (2) decentral conversion plant and (3) central conversion plant. However, having a look at practical experiences, intermediate depots for storing biogenic residues (square bales and wood chips) are more frequently implemented. Thus, the 3-echelon supply chain configuration can be expanded to a 4-echelon supply chain as depicted in Figure 4. At first glance, such a 4-echelon supply chain seems to induce additional costs for additional handling and storage. However, this configuration also accounts for reducing costly transports by farm tractors and simultaneously exploiting the cost advantage of truck transports. Further advantages of an intermediate depot have already been depicted in Table 20.

In particular, dry matter losses can be reduced due to covered storages. This situation also influences the feedstock quantity taken from a certain region. An example is shown in Table 32. Considering the annual required input quantity of a specific FP plant as well as the dry matter loss rates quoted in Table 29, the feedstock utilization in a certain region is considerably higher in a 3-echelon supply chain configuration than in a 4-echelon setting[21]. On average, required feedstock quantity for a 3-echelon supply chain is 5 % higher than for a

[21] For a 4-echelon SC setting it is assumed that feedstock potential is directly transported towards an intermediate depot after consolidation.

4-echelon supply chain. This circumstance represents a further advantage for implementing an intermediate depot.

Table 32: Required feedstock: 3-SC echelon vs. 4-SC echelon

Annual throughputs	Unit	Input quantity *(tons of dry matter)*	Input quantity inkl. dry matter loss (4-echelons)	Input quantity inkl. dry matter loss (3-echelons)		
Fast Pyrolysis	t DM/yr	175,000	178,663	190,315	*Wheat straw*	
Catalytic Pyrolysis	t DM/yr	180,000	185,877	190,693	*Wood chips*	
Hydrothermal Carbonization	t DM/yr	24,024		24,024	*Organic municipal waste*	

The following aims at providing insights into a scenario, in which an intermediate depot pay off. For this purpose, a small case study related to fast pyrolysis is set up. To start with, the required feedstock quantities (t DM/yr) are evaluated as already described above. By multiplying these figures with respective storage costs as indicated in Table 31, annual storage costs are computed. As a matter of course, storage costs in a 4-echelon supply chain setting are higher than in a 3-echelon chain. A notional transport vehicle split is assumed: 70 % of feedstock are transported by farm tractors whereas 30 % by trucks. This distribution is valid for direct transports and for pre-carriages. In case of implementing an intermediate depot, on-carriages are organized only by trucks (exploiting cost advantage!)

Table 33: Case study setting 1

Decentral conversion plant		
Conversion technology		Fast pyrolysis
Raw material		straw
Input quantity	t (DM)/yr	175,000
Input quantity*	t (DM)/yr	190,315
Input quantity**	t (DM)/yr	178,663
Scenario A: 3-echelons*		
Wheat straw: feedstock for 3-echelons	Inventory (t DM/yr)	Storage costs (EUR/yr)
Pile at field	190,315	378,727
Decentral conversion plant	175,090	109,859
		488,586
Transport vehicle split		
Farm tractor and platform trailer*	70%	
Truck and drawbar trailer*	30%	
Scenario B: 4-echelons**		
Wheat straw: feedstock for 4-echelons	Inventory (t DM/yr)	Storage costs (EUR/yr)
Pile at field	-	-
Intermediate depot	178,663	956,704
Decentral conversion plant	175,090	109,859
		1,066,563
Transport vehicle split: Pile > Intermediate depot (pre-carriage)		
Farm tractor and platform trailer**	70%	
Truck and drawbar trailer**	30%	
Transport vehicle split: intermediate depot > DCP (on-carriage)		
Farm tractor and platform trailer**	0%	
Truck and drawbar trailer**	100%	

The above-mentioned question aims at identifying the transport distance (km), at which additional costs arisen through implementing an intermediate depot are compensated by cost advantages of truck transports; provided that the above depicted transport vehicle split holds. Therefore, some further assumptions are made in order to finally draw conclusions.

Based on first results of WP1 an average biomass density of 67 tons per km² is assumed. Considering the required feedstock quantities for a FP plant for the individual scenario (3-echelon vs. 4-echelon SC), a catchment area of 2,850 km² and 2,675 km² is calculated. For the sake of simplicity, it is assumed that the catchment area is quadratic. Therefore, the average transport distance (including 50 % back hauls) can be defined by extracting the route of the catchment area *(DBFZ, 2012, p. 70f).* The average transport distance for a 3-echelon SC amounts to 53 km, whereas a 4-echelon supply chain exhibits 52 km (due to the individual feedstock quantities). However, the latter features a split transport: pre- and on-carriages. Assuming that on-carriages are given by 52 km, pre-carriage distances need to be added. In doing so, the same procedure as for FP plants is applied for intermediate depots. Again, an average biomass density of 67 tons per km² and an annual throughput quantity of 10,842 t DM/ yr (Table 30) are given. By means of these figures, an average transport distance of 13 km can be calculated. In total, a transport distance of a 4-echelon SC of 64 km is yielded. Finally, a simple heuristic is derived: 20% of transport distances relate to pre-carriages and 80 % of transport distances are on-carriages. Accordingly, this heuristic holds for the transport distance for a 4-echelon supply chain.

By means of this setting as well as logistics cost rates evaluated before, total logistics costs including transport, storage and handling are computed (numerical results see annex). In doing so, the logistics costs as indicated in the logistics reference pathways are taken. In particular, these pathways determine the logistics equipment (handling assets, etc.) used.

Comparing both scenarios the following chart can be drawn (Figure 8). Logistics costs per ton as a function of transport distances are calculated. The additional costs of implementing an intermediate depot favours a 3-SC-echelon until a total transport distance of 80 km. Right at this specific kilometrage, the cost advantage of truck transportation can be fully exploited. Therefore, total logistics costs per ton of a 4-echelon SC do not increase as much as of a 3-echelon SC.

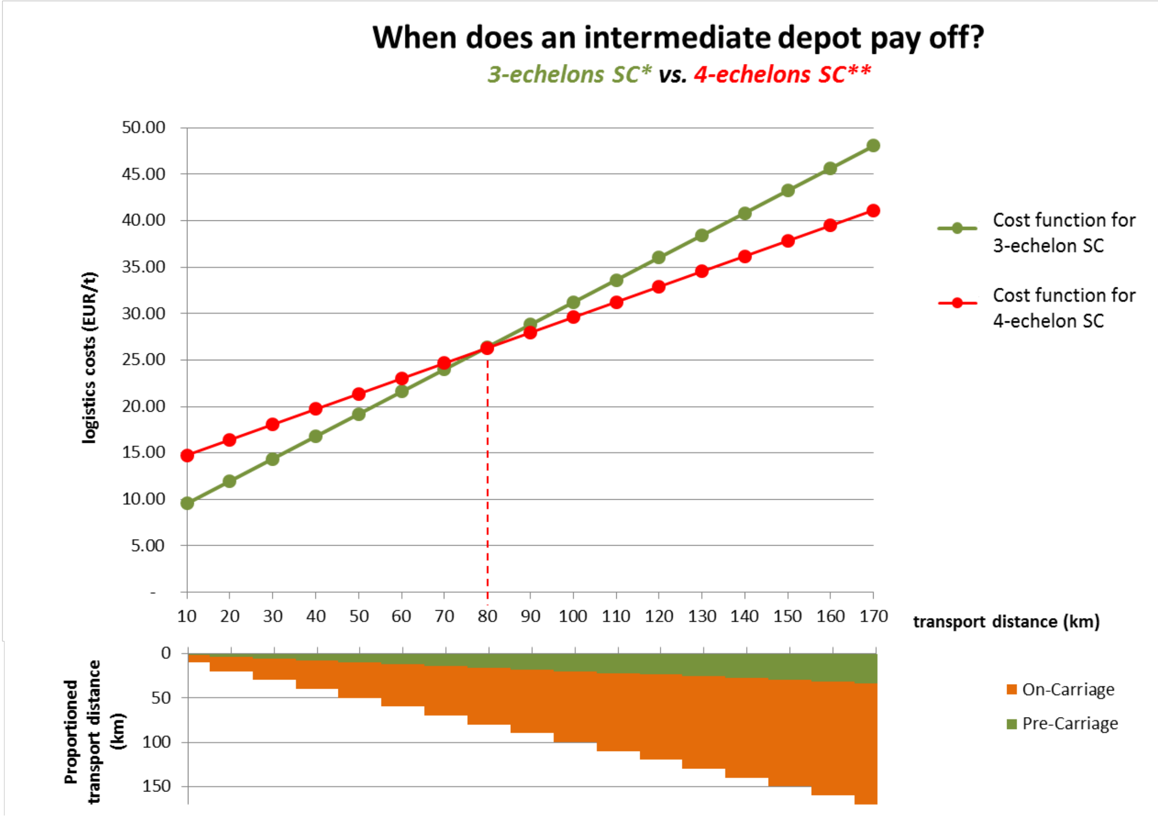


Figure 8: Case study: intermediate depot – 70 % farm tractors, 30 % trucks

5.2 Traffic Impact Assessment for Conversion Plants

Another research questions deals with the traffic impact that arise in locating a conversion plant in a region. In particular, daily inbound as well as outbound trips generated through feedstock deliveries are evaluated within a traffic impact assessment (TIA). The initial stock at DCP, 175,195 t/yr (Table 32) serves as a reference value for the required input material per year. Additionally, the following payloads of the vehicle-trailer combinations are assumed:

Table 34: Payloads of all vehicle-trailer combinations

Payload utilized	Wheat straw	Wood chips	Biodegradable municipal waste
Unit	*Payload utilized (in t)*		
Farm tractor and tippers	13.0	20.0	
Farm tractor and hook lift trailer		11.5	
Farm tractor and platform trailer	16.5		
Truck and drawbar/hook lift trailer		17.2	
Truck (and drawbar trailer)	20.0	25.0	11.5

Time factors for feedstock deliveries are assumed as follows: 48 weeks per year, 5.5 days per week and a delivery window from 7 AM to 7 PM *(Rose energy, 2008, p.5)*. Based on this information, daily attracted and produced trips can be approximated (Table 35). Again, a modal split is assumed as quoted above.

Table 35: Traffic impact assessment: daily in- and outbound trips

	Fast Pyrolysis	Catalytic Pyrolysis	Hydrothermal Carbonization
Modal split *(Weight: truck 30%; farm tractor 70% --> scenario A*)* (vehilces/day)	Wheat straw	Wood chips	Biodegradable municipal waste
Unit	*Vehicles/day (in- and outbound trips)*		
Farm tractor and tippers	36	12	
Farm tractor and hook lift trailer		20	
Farm tractor and platform trailer	29		
Truck and drawbar/hook lift trailer		27	
Truck (and drawbar trailer)	20	19	8
Total arriving vehicles/day	85	78	8

According to a recommendation of the Institute of transportation engineers (ITE) this amount of trips do not require a detailed traffic impact study *(Any proposed site plan or subdivision plan which would be expected to generate over one hundred (100) directional trips during the peak hour of the traffic generator or the peak hour on the adjacent streets, or over seven hundred fifty (750) trips in an average day, ITE, 2013).*

5.3 Distributing Cost Drivers to Geographical Study Area

The above-defined logistics cost rates have been conducted for Austria. In order to allocate cost rates to other European countries, major cost drivers are identified and indexed. Basically, four major cost drivers are identified:

- Labour costs
- Fuel costs
- Vehicle investment costs
- Construction costs

As can be seen in the annex, evaluated indices can be retrieved. These data are based on statistics published by the European Union as well as experiences from sales experts of a transport vehicle manufacturer. Construction costs have already been analysed in another work package. These data also serves as input parameter for the holistic logistics model.

6 Conclusions and Outlook

This report is primarily dedicated to design and evaluate processes in the field of biomass logistics. Information based on existing literature as well as implicit, not published, practical knowledge on manipulating biomass are consolidated and investigated through different calculations. Finally, key implications are drawn.

First, relevant transport, handling and storage assets are determined. Hereby, plenty of expert interviews are conducted. By virtue of these specifications, cost calculations are run in a second step in order to derive target metrics. Generally, farm tractors features higher costs compared to trucks with respect to transports. This can be reasoned by performance data and the fact that this type of transport means is not exclusively dedicated for transports. However, as interviews with practitioners showed, the usage of farm tractors is prevalent in practice (partially due to a lack of investments in trucks).

Referring to handling, four different assets are investigated: (1) farm tractor with front loader, (2) forklift truck, (3) telescopic handler and (4) gantry crane. Additionally, loading and unloading of roll-off containers as well as tipping activities are evaluated. In doing so, some preferential handling assets are identified for each reference feedstock type.

The storage process is analysed by specifying proper assets, evaluating costs and setting up a case study. This case study is dedicated to the question: in which scenario does an intermediate depot pay off? More specifically, two supply chain configurations, i.e. 3-echelon SC and 4-echelon SC including an intermediate gathering point, are evaluated and compared. This analysis shows that at a certain transport distance, an intermediate depot pays off because the cost advantage of trucks can be exploited to a greater extent.

A final assessment about trips generated through locating a conversion plant concluded that the currently assumed scales of conversion plants are not subject to any further traffic impact study.

Subsequently, these results serve as input data for both a techno-economic, social and environmental assessment of complete chains conducted in WP6 as well as ongoing activities in WP4. More specifically, the simulation-based optimization model is fed with key figures generated in this report.

Based on the findings within this report, the energy carrier logistics will be investigated in the following months and finalized in D4.1 Logistics Concept (due date: project month 15). Here, especially railway transports as well as inland waterway transports are analysed. Applying these two transport modes in context of direct transports, transport cost savings compared to truck transports are likely.

7 List of References

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8 Annex

8.1 List of expert interviewed

Table 36: List of expert interviewed

	Interviews conducted with:
1	Agrarservice Hubmann OB
2	AVE Österreich GmbH
3	Biomassekraftwerk Güssing GmbH & Co KG
4	BLT Wieselburg, Lehr- und Forschungszentrum Franisco Josephinum
5	Energie AG Oberösterreich, Kraftwerke GmbH (Biomassekraftwerk Timelkam)
6	FH OÖ, Forschungs & Entwicklungs GmbH
7	Hanl Hackschnitzelerzeugung und Holzhandel
8	Landwirtschaftskammer Steiermark
9	Maschinenring
10	Müllverbrennungsanlage (MVA) Pfaffenau
11	Österreichische Bundesforste AG
12	Riedler Anhänger GmbH
13	Schachinger Logistik Holding GmbH
14	Spedition Billitz
15	Waldverband Steiermark (Biomassehof Leoben)
16	Wien Energie GmbH

8.2 Interview Guide

Table 37: Interview guide

Interview conducted with:	
Company	
Name	
Function	
Condact details	
	1) How is the process of <u>biomass transport</u> designed? a. Which biomass types and annual quantities (throughput) are manipulated? b. Who (farmer, own staff, LSP) is responsible for transportation (coordination, costs, risks)? c. Which loading units and vehicle (trailer) types are used (for which distances) for transportation? d. Are there any value added steps (pre-treatment activities) before or after transportation (e.g. comminution)? e. What is the average, cost-efficient transport distance (from source to sink)? f. What are major performance data (average vehicle speed, payload, fuel consumption, etc.)? g. What are the main cost drivers for biomass transports?
	2) How is the process of <u>biomass handling</u> designed? a. Who (farmer, own staff, LSP) is responsible for handling (coordination, costs, risks)? b. Which types of handling equipment are used for which type of biomass? c. What are major performance data (tons handled per hour, fuel consumption)? d. What are the main cost drivers for biomass handling?
	3) How is the process of <u>biomass storage</u> designed? a. What is the local storage capacity (roofed and open top) as well as average days of inventory? b. What are the main cost drivers for biomass storage? c. Which types of handling equipment are used for which type of biomass? d. Are there any pre-treatment activities as part of storing biomass?
	4) Where do major problems related to the before-mentioned logistics processes arise along a biomass supply chain?

8.3 Labour Cost Calculation

Table 38: Labour cost calculation

Labour costs				
Social security contribution ratio	31%	paid by employer		
Weeks to be paid by the employer				
	weeks	%		
Annual gross wage	52.2	100%		
Christmas allowance	4.33	8%		
Holiday allowance	4.33	8%		
Social security contribution (wage)	16.18	31%		
Social security contribution (wage)	2.68	5.1%		
Total	79.73			
Theoretical time of performance				
	weeks	days	hours	
Annual gross working time	52.20	261	2010	
Vacation	5.00	25	193	
Illness	3.20	16	123	
National holidays	2.20	11	85	
Other absence	0.50	3	19	
Annual net working time	41.30	207	1590	
Non-wage working time	38.43	weeks		
Non-wage labor costs	93%			
Productivity factor	70%			
Feasible time of performance				
	weeks	days	hours	
Annual net working time	28.9	145	1113	
Non-wage labor costs (incl. non-productivity)		176%		
Labor cost calculation				
Assumed gross wage per month	1,498.18	EUR	paid to employee	Link
Allowance per month	200.00	EUR	paid to employee	
Assumed gross wage per month	2,984.98	EUR	paid by employer	
Assumed gross wage per year	35,819.74	EUR	paid by employer	
Assumed gross wage per hour	22.53	EUR	paid by employer	

8.4 Case Study: Numerical Results on Logistics Costs Calculation

Table 39: Case study: numerical results on logistics costs calculation

Scenario A: 3-echelons*																	
TOTAL logistics costs *(handling: front-loader and gantry crane)*	10	20	30	40	50	60	70	80	90	100	120	140	160	180	200	250	300 km
Farm tractor and platform trailer*	1,776,026	2,268,111	2,760,197	3,252,282	3,744,367	4,236,453	4,728,538	5,220,624	5,712,709	6,204,794	7,188,965	8,173,136	9,157,307	10,141,477	11,125,648	13,586,075	16,046,502
Truck and drawbar trailer*	1,436,661	1,692,526	1,948,392	2,204,257	2,460,122	2,715,987	2,971,853	3,227,718	3,483,583	3,739,448	4,251,179	4,762,909	5,274,639	5,786,370	6,298,100	7,577,426	8,856,752
Transport vehicle split*	1,538,471	1,865,202	2,191,933	2,518,664	2,845,396	3,172,127	3,498,858	3,825,589	4,152,321	4,479,052	5,132,515	5,785,977	6,439,440	7,092,902	7,746,365	9,380,021	11,013,677
UNIT logistics *(handling: front-loader and gantry crane)*	10	20	30	40	50	60	70	80	90	100	120	140	160	180	200	250	300 km
Farm tractor and platform trailer*	10.14	12.95	15.76	18.57	21.39	24.20	27.01	29.82	32.63	35.44	41.06	46.68	52.30	57.92	63.54	77.59	91.65
Truck and drawbar trailer*	8.21	9.67	11.13	12.59	14.05	15.51	16.97	18.43	19.90	21.36	24.28	27.20	30.13	33.05	35.97	43.28	50.58
Transport vehicle split*	8.79	10.65	12.52	14.38	16.25	18.12	19.98	21.85	23.72	25.58	29.31	33.05	36.78	40.51	44.24	53.57	62.90
Scenario A: 4-echelons**																	
TOTAL logistics costs (Pile --> ID) *(handling: front-loader and telescopic handler)*	2	4	6	8	10	12	14	16	18	20	24	28	32	36	40	49	59 km
Farm tractor and platform trailer**	1,978,613	2,077,859	2,177,105	2,276,351	2,375,597	2,474,842	2,574,088	2,673,334	2,772,580	2,871,826	3,070,318	3,268,810	3,467,302	3,665,794	3,864,286	4,360,515	4,856,745
Truck and drawbar trailer**	1,790,638	1,842,242	1,893,846	1,945,450	1,997,054	2,048,658	2,100,262	2,151,866	2,203,470	2,255,074	2,358,282	2,461,490	2,564,698	2,667,906	2,771,115	3,029,135	3,287,155
Transport vehicle split**	1,922,220	2,007,174	2,092,127	2,177,080	2,262,034	2,346,987	2,431,941	2,516,894	2,601,847	2,686,801	2,856,707	3,026,614	3,196,521	3,366,428	3,536,334	3,961,101	4,385,868
TOTAL logistics costs (ID --> DCP) *(handling: telescopic handler and gantry crane)*	8	16	24	32	40	48	56	64	72	80	96	112	128	144	160	201	241 km
Farm tractor and platform trailer**	967,275	1,362,099	1,756,923	2,151,748	2,546,572	2,941,396	3,336,221	3,731,045	4,125,869	4,520,694	5,310,342	6,099,991	6,889,640	7,679,288	8,468,937	10,443,059	12,417,181
Truck and drawbar trailer**	702,104	907,397	1,112,691	1,317,984	1,523,277	1,728,571	1,933,864	2,139,157	2,344,450	2,549,744	2,960,330	3,370,917	3,781,503	4,192,090	4,602,676	5,629,143	6,655,609
Transport vehicle split**	702,104	907,397	1,112,691	1,317,984	1,523,277	1,728,571	1,933,864	2,139,157	2,344,450	2,549,744	2,960,330	3,370,917	3,781,503	4,192,090	4,602,676	5,629,143	6,655,609
UNIT logistics costs (Pile --> ID) *(handling: front-loader and telescopic handler)*	2	4	6	8	10	12	14	16	18	20	24	28	32	36	40	49	59 km
Farm tractor and platform trailer**	11.07	11.63	12.19	12.74	13.30	13.85	14.41	14.96	15.52	16.07	17.18	18.30	19.41	20.52	21.63	24.41	27.18
Truck and drawbar trailer**	10.02	10.31	10.60	10.89	11.18	11.47	11.76	12.04	12.33	12.62	13.20	13.78	14.35	14.93	15.51	16.95	18.40
Transport vehicle split**	10.76	11.23	11.71	12.19	12.66	13.14	13.61	14.09	14.56	15.04	15.99	16.94	17.89	18.84	19.79	22.17	24.55
UNIT logistics costs (ID --> DCP) *(handling: telescopic handler and gantry crane)*	8	16	24	32	40	48	56	64	72	80	96	112	128	144	160	201	241 km
Farm tractor and platform trailer**	5.52	7.78	10.03	12.29	14.54	16.80	19.05	21.31	23.56	25.82	30.33	34.84	39.35	43.86	48.37	59.64	70.92
Truck and drawbar trailer**	4.01	5.18	6.35	7.53	8.70	9.87	11.04	12.22	13.39	14.56	16.91	19.25	21.60	23.94	26.29	32.15	38.01
Transport vehicle split**	4.01	5.18	6.35	7.53	8.70	9.87	11.04	12.22	13.39	14.56	16.91	19.25	21.60	23.94	26.29	32.15	38.01
UNIT logistics costs (Pile --> DCP) *(handling: telescopic handler and gantry crane)*	10	20	30	40	50	60	70	80	90	100	120	140	160	180	200	250	300 km
Farm tractor and platform trailer**	16.60	19.41	22.22	25.03	27.84	30.65	33.46	36.27	39.08	41.89	47.51	53.14	58.76	64.38	70.00	84.05	98.10
Truck and drawbar trailer**	14.03	15.49	16.96	18.42	19.88	21.34	22.80	24.26	25.72	27.18	30.11	33.03	35.95	38.88	41.80	49.10	56.41
Transport vehicle split**	14.77	16.42	18.06	19.71	21.36	23.01	24.66	26.30	27.95	29.60	32.90	36.19	39.49	42.78	46.08	54.32	62.56

8.5 Index for Major Cost Drivers

Table 40: Index for major cost drivers

Index for		Labour costs				Fuel costs		Vehicle investment costs	
Country Code		Gross hourly wage (EUR/h)	Social security contribution ratio (% of gross hourly wage)	Total hourly wage (EUR/h)	**Labor costs index**	Diesel fuel gross price (EUR/l)	**Fuel cost index**	Index by sales expert (100 = Mean in Europe)	**Investment cost index**
BE	Belgium	39.3	47%	57.8	1.44	1.42	1.00	103	1.00
SE	Sweden	39.1	52%	59.4	1.49	1.67	1.19	108	1.05
DK	Denmark	38.9	15%	44.7	1.12	1.48	1.05	106	1.03
FR	France	34.2	50%	51.3	1.28	1.37	0.97	97	0.94
LU	Luxembourg	33.7	15%	38.8	0.97	1.26	0.89	103	1.00
NL	Netherlands	31.1	30%	40.4	1.01	1.47	1.04	106	1.03
DE	Germany	30.1	28%	38.5	0.96	1.50	1.07	99	0.96
FI	Finland	29.7	28%	38.0	0.95	1.55	1.10	108	1.05
AT	Austria	29.2	37%	40.0	1.00	1.41	1.00	103	1.00
IE	Irland	27.4	18%	32.3	0.81	1.58	1.12	105	1.02
IT	Italy	26.7	41%	37.6	0.94	1.71	1.21	107	1.04
ES	Spain	20.6	37%	28.2	0.71	1.36	0.96	89	0.86
UK	Great Britain	20.1	16%	23.3	0.58	1.73	1.23	100	0.97
CY	Cyprus	16.5	21%	20.0	0.50	1.34	0.95	86	0.83
GR	Greece	16.4	29%	21.2	0.53	1.44	1.02	89	0.86
SI	Slovenia	14.4	17%	16.8	0.42	1.40	0.99	105	1.02
PT	Portugal	12.1	26%	15.2	0.38	1.45	1.03	105	1.02
MT	Malta	11.9	10%	13.1	0.33	1.40	0.99	89	0.86
CZ	Czech Rep.	10.5	37%	14.4	0.36	1.43	1.01	109	1.06
SK	Slovakia	8.4	36%	11.4	0.29	1.44	1.02	109	1.06
EE	Estonia	8.1	37%	11.1	0.28	1.40	0.99	91	0.88
HU	Hungary	7.6	34%	10.2	0.25	1.52	1.08	109	1.06
PL	Poland	7.1	20%	8.5	0.21	1.36	0.96	91	0.88
LV	Latvia	5.9	27%	7.5	0.19	1.38	0.98	91	0.88
LT	Lithuania	5.5	40%	7.7	0.19	1.32	0.94	91	0.88
RO	Romania	4.5	31%	5.9	0.15	1.33	0.94	109	1.06
BG	Bulgaria	3.5	19%	4.2	0.10	1.31	0.93	109	1.06
CH	Switzerland	41.9	20%	50.3	1.26	1.62	1.15	109	1.06