

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Improving physical flows in biomass-to-energy
supply chains by means of pre-treatment
technology and coordination

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Abstract

The transition from fossil fuel to renewable energy sources such as biomass-to-energy (B2E) is an environmentally sustainable pathway. However, increased use of biomass is hampered by the high costs of logistics activities within the physical flow. There are several approaches for improving the physical flow, and in this thesis pre-treatment technology and coordination of activities have been explored. The purpose of this thesis is: to investigate how pre-treatment technology and coordination can improve the physical flow in B2E supply chains. This thesis consists of a kappa and five appended papers, based on two interview studies; a conceptual study; a techno-economical study and one multiple case study.

This thesis is built on three cornerstones; supply chain attributes, pre-treatment technology and coordination, all centred on the physical flow as the unit of analysis. In order to improve the physical flow, the unique attributes of the B2E supply chain in which the flow is embedded need to be understood. Identification of these attributes has been an ongoing activity throughout the entire research process, using literature reviews and interviews as data collection methods. Biomass is a unique type of good for which it is concluded that there are nine distinct attributes in terms of (1) perishability, (2) shape of goods, (3) geographical spread, (4) weather and climate, (5) customer diversity, (6) fluctuations in demand, (7) time gaps between supply and demand, (8) system openness and (9) interorganisational relationships. These determine the configuration of supply chains and the physical flow therein. Also, these attributes serve as a platform for understanding how to make use of pre-treatment technology and coordination of activities to improve the physical flow.

This thesis concludes that pre-treatment technology, in this thesis represented by torrefaction, has great potential to improve the physical flow within B2E supply chains, primarily by altering supply chain attributes. In particular, torrefaction alters the shape of goods, which then allows transport across longer distances. However, attributes also shape the ways in which torrefaction is made use of; e.g., variances in geographical spread shape the optimal size of a torrefaction plant. Also, the production strategies of torrefaction plants need to accommodate different end users and their respective distribution system.

It is also concluded that in comparison to pre-treatment technology that alters a number of attributes, coordination of activities can primarily reduce the relative importance of B2E supply chain attributes, especially that of the shape of goods, which renders an improved physical flow in terms of higher transport efficiency. Similarly, the relative importance of fluctuations in demand and perishability can be reduced by moving storage downstream to power plants, or by power plants themselves investing in supplementary businesses, e.g. producing pellets. Also, the attributes shape the use of means of coordination; e.g., B2E supply chains are characterised by system openness, and therefore, network connections to other energy producers can be a barrier towards as well as an enabler for various means of coordination.

Keywords: *physical flow, supply chain, logistics, biomass-to-energy, pre-treatment technology, torrefaction and coordination*

List of appended papers

This thesis is based on five appended papers:

Paper 1: Svanberg (2016), ‘Factors shaping biomass-to-energy supply chain configuration – The case of forest fuel’, An earlier version of this was published in Proceedings of the LRN Conference, 2011 University of Southampton, UK. Submitted to a journal within the field of biomass and bioenergy in January 2016.

Paper 2: Svanberg and Halldórsson (2013), ‘Supply chain configuration for biomass-to-energy: the case of torrefaction’, International Journal of Energy Sector Management, Vol. 7 Iss: 1, pp.65-83

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Paper 3: Svanberg et al. (2013), ‘Analysing biomass torrefaction supply chain costs’, Bioresource Technology, Vol. 142, pp.287–296

Paper 4: Svanberg (2016), ‘Coordination of activities in the physical flow of forest biomass’. An earlier version of this was published in Proceedings of the LRN Conference, 2014, University of Huddersfield, UK. Submitted to a journal within the field of logistics in January 2016.

Paper 5: Svanberg (2016), ‘Biomass-to-energy transport efficiency: Hauliers’ perspectives on improvement efforts’. An earlier version of this was published in Proceedings of the LRN Conference, 2015, University of Derby, UK. Submitted to a journal within the field of logistics in January 2016.

Contribution in each paper:

Paper 1. I am the sole author of the paper.

Paper 2. I am the main author of this paper. I developed the idea behind the paper, did the literature review and had the major responsibility in writing of the paper.

Paper 3. I am the main author of this paper. Model development, system design and analysis was done jointly by Ingemar Olofsson and me. Jonas Floden had the major responsibility for calculations on the distribution system. Anders Nordin had a very small part in the writing of the paper. I had the major responsibility for writing the paper, except for technical aspects.

Paper 4. I am the sole author of the paper.

Paper 5. I am the sole author of the paper.

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Martin Svanberg, January, 2016.

Table of contents

1. Introduction	1
1.1 Background	1
1.2 Challenges in the physical flow of biomass-to-energy (B2E)	2
1.3 The importance of energy as a commodity and the transition to renewable fuels	4
1.4 Improving physical flows: The need to understand supply chain attributes	6
1.4.1 Improving physical flows with pre-treatment technology	7
1.4.2 Improving physical flows with coordination	8
1.5 Purpose and research questions	9
1.5.1 B2E supply chain attributes	10
1.5.2 Pre-treatment technology	11
1.5.3 Coordination	13
1.6 Summary of the research depicted in links and nodes	14
2 Research design	17
2.1 The research process	17
2.2 Method	20
2.2.1 Supply chain attributes (RQ1)	21
2.2.2 Pre-treatment technology (RQ2)	23
2.2.3 Coordination (RQ3)	24
2.3 Empirical context	25
2.4 Collection of evidence	27
2.4.1 Literature review	27
2.4.2 Interviews	29
2.4.3 Observations	29
2.4.4 Documents	30
2.5 Evidence and analysis procedure	30
2.5.1 Analysis of B2E supply chain attributes (RQ1)	31
2.5.2 Analysis of pre-treatment technology (RQ2)	32
2.5.3 Analysis of coordination (RQ3)	33
2.6 Validity and reliability	35
2.6.1 Construct validity	35
2.6.2 Internal validity	37
2.6.3 External validity	38
2.6.4 Reliability	39
2.7 Methodological standpoint	40
2.7.1 Unit of analysis	40
2.7.2 A systems approach	41
2.7.3 The B2E supply chain as a system	43
2.7.4 Implications of a systems approach for this thesis	45
2.7.5 Epistemology and ontology	46
3 Frame of Reference	47

3.1	Physical distribution and transportation	47
3.2	Supply chain design.....	49
3.3	Technology	53
3.3.1	Technology in a logistics context	53
3.3.2	Torrefaction: A pre-treatment technology	54
3.3.3	Torrefaction in a logistics context.....	54
3.4	Coordination.....	55
3.5	B2E: The context of the focal product	57
3.5.1	Feedstock.....	58
3.5.2	Harvesting and forwarding	59
3.5.3	Storage.....	60
3.5.4	Comminution	60
3.5.5	Road transportation	61
3.5.6	Transport network configuration	61
3.5.7	Refinement of biomass by pelletising and/or torrefaction	63
3.5.8	Distribution of refined products	64
3.5.9	Energy production	65
4	<i>Summary of appended papers</i>	<i>67</i>
4.1	Paper 1 – ‘Factors shaping biomass-to-energy supply chain configuration – The case of forest fuel’	67
4.2	Paper 2 – ‘Supply chain configuration for biomass-to-energy: The case of torrefaction’	70
4.3	Paper 3 – ‘Analysing biomass torrefaction supply chain costs’	72
4.4	Paper 4 – ‘Coordination of activities in the physical flow of forest biomass’	75
4.5	Paper 5 – ‘Biomass-to-energy transport efficiency: hauliers’ perspectives on potential improvement efforts’	76
5	<i>Analysis.....</i>	<i>79</i>
5.1	B2E supply chain attributes	79
5.2	Pre-treatment technology and B2E supply chain attributes	84
5.3	Coordination and B2E supply chain attributes.....	89
6	<i>Discussion</i>	<i>95</i>
6.1	Proposition 1: Actors in energy supply chains should be reconceptualised as energy service providers.....	97
6.1.1	Justification and significance for actors.....	97
6.1.2	Relation to the literature	98
6.2	Proposition 2: Actors must acknowledge three structural elements of transport networks that facilitate efficient and effective supply chain configuration	99
6.2.1	Justification and significance for actors.....	100
6.2.2	Relation to the literature	102
6.3	Proposition 3: Operators of torrefaction plants must consider location, scale, and production strategy as key aspects of economic viability	103
6.3.1	Justification and significance for actors.....	104

6.3.2	Relation to the literature.....	105
6.4	Proposition 4: Actors in the supply chain can benefit from moving storage downstream	106
6.4.1	Justification and significance for actors	106
6.4.2	Relation to the literature	107
6.5	Proposition 5: Actors in the supply chain can benefit from long-term relationships.....	108
6.5.1	Justification and significance for actors	108
6.5.2	Relation to the literature	109
7	<i>Conclusions, Contributions, Directions for Future Research, and Reflections.....</i>	<i>111</i>
7.1	Conclusions.....	111
7.1.1	B2E supply chain attributes.....	111
7.1.2	Pre-treatment technology.....	112
7.1.3	Coordination	113
7.2	Contributions.....	114
7.3	Directions for future research.....	116
7.4	Reflections.....	117
8	<i>References</i>	<i>121</i>

List of figures

<i>Figure 1: The transition from fossil-based to renewable energy</i>	5
<i>Figure 2: Pre-treatment and coordination in the physical flow of B2E supply chains</i>	10
<i>Figure 3: Attributes determining the configuration of physical flow in B2E supply chains</i>	11
<i>Figure 4: Pre-treatment technology to improve the physical flow</i>	12
<i>Figure 5: Coordination to improve the physical flow</i>	14
<i>Figure 6: The three cornerstones of this thesis, depicted in links and nodes</i>	14
<i>Figure 7: An overview of the research process</i>	19
<i>Figure 8: Areas of large unutilised potential of biomass and areas of large consumption, left-hand side, and a possible supply chain (not according to scale), right-hand side</i>	26
<i>Figure 9: Analysis according to the research model</i>	32
<i>Figure 10: The unit of analysis in this thesis</i>	40
<i>Figure 11: An interpretation of Churchman’s view of systems in a supply chain context</i>	42
<i>Figure 12: Physical flow, actors, activities, logistics resources and infrastructure of a B2E supply chain</i>	44
<i>Figure 13: A model of a transportation network, adapted from Lumsden (2006)</i>	47
<i>Figure 14: The function of terminals, adapted from Hultén (1997)</i>	55
<i>Figure 15: Stages in the physical flow in B2E supply chains</i>	58
<i>Figure 16: Alternative supply chain routes</i>	61
<i>Figure 17: A framework for torrefaction configuration</i>	71
<i>Figure 18: Cost for the torrefaction supply chain</i>	73
<i>Figure 19: Costs for different activities</i>	73
<i>Figure 20: Optimal size of torrefaction plant for amount of available biomass and type of truck</i>	74
<i>Figure 21: A layered approach for transport efficiency</i>	77
<i>Figure 22: The overall research model as an analytical model</i>	79
<i>Figure 23: B2E supply chain attributes</i>	83
<i>Figure 24: The first-mile network</i>	100
<i>Figure 25: Node function, adapted from Hultén (1997)</i>	101
<i>Figure 26: Interaction of flows of B2E and other products</i>	102

List of tables

<i>Table 1:</i> Characteristics of the research fields	27
<i>Table 2:</i> Data collection in the appended papers	30
<i>Table 3:</i> A summary of the research in each paper	34
<i>Table 4:</i> Tactics to ensure validity, adapted from Yin (2009) and tactics deployed in this thesis	35
<i>Table 5:</i> Perspectives and units of analysis.....	39
<i>Table 6:</i> Performance measurement in the papers	46
<i>Table 7:</i> A comparison of six papers addressing supply chain design.....	51
<i>Table 8:</i> A summary of literature derived factors shaping supply chain configuration	68
<i>Table 9:</i> A summary of interview derived factors shaping supply chain configuration	69
<i>Table 10:</i> Different means of coordination.....	75
<i>Table 11:</i> How different improvement efforts shape outputs and inputs of transport.....	78
<i>Table 12:</i> The interplay between B2E supply chain attributes and torrefaction	85
<i>Table 13:</i> The interplay between B2E supply chain attributes and coordination.....	90
<i>Table 14:</i> The interplay between attributes in B2E supply chains and torrefaction and coordination.....	94
<i>Table 15:</i> Five propositions for improved physical flow in B2E supply chains.....	96

Terminology

By-products, secondary forest fuel	A product that is “waste” from the forestry industry, e.g., sawdust or bark
Combo truck	A truck with an integrated chipper (a grinding machine)
Comminution	Crushing or grinding of biomass into small pieces, which are often labelled as forest chips
Coordination	Aligning different parts of systems with each other
Densification	The process of turning biomass with high volume into a compact uniform low volume good. Different types of this process includes pelletizing or briquetting
Distribution system	A part of the supply chain, in this thesis seen as the downstream part of the supply chain from the view of the torrefaction plant
Forest residues	The branches and tops of a tree, sometimes labelled as forest waste or forest slash
Forwarding	Within this thesis and the bioenergy literature, a term for in-forest transportation of biomass
Means of coordination	An arrangement of an activity to suit activities of other actors in the supply chain
Pre-treatment process	A term describing a number of different processes for biomass refinement such as torrefaction, pyrolysis and steam explosion. In the biomass-to-energy literature and this thesis, the phrasing pre-treatment process is in general synonymous to all the activities of biomass transformation within the plant where the refinement takes place.
Pre-treatment technology	Describes the process from a technological perspective, to make it comparable with e.g. Information technology
Primary forest fuel	Biomass sourced directly from the forest
Refinement	A term for describing the transformation of low valued biomass to higher valued biomass.
Roundwood	The part of the tree that is the stem, i.e. not the branches, tops or the stump

Supply chain configuration	Refers to how components such as nodes and links are arranged into networks.
Supply system	A part of the supply chain, in this thesis seen as the upstream part of the supply chain from the view of the torrefaction plant
Torrefaction	A thermochemical process for refinement of biomass.
Torrefaction configuration	Refers to decisions regarding the organisation of production as well as upstream and downstream activities seen from the perspective of the torrefaction company
Torrefaction plant	A plant that contains a torrefaction process and almost always, a subsequent densification process.
Torrefaction supply chain	A biomass-to-energy supply chain containing a torrefaction plant

Abbreviations

B2E	Biomass-to-energy
CHP	Combined heat and power
DH	District heating
SCM	Supply chain management
TDB	Torrefied densified biomass, sometimes labelled torrefied pellets within the literature

1. Introduction

This chapter introduces the topic of the thesis, by first presenting the background, followed by the problem area and context studied, all toward presenting the purpose and research questions of the thesis.

1.1 Background

In the forms of heat, electricity, and vehicle fuel, energy is undeniably essential for households and industries. At present, the primary sources of energy worldwide are crude oil, coal, and gas, all of which cause and exacerbate global warming when used (Shafiee and Topal, 2009). By contrast, a sustainable alternative in the portfolio of renewable energy is biomass-to-energy (B2E)—that is, biomass sourced from e.g. forests, for which there is a large untapped potential, used to produce heat and electricity in e.g. combined heat and power (CHP) plants. As such, replacing fossil fuels with forest biomass can benefit the world's climate (Gustavsson et al., 2015). However, since the supply of biomass (i.e., from forests), demand (e.g., in households), and power plants are all located in different places and managed by different actors, a supply chain is necessary to move the energy in its various forms and thereby fulfil customer demands. According to the Council of Supply Chain Management Professionals (2010), a supply chain begins with unprocessed raw materials and ends with customers' use of the finished product, thereby linking many companies and actors together. In a supply chain for any type of good, providing that good—for example, biomass—in the right quantity, in the right condition, at the right time, to the right place, to the right customer and at the right cost is a logistics challenge (cf. Lumsden (2006). Hence, in order to make B2E competitive compared to fossil fuel, managing supply chains represent a key overall challenge.

For B2E supply chains, high logistics costs within the physical flow, particularly in terms of handling and transport, remain among the top barriers to the good's increased use and persist in making fossil fuels more competitive power-generating options due to their lower costs (Akhtari et al., 2014). Therefore, generally, as Flisberg et al. (2015) have stated, 'efficient logistics is crucial to make forest fuel a competitive source of bioenergy' (p. 365). More specifically, Lautala et al. (2015) have argued that 'effective supply chains are of utmost importance for bioenergy production, as biomass tends to possess challenging seasonal production cycles and low mass, energy and bulk densities' (p. 1397). Clearly, the physical flow in the supply chain is an important managerial challenge in making B2E competitive compared to fossil fuel in terms of costs.

The largest share of costs for producing energy stems from logistics operations in terms of physical handling (movement, processing, transshipment and storage) with the physical flow of biomass (Rentizelas et al., 2009). In Sweden, for example, the cost of delivering biomass to the gates of power plants fluctuated between 186 and 209 SEK/MWh during a 5-year period from 2011–2015 (Parikka, 2015). If this portion of the cost is subdivided into its different parts, then the cost paid to forest owners is roughly 25%, whereas the remainder consists of logistics costs of within the physical flow, in particular due to transportation

and handling (cf. Athanassiadis (2009); Brunberg (2010)). Owing to the large cost of logistics activities, logistics management of the physical flow represents a key overall challenge to the economic viability of B2E. By definition, *logistics management* is the 'part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements' (CSCMP, 2010). Thus, logistics management, of the physical flow in particular, to reduce logistics cost, is of significant importance for the economic viability of B2E.

1.2 Challenges in the physical flow of biomass-to-energy (B2E)

Energy can be defined as a source of power produced through networks of companies using different technologies to transform a variety of energy carriers (e.g., solid, gaseous, liquid, and kinetic energy) into consumable entities such as electricity, heat, and vehicle fuel for use in transportation, industry, and households (Halldórsson and Svanberg, 2013). So far, it has been argued that managing the supply chain and the physical flow in particular are the overall key logistics challenges for B2E. Below, three distinct challenges for logistics management within the physical flow of B2E-supply chains are identified: challenges with moving biomass across space, storing it across time, and processing it through the existing energy infrastructure. Addressing these challenges is essential to making existing B2E supply chains competitive with those providing fossil fuels in terms of cost. Put differently, these challenges pose barriers that must be overcome in order to access the untapped potential of biomass.

1. Moving energy carriers across space

Due to poor transportation properties such as high bulk volume, low energy density, and high moisture content, biomass has often been conceived as a fuel for local or regional use only. Indeed, transporting biomass is costly at several levels due to characteristics of the supply chain. At the regional level, biomass is often scattered in small volumes across large areas controlled by multiple actors (Kanzian, 2009, Möller, 2003), which thereby limits the possibility of gaining economies of scale within modes of transport. On a national level, towns are not always located near forests, which thus requires costly long-distance transportation (Möller, 2003). Likewise, on an international level, regions rich in biomass are not necessarily located near densely populated cities with the greatest demands for energy (Searcy et al., 2014). Also, in B2E supply chains, transport costs are significant, since costly transportation positions B2E among the expensive energy sources in the market (Shabani et al. (2014). Wolfsmayr and Rauch (2014) have added that 'due to spatial distribution, low mass density, low energy density and low bulk density, the transportation of primary forest fuel is crucial for economic efficiency as well as for reduced CO₂ emissions' (p. 203). In sum, managing transports in ways that reduce transport costs at different levels is of vital importance for the competitiveness of B2E among sources of energy.

In Sweden, road transport accounts for 20–30% of the cost of receiving forest biomass at the gates of power plants, depending on the distance to customers (cf.

Athanassiadis (2009); Brunberg (2010). At the same time, in transatlantic supply chains, the distribution cost (i.e., cost related to movement and handling) for biomass pellets accounts for about 62% of the total cost (Sikkema et al., 2010). In general, when biomass use increases, transportation distances increase as well, and the longer transportation distances that result generate even higher transportation costs. In effect, as Tumuluru et al. (2011) have argued, the ‘transportation and handling of low-density, cohesive, and degradable biomass materials are substantial barriers to a long-distance biomass feedstock supply system’ (p. 108). Therefore, though necessary, moving biomass generates excessive transport costs due to its poor product properties and characteristics of the supply chains. Plus, these challengingly high costs become even greater as transport distances increase with the increased use of biomass. In short, biomass needs to be moved across space, but high transport costs pose a key challenge in making B2E competitive with other sources of fuel, particularly fossil fuels, in terms of cost.

2. Storing energy carriers across time

Despite having no intrinsic value, the storage of biomass is necessary to bridge the gap between supply, on the one hand, and on the other, demand that fluctuates due to e.g. due to seasonal changes in weather (cf. Wolfsmayr and Rauch (2014). In that sense, biomass needs to be stored—in other words, held across time—in order to be accessible when there is a demand for energy. The biological properties of biomass, however, typically force high storage costs; for example, substance losses of comminuted biomass—that is, biomass chipped into small pieces by machinery—can range from 6.6–16.6 wt% during 6 months of storage (Wihersaari, 2005). This trait of biomass thus poses a time constraint for efficient storage, which must be managed shrewdly in order to prevent loss of substance and thus financial loss. For conventional pellets, covered storage is additionally required in order to overcome remoistening problems, which further drive up the cost of storage. In all, in the physical flow of B2E supply chains, though storage is necessary to hold biomass across time, the properties of biomass raise its costs, thereby making storage a key challenge for B2E’s competitiveness among other sources of energy.

3. Processing energy carriers through existing energy infrastructure

Existing energy infrastructure, including power plants and ports, remains largely adapted to fossil fuels. Large investments have been made in coal-fired power plants, in which conventional wood pellets can be co-fired only to a limited extent—that is, combusted simultaneously with coal—owing to the properties of biomass (Bergman, 2005). At the same time, logistics infrastructure—for example, in terms of ports—is not always compatible with unrefined biomass, which places additional requirements on investments and improvements in biomass product quality to make infrastructure usable (Searcy et al., 2014). Similarly, as a means to achieve efficient logistics, power plants might need to invest in customised pellet unloading stations ((Junginger et al., 2008). Therefore, for B2E products, existing energy infrastructure needs to be adapted, if not replaced, either of which poses a cost. In effect, since new infrastructure must be competitive in terms of cost, actors involved in B2E supply chains face a logistical challenge in processing energy carriers through existing energy infrastructure.

Altogether, to access the untapped potential of renewable energy in biomass, it is necessary to move biomass across space and among different places, hold it across time using storage so that it is available when in demand, and process it through existing energy infrastructure. Counter to these needs, however, is the high logistics cost of activities in the physical flow, particularly in terms of transportation and storage. Since the movement of goods across space, their storage across time, and the design of physical networks are central concepts in logistics (cf. Hesse and Rodrigue (2004)), these three challenges should accordingly be addressed from a logistics perspective. In particular, applying logistics principles to improving the physical flow is necessary to address these challenges and, in turn, reduce the cost of activities in the physical flow.

1.3 The importance of energy as a commodity and the transition to renewable fuels

As a commodity, energy is vital in today's modern societies, as Cottrell (1955) argued early on, stating that 'energy available to man limits what he can do and influences what he will do' (p. 2). From an economics standpoint, there is also often and above all a causal relationship between energy use and gross national product (e.g., Altinay and Karagol (2005); Brown et al. (2011); Shiu and Lam (2004). Hence, energy has been and will continue to be one of the most important resources for the modern society.

In that light, a transition from conventional non-renewable fossil fuels to renewable energy sources is desirable for at least three reasons: reserves of fossil fuel are limited, fossil fuel use is associated with negative impacts upon the environment, and energy security is necessary. More specifically, the first reason is that conventional fossil-based energy resources such as oil and coal are admittedly limited and non-replenishable, though estimating their remaining potential is difficult, due in part to a lack of transparency within the oil industry (Kjärstad and Johnsson, 2009). Nevertheless, estimations do exist; for instance, Shafiee and Topal (2009) have quantified in their model that the world's reserves of oil, gas, and coal will be depleted by 2040, 2042, and 2112, respectively. Regarding the second reason, fossil-based energy is not only unsustainable, but also exacerbates global warming, and using a combination of renewable energy technologies in response has been proposed as a workable solution (Pacala and Socolow, 2004, Hoffert et al., 2002). Third and lastly, as Kjärstad and Johnsson (2007) have argued, with continued use of non-replenishable fossil fuels, the world's national economies and societies in general will become increasingly dependent upon Russia and a few countries in the Middle East for energy products. Accordingly, future energy policies should promote indigenous renewable fuel as a means to both facilitate a more sustainable energy system and ensure energy security. Otherwise, parts of the world such as Europe that depend heavily upon energy imports will become even more vulnerable to crises such as piracy, terrorism, political conflict, and even war—all in the name of energy (Urciuoli et al., 2014). Therefore, though the forces driving a general transition to renewable energy chiefly relate to societal challenges, individual and often private companies are ultimately the actors responsible for sourcing, producing, and distributing energy to end users.

Unsurprisingly, however, current efforts to transition to renewable energy continue to face major barriers. For renewable energy technologies in general, these barriers can be grouped as cost-effectiveness barriers, technical barriers, and market-related barriers (Painuly, 2001); Figure 1), though they differ for different sources of renewable energy. McCormick and Kåberger (2007) have noted that barriers to the increased use of biomass are not technical ones, but ‘economic conditions, know-how, institutional capacity and supply chain coordination’ (p. 443). As argued earlier, for B2E specifically, the cost of logistics activities in the physical flow represents a significant overall challenge to its competitiveness with fossil fuel. Given all of the above, the practical relevance of this thesis thus lies in its addressing the underlying challenge of the general transition from fossil fuel energy to renewable energy, as represented by the left-to-right arrow in Figure 1. Though numerous drivers motivate the progress of the transition, barriers currently thwart the transition, as represented by the dotted arrows in Figure 1. Notably, the three aforementioned challenges for physical flow fall within the domain of cost-effectiveness (or efficiency) as a barrier to B2E’s increased use.

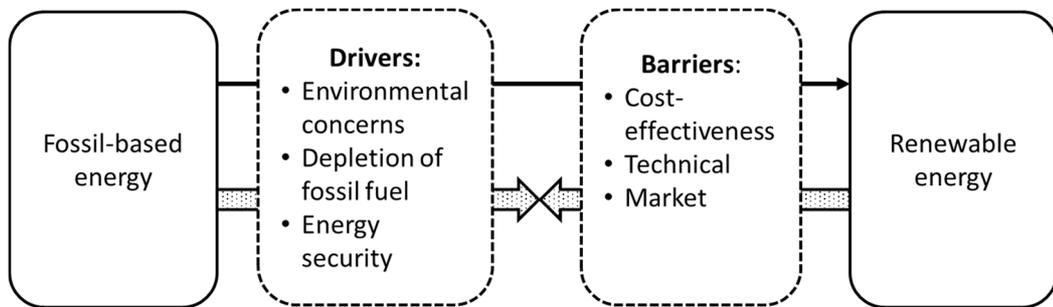


Figure 1: The transition from fossil-based to renewable energy

As argued earlier, one sustainable alternative in the renewable energy portfolio is B2E. Though biomass is often deemed a ‘carbon-neutral renewable resource’ (e.g., Ragauskas et al. (2006), its neutrality is affected by subsequent land use—for instance, new trees need to be planted in order to recapture carbon releases from combustion in power plants. In any case, woody biomass is currently the most important source of renewable energy in the world (Lauri et al., 2014). Yet, similar to fossil fuel potential, biomass potential is hard to estimate, as well as depends upon assumptions such as about competition with the food industry (e.g., de Wit and Faaij (2010) and concerning environmental, technical, and social constraints (Verkerk et al., 2011). One estimate holds that only 40% of the world’s biomass potential is realised, of which woody biomass accounts for roughly 42%, thereby exhibiting its potential to replace 30% of sources of energy currently used (Parikka, 2004). In absolute numbers, Ericsson and Nilsson (2006) have gauged the potential of biomass to be 11.7 EJy^{-1} in the EU15 compared to the overall energy supply in the EU in 2001, which amounted to 62.6 EJy^{-1} . Similarly, more recent studies have concluded that only half of all solid biomass in Europe is currently used (Alakangas et al., 2012). Thus, though difficult to estimate, biomass’s potential is significantly untapped, and biomass from forests poses the greatest share of that potential.

1.4 Improving physical flows: The need to understand supply chain attributes

During the last decade, researchers have sought to respond to the first two aforementioned challenges afflicting B2E supply chains—namely, moving energy across space and storing it across time. Within substantial research on how to lower the costs of B2E supply chains, optimisation and techno-economic models have been developed for making decisions about whether to use terminals, the location and amount of storage needed, and the selection of transport mode and individual vehicles (e.g., Chinese et al., 2009; Flisberg et al. (2012); Gronalt and Rauch (2007); Gunnarsson et al. (2004); Johansson et al. (2006); Kanzian et al., 2009; Ranta et al., 2005; Ranta et al., 2006; Rauch and Gronalt, 2011; Rentizelas et al. (2009)). However, as a discipline, logistics offers several alternative approaches for improving the physical flow, both managerial and technological, that could be further explored in the context of B2E supply chains. Within logistics, many feasible approaches for improvement involve technology, for example, to manage product properties, product packaging, containers for transportation, and information. Also, since logistics acknowledges that efficient flow is a managerial challenge as well, logistics concepts such as integration, collaboration, and coordination can be relevant to improving the physical flow in B2E supply chains.

Since the physical flow of biomass is embedded within its supply chains, to understand how to improve physical flow, the context of the product and the supply chain needs to be identified and understood. Managing the physical flow is a domain within the two overlapping research areas of supply chain design and supply chain strategy, from which the justification of the importance of supply chain attributes describing the context is derived. In fact, Lee (2002) has averred that any supply chain strategy based on a one-size-fits-all approach will fail. Among its different treatments in the literature, supply chain design has been treated as the problem of deciding between physically efficient or market-responsive supply chains according to demand characteristics, which differs for functional and innovative products (Lee, 2002, Fisher, 1997). By contrast, Pagh and Cooper (1998) have conceived supply chain strategy as a matter of deciding between postponement and speculation based on product, market and demand, and manufacturing and logistics. More recently, Christopher et al. (2006) have provided support for choosing among lean, agile, or so-called leagile supply chains based on predictability and replenishment lead times. Altogether, though the scope of supply chain design is broad and diverse, all of the above-cited research has described similar approaches, as a more extensive review of supply chain design shows in Chapter 3.2. Common among this research are approaches that involve capturing both major and minor attributes of supply chains, all of them important factors describing the supply chains, e.g., in terms of product characteristics, demand and performance factors, or factors in the supply chain, which are also used to determine its design. The implication for the physical flow is that attributes determine its configuration—that is, how links, nodes, and resources are combined within the flow. Given this background, to provide a foundation for understanding how to improve the physical flow in B2E supply chains in terms of which approaches to take (e.g., technological or managerial) and how to make use of them, a thorough description of the supply chain is critical,

particularly one that identifies the attributes capturing its essence. In that light, B2E supply chain attributes can bolster understandings of how to make use of technological advancements and managerial concepts for improving the physical flow.

1.4.1 Improving physical flows with pre-treatment technology

Pre-treatment technology is a technical process that improves the product properties of biomass. By implementing pre-treatment technology early in the supply chain, transport and handling efficiency can be increased and, in turn, the physical flow can be made more efficient. Of the various pre-treatment technologies in development (e.g., torrefaction, pyrolysis, steam explosion and hydrothermal carbonization), torrefaction is the focus on this thesis. By definition, *torrefaction* is a thermochemical process using heat at 200–350 °C to accelerate drying and refinement of the biomass. When torrefaction precedes a densification process (e.g., pelletising), it yields torrefied densified biomass (TDB) which has even more appealing product characteristics for handling and transport.

Though torrefaction comes at a cost, from a supply chain perspective torrefied pellets can be a less costly alternative than forest chips and conventional pellets due to their lower distribution cost (Uslu et al., 2008, Mobini et al., 2014, Bergman, 2005). Torrefied pellets can also be preferable from an environmental perspective given their capacity to reduce both fossil fuel consumption and greenhouse gas emissions (Adams et al., 2015). Several authors have proposed torrefaction as a feasible pathway for increasing biomass use (Richard, 2010, Sikkema et al., 2010, Mobini et al., 2014, Uslu et al., 2008). Among the reasons why, diverse types of low-valued biomass assortments (e.g., pine, birch, oak, eucalyptus, and bamboo) can be used for torrefaction (van der Stelt et al., 2011). Compared to the low-valued material fed into the process, the product—that is, TDB—exhibits excellent properties, that can address be used to address the three aforementioned challenges towards increased use of B2E. First, next to different types of primary forest fuel, TDB has an energy density up to seven times greater. In theory, such density means that TDB has up to seven times greater transport efficiency compared to, for instance, forest residues and up to twice greater efficiency compared to conventional pellets. In effect, torrefaction is a clear option for addressing the first challenge of moving energy across space, sometimes for great distances.

Second, owing to its greater energy density, less storage area is necessary to store TDB than conventional pellets and untreated biomass. Furthermore, TDB is a far less perishable commodity than primary biomass due to its improved hydrophobic properties and greatly reduced biological activity (Bergman, 2005). Consequently, next to other types of biomass, TDB has excellent storage properties and can more suitably address the second challenge of holding energy across time.

Third, since different types of low, sometimes unknown, heterogeneous quality biomass can be torrefied into biomass with higher homogenous product quality, torrefaction improves product quality. The product can thus potentially be used by customers with a high demand for quality material in energy production in

different types of small-scale household boilers and other energy production units. Furthermore, as a commodity with properties resembling coal in many aspects and superior fuel properties to untreated biomass (Phanphanich and Mani, 2011), TDB can be efficiently used in coal-fired power plants (Li et al., 2012). In that sense, torrefaction can partly overcome the third challenge of processing biomass through existing energy infrastructure. In all, torrefaction is an emerging technology whose product (TDB) can help to overcome the three challenges limiting use of energy carriers such as biomass—to reiterate, their movement across space, their storage across time, and their refinement through existing energy infrastructure. Briefly put, torrefaction is a viable technological approach for improving physical flow in B2E supply chains.

1.4.2 Improving physical flows with coordination

Though the previous section has argued that physical flow can be improved by implementing pre-treatment technology in order to enhance product properties, improving physical flow can also be approached as a managerial challenge. To explain, in what follows the perspective is first shifted from physical flow in B2E contexts to supply chains in general, as well as from cost to performance. After all, cost and service level are generally two central measurements of performance (Beamon, 1999).

In a supply chain, performance is influenced not only by the characteristics of the products involved, but also by the interdependence among activities managed by actors along the supply chain. Thus, improving supply chains is not only a technical challenge, for their performance depends upon how different actors align their activities, hence also a managerial one. In this context, *coordination* is a commonly used term to describe this dynamic. Arshinder et al. (2008) have argued that performance in supply chains depends upon how well actors coordinate their activities. Simatupang et al. (2002) have posited that ‘changes that occur in a chain are likely to affect the performance of the others, and coordination is therefore a means for managing interdependent activities in order to mitigate demand variability and unnecessary inventory’ (pp. 289-290). Hence, the performance of a supply chain is shaped by how actors along the supply chain coordinate their various activities with each other.

Each actor in a supply chain tends to have diverse objectives and coordination among activities does not spontaneously occur. In general, the reason for coordination problems in supply chains is either bounded rationality or opportunism, if not both (Van Der Horst and De Langen, 2008). More specifically, coordination problems can also occur due to (1) unequal distribution of costs and benefits of coordination, (2) lack of resources or of will to invest, (3) strategic considerations, (4) lack of a dominant firm, and (5) risk-adverse behaviour and short-term focus (Van Der Horst and De Langen, 2008). Among its results, lack of coordination can induce the generally poor performance of supply chains, as well as increased costs and diminished service level, as Flygansvær et al. (2008) have pointed out. On the flipside, Fugate et al. (2006) have argued that the benefits of coordination include reduced risk and inefficiency, minimised costs, and maximised profit. Plus, to overcome the bullwhip effect in supply chains, coordination via information sharing, channel alignment, and operational

efficiency can be useful mechanisms (Lee et al., 1997). In short, for coordination and the lack thereof, there are both different causes and different consequences.

As the above elucidates, for supply chains in general, the coordination of activities can improve the performance of the physical flow. By narrowing the scope to the physical flow in B2E supply chains and from performance to cost, the suggestion is that the physical flow can be improved through coordination of activities. Also, three arguments, specific for the physical flow in a B2E context justifies supports this suggestion. These consist of (1) the attributes of B2E-supply chains, (2) researchers highlighting the importance of coordination and (3) a quantified potential of coordination of activities. First, the attributes of the B2E supply chain can cause coordination problems, for as with supply chains in general, multiple actors within the supply chain—each with diverse objectives—can inadvertently foster a lack of coordination and thereby promote poor performance. Furthermore, and as argued earlier, storing energy across time is a challenge, since B2E supply chains suffer from uncertainty due to fluctuating supply and demand. However, logistics literature has acknowledged coordination as a concept for addressing the uncertainty of demand (e.g., Weng and McClurg (2003) and of both supply and demand (e.g., He and Zhao (2012)). Thus, the attributes of B2E supply chains imply that the coordination of activities can suitably improve the physical flow.

Second, among literature addressing B2E logistics and highlighting the importance of coordination therein, Lautala et al. (2015) have stated that ‘Careful planning and coordination is required to optimize the movement of a low-density, low-cost, widely dispersed feedstock to one or more processing units’ (p. 1398). Similarly, Iakovou et al. (2010) have argued that the complexity of waste B2E supply chains recommends what the authors call ‘coordination methodologies (p. 1861). These have thus clearly emphasised why coordination matters for various reasons.

Third, though coordination in general remains unexplored in B2E contexts, a few papers have illustrated the potential of the coordination of activities. Rauch et al. (2010) have posited that since suppliers maintain forest areas that overlap and guard their supply sources, transport distances are far from optimal. Yet, if energy producers could cooperate to jointly select suppliers according to distance, then transportation distances could be lowered by 26% and transportation costs by 23%. Similarly, in Sweden, collaboration in supply chains can pose saving of up to 6% (Flisberg et al., 2015). In sum, attributes of B2E supply chains, in combination with proven potential, justify that coordination of activities can improve the physical flow, though more detailed knowledge on the subject remains scarce.

1.5 Purpose and research questions

This thesis has thus far suggested three logistics challenges: moving energy carriers across space, storing them across time, and processing them through existing energy infrastructure. By extension, to sustain the competitiveness of existing B2E supply chains and advance the general transition from fossil to renewable energy (e.g., B2E) toward reducing the negative effects on the environment associated with fossil energy use, two particular approaches have

been justified. First, introducing pre-treatment technology, which enhances logistics properties of biomass as a commodity, can improve the physical flow in B2E supply chains. Second, as an alternative, the physical flow can be improved through the coordination of activities among different actors along the supply chain. Given this background, the purpose of the thesis is thus:

to investigate how pre-treatment technology and coordination can improve the physical flow in B2E supply chains.

Figure 2 illustrates pre-treatment and the coordination of activities in the context of the physical flow of a B2E supply chain. In short, pre-treatment concerns introducing technology that can manage product quality toward improving the physical flow, largely via increased transport and handling efficiency. By contrast, coordination considers improving physical flows by efficiently organising and aligning various activities between actors.

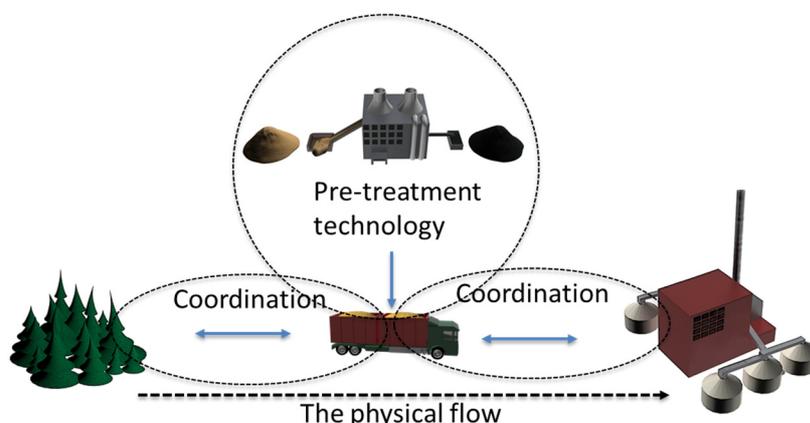


Figure 2: Pre-treatment and coordination in the physical flow of B2E supply chains

1.5.1 B2E supply chain attributes

Put simply, the justification for focusing on providing a description of the physical flow in B2E supply chains is the need for deeper understanding, for biomass and its supply chains differ, respectively, from many other types of goods and their supply chains. For one, biomass is a biological product with low value that is handled outside. At the same time, the demand of B2E shifts with seasonal fluctuations in weather. As a result, when it comes to determining how to manage its physical flow, biomass cannot be treated as, for instance, standard palletised goods handled in conventional terminals. This view is mirrored in the literature, particularly by Gautam et al. (2012), who have argued that ‘knowledge from other domains cannot be directly transferred to improve flexibility in supply due to the unique challenge faced during raw material procurement in the forest products supply chain’ (p. 228). Furthermore, as shown earlier by examples from literature addressing supply chain design and as can be seen in Figure 3, supply chain attributes determine the configuration of the physical flow, which in turn shapes the performance of the physical flow. It is therefore also justifiable that attributes of the B2E supply chain, in which the physical flow is embedded, need to be

understood before identifying how the physical flow can be improved. This necessity prompts the first research question:

RQ1: What attributes characterise the physical flow in B2E supply chains?

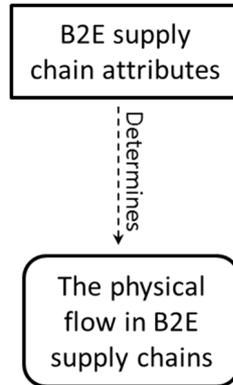


Figure 3: Attributes determining the configuration of physical flow in B2E supply chains

1.5.2 Pre-treatment technology

As argued earlier, torrefaction generates new possibilities in terms of both sourcing a larger potential of feedstock and the kinds of customer to which TDB can be distributed. For example, forest residues can be used to produce TDB, which can either replace coal in coal-fired power plants or be used to produce heat—for instance, in district heating power plants. Since TDB exhibits superior product properties, which increase transport efficiency, biomass can be sourced from regions that otherwise would not be economically viable for use. Furthermore, numerous decisions must be made—for example, regarding vehicle selection and storage design—at each stage of the supply chain, which results in several possible supply chain configurations. For those, torrefaction offers a range of potential logistical benefits, including those that can mitigate the aforementioned challenges of moving biomass across space, storing it across time, and processing it through the existing energy infrastructure.

Torrefaction allows greater flexibility in the sourcing of feedstock and in which customers can be targeted than conventional pelletising technology (producing conventional white pellets). However, it is likely to pose similar challenges in the configuration of supply chains due to, for instance, similar types of feedstock and operation within the same infrastructure with the same or similar vehicles for transportation and handling. In conventional pellet supply chains, to make the chains competitive in terms of cost, aspects of the plant such as location and up- and downstream decisions first need to be understood. On that topic, in evaluating location as a function of feedstock, investment climate, electricity prices, market potential, and logistics, Smith and Junginger (2011) concluded that some regions are more favourable than others, though factors such as increases in freight cost quickly reduce the performance of long-distance supply chains. Thus, the viability of pellet plants clearly depends upon factors in the supply chain. Moreover, Wolf et al. (2006) have explained the different prices for feedstock used for pellet production; whereas pellets made from cheap feedstock (e.g., bark) can be sold

only to large-scale customers since they are unsuitable for small-scale combustion, pellets made from high-quality feedstock (e.g., sawdust) can be used by both small- and large-scale customers. Another consideration is that biomass is a geographically dispersed resource, for which the yield per area varies depending on assortments and geographical location. As with all production units for biomass, the production economy of pellet plants gains advantages from economies of scale, which are counteracted when the procurement area increases along with distances (Sultana et al., 2010). From the above, two observations can be made. First, for economic viability, a supply chain perspective needs to be taken when configuring the supply chain. For example, the procurement strategy must be decided in connection with the market strategy. Second, there is no one-size-fits-all solution for pre-treatment technology, and its viability depends upon its adaptation to local circumstances.

In sum, a torrefaction plant is a production unit vital to transforming biomass into usable forms of energy, since it increases the quality and value of biomass, thereby rendering it suitable for further refinement. Such plants also constitute an important part of the supply chain, for they enhance product properties toward overcoming aforementioned challenges regarding the movement of biomass across space, its storage across time, and its refinement through the existing energy infrastructure. In that way, torrefaction significantly influences the physical flow in B2E supply chains. However, and as noted regarding conventional pellet supply chains, there is no one-size-fits-all solution, meaning that the attributes of supply chains need to be understood in order to assess how torrefaction can influence the physical flow. Given this background, the logic behind the second research question, as visualised in Figure 4, is that pre-treatment with torrefaction can substantially improve the physical flow. However, the necessary means for understanding how torrefaction can improve the physical flow are the B2E supply chain attributes, a logic represented by a curved arrow in Figure 4. The second research question is:

RQ2: How can pre-treatment technology impact the physical flow in B2E supply chains?

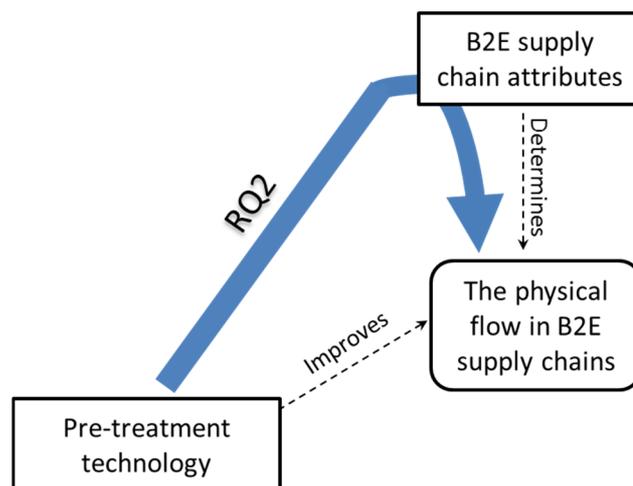


Figure 4: Pre-treatment technology to improve the physical flow

1.5.3 Coordination

Although coordination in general is an extensively studied area, as observed by Arshinder et al. (2008), it at times merits additional attention for special types of goods with unique characteristics. For example, Balcik et al. (2010) have argued that six factors affect coordination in humanitarian relief: (1) number and diversity of actors, (2) donor expectations and funding structure, (3) competition for funding and the effects of the media, (4) unpredictability, (5) resource scarcity and oversupply, and (6) cost of coordination. In coordinating these kind of relief activities, the location, timing, and intensity of sudden disasters are naturally unknown until the disasters occur (Balcik et al., 2010). For hazardous waste management, Sheu (2007) has portrayed coordination as a problem of minimising both cost and the risk of hazardous waste. For return flows, Flygansvær et al. (2008) have concluded that coordination mechanisms depend on customer base (i.e., heterogeneous versus homogenous) and behaviour (i.e., passive versus active). In an earlier study, Hill and Scudder (2002) averred that the primary problem for coordination, at least in the context of food supply chains, is the bullwhip effect, which promotes inefficiency in terms of excess inventory. In their study, the approach taken was electronic data interchange for coordinating activities. In the light of this comparison, coordination is clearly treated differently in various supply chain contexts and shaped by supply chain attributes that noticeably distinguish disaster relief from, for example, return flow supply chains. Since different coordination problems afflict different types of goods, supply chain attributes necessarily constitute a lens for identifying first what can and needs to be improved and, second, how coordination can help.

Before defining the third research question, a basic premise touched upon earlier in this chapter needs to be more firmly established. Different activities within the physical flow of B2E such as storage, transport, and handling are needed to move energy across space and store it across time. Yet, the efficiency of these activities is not only managed internally—for instance, hauliers not only control efficiency through measures such as eco-driving. Instead, efficiency is also shaped by actors in the supply chain—for example, demands placed upon delivery precision shape transport cost. In fact, Flisberg et al. (2012) have shown that if supply is levelled throughout the year, then transport costs can be reduced by 3.4%. Similarly, the open hours of receiving stations managed by energy producers determine the number of roundtrips that a haulier can make during a day, which in turn determines the cost-efficiency of transport (cf. Rogers and Brammer (2009)). These suggestions are consistent with theories central to networks (e.g., Håkansson and Ford (2002), which hold that individual companies can influence networks and be influenced by them. Accordingly, the physical flow can be improved by coordinating activities among actors.

Altogether, four premises for improving the physical flow justify and frame the third research question. First, key challenges hinder the movement of energy carriers such as biomass across space and their storage across time. Second, activities in the physical flow required for both movement and storage pose high costs. Third, those high costs result not only from the poor product properties of biomass, but also from a lack of coordination of activities, due to both the self-interest of actors and B2E supply chain attributes—for instance, demand

uncertainty creates storage problems—meaning that the coordination of activities is a relevant scope for improving the physical flow in B2E supply chains. Fourth and lastly, to understand how activities can be coordinated to improve the physical flow, B2E supply chain attributes need to be identified and understood. Given this background, the logic behind the third research question, as illustrated in *Figure 5*, is that the coordination of activities can improve the physical flow, though understanding how activities can be coordinated must accommodate B2E supply chain attributes. Accordingly, the third research question can be phrased:

RQ3: How can activities be coordinated to improve the physical flow in B2E supply chains?

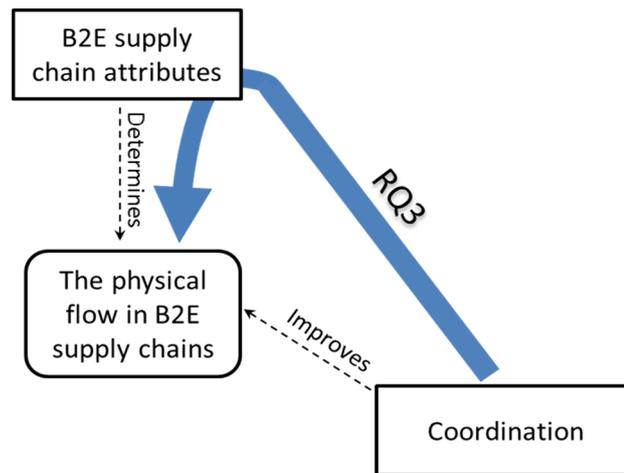


Figure 5: Coordination to improve the physical flow

1.6 Summary of the research depicted in links and nodes

To sum up and illuminate, Figure 6 depicts the three cornerstones of this thesis and their relation to the physical flow, all through links and nodes.

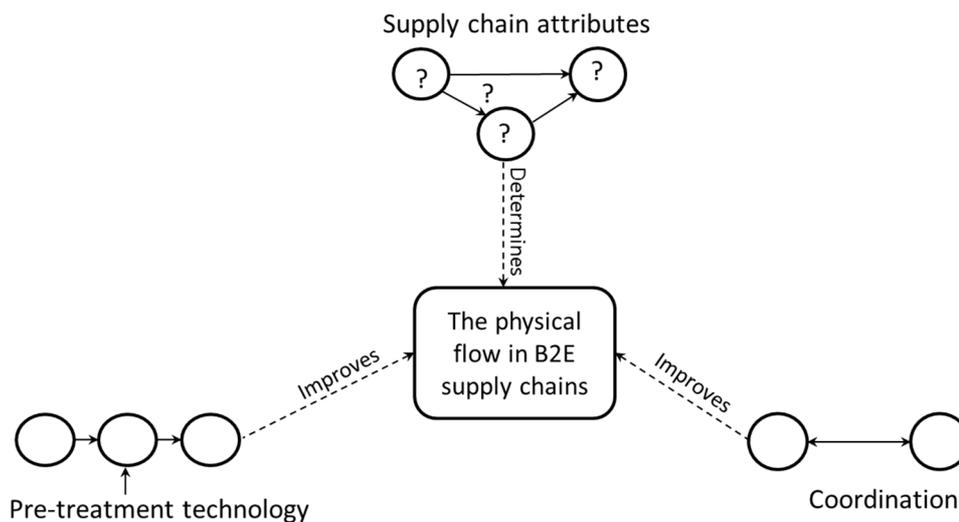


Figure 6: The three cornerstones of this thesis, depicted in links and nodes

The first cornerstone is collectively the supply chain attributes that determine the configuration of the supply chain and the physical flow therein, and in turn shape its performance, e.g. in terms of cost-efficiency. These attributes inform an understanding of the configuration of the physical flow in terms of, for example, why a mixture of supply via terminal and direct supply can be required, as represented by question marks within nodes and links in the upper part of Figure 6. The second cornerstone involves introducing pre-treatment technology in a node, as shown on the left-hand side of Figure 6 which improves product properties and enables improved physical flow. Presented on the right-hand side of Figure 6, the third cornerstone acknowledges that actors operate in nodes and that the physical flow can be improved by coordination of activities between them.

2 Research design

This chapter presents the research design used in this thesis. It starts by presenting the research process behind the thesis. Subsequently, central elements in the research design are presented. Finally, the methodological assumptions are stated.

2.1 The research process

Background

The research process started in 2009 as a part of the project ‘Sustainable Logistics Systems for Biofuel Production’. The project was a collaboration between two research groups, one at Chalmers University and one at Umeå University. The latter conducted research from a technical perspective on the pre-treatment technology known as *torrefaction*. However, in order to continue to develop the technology, they wanted input from a logistical perspective, but lacked such skills. Hence, the project was an attempt to develop an understanding of the technology using an interdisciplinary perspective, involving both technical and logistical aspects. The author of this thesis participated in this project and early on developed an interest in understanding how the physical flow of B2E supply chains could be improved, for example, through the implementation of a pre-treatment technology such as torrefaction.

Physical flows

At the beginning of the research process, the author conducted a literature review on B2E logistics. Even though there was a great deal of research on configuration of B2E supply chains, there appeared to be a research gap in that the research was most often done through simulation, optimisation or techno-economic models, and it often overlooked the actors in the supply chain, which could present conflicting interests. In order to develop the contextual knowledge required for carrying out subsequent research, the author did a descriptive interview study, which resulted in Paper 1, which was presented at LRN 2011 and has been reworked since then.

Pre-treatment technology

During the research process, the author acknowledged that the common saying ‘no one size fits all’ did also apply to torrefaction technology. Hence, in order to understand how the torrefaction supply chain could be configured, two paths were taken. First of all, given that at that time no torrefaction plants had been built and that the research on torrefaction was in its early stage, the author felt that doing a conceptual study to understand the diversity of potentially different torrefaction supply chains was necessary. The study borrowed theories from B2E literature, pre-treatment technology, and from logistics and supply chain design. The outcome was Paper 2, published in the *International Journal of Energy Sector Management (IJESM)*. Secondly, the author also wanted to model a torrefaction supply chain to understand the influence of different parameters on supply chain performance in terms of cost. This study resulted in the third paper, published in *Bioresource Technology (BITE)*. The second and third papers are thus complementary in nature. All in all, the first three papers resulted in the licentiate

thesis, entitled ‘A Framework for Supply Chain Configuration of a Biomass-to-Energy Pre-treatment Process’, in which the purpose was stated as: ‘to understand the logistics implications of pre-treatment process in order to propose supply chain configurations’.

Post-licentiate thesis

After some paternal leave, the work commenced again, but the author did not have a given project within which to work. This can be both a benefit and a drawback, as it opens up a number of different possibilities. The author felt that torrefaction development within the industry was slow and was not sure that reliable quantitative data would be available for doing interesting quantitative studies with both academic and industrial relevance. Hence, the author decided to take another, slightly different path, still interested in understanding how the physical flow in B2E supply chains could be improved. The author felt that improving the physical flow was not only a technological challenge, but also a managerial challenge. During the work until the licentiate thesis, the author had a growing feeling that the physical flow in supply chains was far from optimal due to how the actors responded in interviews in the study leading to Paper 1. For example, there were indications suggesting that the lack of coordination of activities in supply chains caused high supply chain costs. Also, it was heard several times that the forest industry was very ‘old-fashioned’ and ‘conservative’ which could imply that the physical flow is far from optimal. Likewise, within the B2E logistics literature, it is often overlooked that there are different actors, e.g., it is often assumed that the physical flow is treated as a pool of resources working flawlessly towards the same goal. Yue et al. (2014) support this claim, stating, ‘In most existing literature, the entire biofuel supply chain is considered as an entity centralized system...which might not be true as parties are non-comparative’ (p. 46). Hence, with the conventional logistics literature in-mind, the author approached the following research with the assumption that there could be a potential to improve the physical flow through adapting theories on coordination to a B2E context.

Coordination

In order to investigate if coordination as an approach was fruitful for further studies of improvement of the physical flow, an interview with a logistics manager of a power plant was set up. The energy procurer stated that they had suggested a certain means of coordination which could lower the cost of the upstream physical flow, but that suppliers did not expect that, as they are a municipal company. Also, several means of coordination that could improve the physical flow that had not previously been covered in the B2E logistics literature, were identified. Given this interview, earlier perceptions of the forestry industry as old-fashioned and the shown potential of coordination for other types of goods, it was justified to further investigate coordination as an approach to improve the physical flow in a B2E-context. Firstly, a case study, which aimed at identifying the means of coordination that could be applied in a B2E context, was performed. The study took primarily the perspective of energy producers, but interviews with two hauliers and a supplier were conducted to validate the findings. The study resulted in Paper 4, presented at LRN 2014, and which has since been reworked. Finally, in order to both validate findings and to explore a bit further, the author did an interview study, going into depth with hauliers. Ultimately, these are the ones who

will move the biomass, which is a key challenge in B2E competitiveness. Since B2E-transport has not been extensively treated in conventional logistics studies, literature on transport efficiency in general was reviewed. The outcome of the study is a paper which was presented at LRN 2015.

The entire research process, in terms of empirical data, theoretical support through literature and papers can be seen in Figure 7.

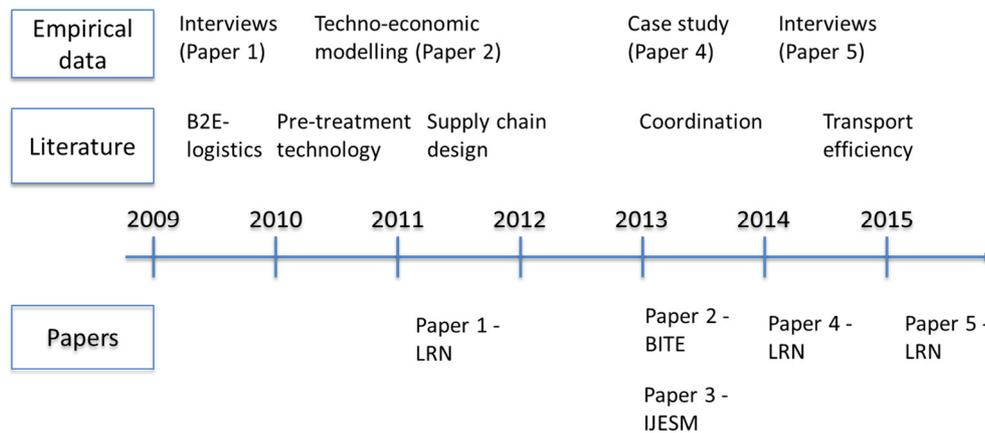


Figure 7: An overview of the research process

As argued in the introduction, there are several feasible approaches for improving physical flows. Therefore, it should be justified why, in this thesis, pre-treatment technology and coordination were chosen to be investigated. It was stated in the introduction that torrefaction and coordination was chosen as approaches as they address key challenges in the physical flow regarding the movement of biomass across space and among different places, and holding it across time using storage so that it is available when in demand. They have also been highlighted by multiple authors as approaches with great potential, yet unexplored. Furthermore, both approaches (pre-treatment technology and coordination) align well with the physical flow as a unit of analysis within this thesis. Finally, acknowledging that improving the flow has different dimensions, one technical (pre-treatment technology) and one managerial (coordination) aspect is a strength of this thesis due to their complementary nature. Hence, the chosen approaches in this thesis are two unexplored paths with great potential, aligning well with the unit of analysis and are complementarily in nature.

Alternative approaches for improving the physical flow can be found both within and outside of the logistics. Outside logistics, approaches include political subsidies to reduce cost of transporting of renewable energy carriers or legislation to allow higher payloads. Within the logistics domain, there are many different approaches, e.g., technology is not limited to pre-treatment technology, rather information technology such as using RFID on containers could allow for more efficient unloading procedures of containers at power plants (Ranta et al., 2014). Information technology could also be used to monitor fuel use, which could enable detecting and avoiding siphoning, which can be a major issue for haulage companies (Devlin et al., 2013). Hence, there are multiple potential approaches for improving the physical flow.

In this thesis, the term *approach* was used, whereas Karttunen (2015) in his thesis used the term *innovation*, describing incremental innovation, radical innovation and network innovation to indicate how a B2E supply chain can be improved. Incremental innovation comprises, e.g., the introduction of new transport modes such as barges to improve transport efficiency, cf. Karttunen et al. (2012) or long distance transport with ships (Searcy et al., 2007). Radical innovation is undertaken when incremental innovation is insufficient to sustain a competitive advantage (Karttunen, 2015), e.g., through the use of completely new solutions for intermodal transports, cf. Karttunen et al. (2013). Innovation also comes in the shape of network innovation, which is more comprehensive, ranging from the forest owners to the end user, e.g., through the process of using entire assortments (for example, small-diameter trees) differently (Karttunen, 2015). In light of this framework, it is concluded that the two approaches for improvement in this thesis are rather different with regards to comprehensiveness. Coordination is an incremental innovation, where means of coordination can often be taken in short-time horizons or in existing flows. In comparison, introducing new pre-treatment technology is a major change, classified as a network improvement. Hence, the complementary nature is an additional strength and justification of the chosen paths for improvement in this thesis.

2.2 Method

The research design can be defined as a logical plan for how to get to the conclusions of the posed research questions (Yin, 2009) or as a framework for the collection and analysis of data (Bryman and Bell, 2007). Maxwell (2005) presented a framework for structuring the research design, suggesting that (1) goals of the research, (2) the conceptual framework used, (3) research questions, (4) methods and (5) validity must work harmoniously together. Maxwell (2005) also suggests going back and forth between the different components and assessing the implications and threats for one another. Other authors provide similar arguments and that there are a number of factors that affect how research is performed. Bryman and Bell (2007), for example, argue for the following influences on business research: theory, values, practical considerations, epistemology and ontology. Hence, it is necessary to discuss how different elements of research design are related. Thus, the method, empirical context, collection of evidence, analysis procedure and validity are discussed in the following sections.

A major distinction in research is whether methods applied are qualitative or quantitative. Bryman and Bell (2007) state that mixed methods, using both quantitative and qualitative approaches, can be used for triangulation, facilitation or complementation (*ibid*). Similarly, Greene et al. (1989) identify triangulation, complementary, development, initiation and expansion as purposes for mixed methods. Regarding complementary methods in logistics and supply chain management, Golicic and Davis (2012) state, ‘The purpose of the complementarity design is to examine different, but complementary, aspects of the same phenomenon to address the research question’ (p. 735). Hence, it is both possible and, in some cases, desirable, to combine both qualitative and quantitative research methods. In this thesis, both quantitative and qualitative

methods are used, as the approaches for improvement (technology and coordination) call for different methods due to their nature.

When selecting the research method, Yin (2009) states that it is important to choose the most appropriate method for the investigation of a research question. Karlsson (2009) acknowledges the appropriateness of different methods, stating that there is no best method; rather method selection should be driven by a fit with the research question and its intended contribution. Decisions on method are dependent on the specific context and the research issue as well as the other components of the research design (Maxwell, 2005). Similarly, Marshall and Rossman (2006) argue that it is important to match the data collection method with the purpose of a study. Hence, method selection is driven by the research question and the problematizing of the physical flow as both a technical (pre-treatment) and managerial (coordination) challenge.

According to Maxwell (2005), the research questions are central to research design as they directly link all the other components of the research design, in terms of their relationship to methods and validity. Research questions should be framed to point toward the information and understanding that will help accomplish the practical goals of the researcher (ibid.). Similarly, Flick (2009) argues that decisions about research questions often depend on the practical interests of the researcher. They are the starting point and determinant of the research design and help to shape the focus of the study and give guidance on how to conduct the research (Maxwell, 2005). The formulation of questions needs to be clear, as the research questions act as a control mechanism ensuring the focus the research, and in the end, essentially determine the success of the qualitative research (Flick, 2009). Given this background, it is both relevant to discuss how the overall research model and the research questions shape method selection. This thesis has three cornerstones: (1) B2E-supply chain attributes, (2), pre-treatment technology and (3) coordination. Each of these has its adherent research question. The method selection for these is presented below, including a discussion of strengths but also weaknesses of each method.

2.2.1 Supply chain attributes (RQ1)

Regarding the first cornerstone, supply chain attributes, the word *attribute* can be defined as ‘a quality or feature regarded as a characteristic or inherent part of someone or something’ (Oxford Dictionary, 2015). This is in line with the argumentation provided in the introduction, stating that attributes capture the essence of the supply chains. In order to identify attributes, interviews are deemed suitable, as they allow for capturing the views of people working within companies along the supply chain. This reasoning is in line with Craighead et al. (2007) who argued that interviewing is about capturing interviewees’ views of object reality. More simply put, Kvale (1996) stated that: ‘If you want to know how people understand their world and their life, why not talk to them (p. 1). Hence, interviews represent a suitable method for capturing the essence (attributes) that describes reality. Furthermore, as stated earlier, research questions shape method selection. The first research question is as follows:

RQ1: What attributes characterise the physical flow in B2E supply chains?

The key terms are ‘*attributes*’ and ‘*characterises*’, which refers to a description of the supply chain and aligns well with the previous discussion. Secondary data, in terms of making use of the existing body of knowledge within the scientific literature covering B2E logistics, is also a relevant source for providing such descriptions. There is a large body of literature that address the configuration of the physical flow through e.g. optimisation models, which provides both empirical results as well as contextual descriptions of the studied supply chains (see e.g., Shabani et al., 2013; Yue et al., 2013). This justifies a literature review as an important source of evidence, serving as the only source of evidence in Paper 2, as well as an important part of Paper 1.

There is currently a lack in breadth of methods in biomass logistics research. In a review of bioenergy supply chains (Gold and Seuring, 2011), only 3 out of 54 papers used data collection methods that included focus group and expert interviews. Hence, given the dominant use of quantitative research, it seems possible that qualitative methods, e.g. using interviews to collect data, could reveal additional insights. This is further justified as the research question is phrased with *B2E*, highlighting that the product (B2E) is important for understanding the flow, which is in line with previous arguments and implies that interviews with actors working with the specific product (within the supply chain) represent a relevant method for collecting data. Given this background, semi-structured interviews were chosen as the data collection method in Paper 1. Finally, the research question is also phrased with the terms ‘*physical flow*’ and ‘*supply chain*’, which implies that data should be collected from various stages and actors along the supply chain, and which is further justified by the assumption of a systems approach as an appropriate research approach and the physical flow as a unit of analysis. Consequently, this justifies interviews and literature reviews, as such methods are suitable for easily collecting evidence and data from various stages along the supply chain.

In comparison to other methods, one primary advantage of interviews is that they provide more detailed information than other data collection methods such as surveys (Boyce and Neale, 2006). Furthermore, Bryman and Bell (2007) argued that one strength of the qualitative interview lies in capturing the view of interviewees by allowing them to provide insights about what they believe is relevant and important. This justification of interviews confirms with the aforementioned argumentation of identifying attributes capturing the essence of the supply chains. In contrast, a weakness of the interview method lies in the time-consuming analysis and the need for validation (addressed in Chapter 2.6). Furthermore, interviewers must be trained in interview techniques (Boyce and Neale, 2006). On that topic, it should be noted that the author significantly improved his research competence during the process behind this thesis, in particular in the interviewing. Kvale (1996) listed ten criteria of a successful interviewer, and the author of the present study has particularly improved on the following during the research process: *open* (responding and being flexible), *gentle* (letting people finish), *remembering* (picking up and coming back), and *structuring* (the overall interview structure). As a result, a higher quality of research was produced towards the end of the research process.

2.2.2 Pre-treatment technology (RQ2)

Regarding the second cornerstone, it has been argued in the introduction that there is no one-size-fits-all for technology in a supply chain perspective. The implication for method selection is that modelling is a suitable approach for understanding the relationship between different components in the supply chain. Even though the technology cannot be studied in its natural setting, it is feasible to collect techno-economic data to quantitatively evaluate different configurations of the supply chain. However, it also implies that methods such as case studies and surveys are not feasible as there is no natural setting for collecting such data. Hence, modelling accompanied by a conceptual study was chosen as method for addressing RQ2. Furthermore research questions shape method selection and the second research question is:

RQ2: How can pre-treatment technology impact the physical flow in B2E supply chains?

The words ‘*how*’ and ‘*impact*’ are used in the research question to capture a relationship; therefore, modelling is a suitable method. However, given that there was no real torrefaction supply chain to study, there was a need to perform a conceptual study to identify feasible torrefaction supply chains, resulting in Paper 2. Writing a conceptual paper is appropriate when there is an emerging research phenomena (Fawcett et al., 2014, Yadav, 2010), which is the case for the emerging and promising technology called torrefaction. The primary role of conceptual papers is within theory development, and must be followed by theory assessment and theory enhancement through other methods (Yadav, 2010). Thus, conceptual studies should naturally be followed by empirical studies, a process that has, to some extent, been done in Paper 3 through modelling one of the identified supply chains, but torrefaction must be implemented in real life supply chains to fully assess the results of Paper 2.

Paper 3 used techno-economic modelling, a type of simulation, in Microsoft Excel to address RQ2. The method was appropriate, as it allows quantification of relationships between components within a system, which aligns well with using the word ‘*impact*’ in the research question. Furthermore, ‘*physical flow*’ and ‘*supply chain*’ imply that data and evidence should be collected from the entire supply chain, which conceptual studies based on literature and modelling allow for.

Modelling is a type of simulation with strong internal validity, as expressed by Davis et al. (2007) who argued, ‘The computational rigor of simulation forces precise specification of constructs assumptions, and theoretical logic that creates strong internal validity’ (p. 495). A main weakness is the external validity, to which Davis (2007) state that simulation eliminates complexity to focus on core aspects of the studies and risks an overly simplistic model that fails to capture critical aspects of reality. Thus, RQ2 was addressed through mixed methods, in terms of a conceptual study and a techno-economic modelling study—a type of simulation, which in light of theory on mixed methods should be seen as expansion of theory, cf. Greene et al. (1989).

2.2.3 Coordination (RQ3)

Compared to the second cornerstone, torrefaction, the third cornerstone, coordination is applied in the industry today to various degrees, which enables additional methods in terms of case studies, as the phenomenon can be studied in its natural context. As a concept, coordination calls for collecting data from at least two stages along the supply chain. In order to address RQ3, a multiple case study was used in Paper 4 and interviews were used in Paper 5. As previously argued, the research question frames method selection, which for the third cornerstone was phrased as:

RQ3: How can activities be coordinated to improve the physical flow in B2E supply chains?

According to Yin (2009), case studies are preferable when questions are phrased with ‘how’ and ‘why’, as these are explanatory. However, RQ3 is more exploratory than explanatory. Yet, Yin (2009) also argues that case studies can be suitable for exploratory case studies, but adds that several other methods can be used for those as well. Thus, the phrasing of research questions in terms of the use of ‘how’, ‘why’, ‘what’, and ‘how many’ does not solely determine method selection (cf. Yin (2009) Rather, justification for method selection is largely drawn from the existing knowledge on the study object (coordination of activities in the physical flow). On that topic, (Eisenhardt, 1989) argued that case studies constitute a suitable research method in early exploratory investigations in which there is typically little known about a phenomenon and new perspectives are needed. Given that coordination is almost completely overlooked in B2E supply chain research, case studies are suitable for exploring the coordination of activities in a B2E supply chain context.

Furthermore, Barratt et al. (2011) defined a qualitative case study as ‘an empirical research that primarily uses contextually rich data from bounded real-world settings to investigate a focused phenomenon’ (p. 329). In line with this, Yin (2009) argued that one strength of case study research is the possibility to use multiple methods for collecting data, of which interviews is one important method. Due to the exploratory nature of the research question and the need to understand the context of the product (*B2E*), using interviews as a method for data collection within the case study is justified based on the same argumentation as in RQ1. Also, as the term ‘*physical flow*’ is important and power plant internal material flows are set up differently, case studies are suitable because they can make use of observations, e.g. to identify different means of coordination for the physical flow, and is therefore a relevant complementary method for data collection. Furthermore, case studies are a suitable method when a systems approach is taken (Churchman, 1981, Arbnor and Bjerke, 1997), which is the approach in this thesis.

‘*Coordination*’ and ‘*physical flow*’ in a ‘*supply chain*’ are concepts that call for collecting data from multiple actors. This was to some extent covered in Paper 4, as the findings were explored with two hauliers and one supplier. However, to fully understand the implications of coordination of activities, there was a need to explore the perspectives of hauliers a bit further, resulting in the use of structured

interviews as the data collection method in Paper 5. By this research design, one major critique of case studies is also met, as Seuring (2008) argued that one drawback of contemporary case studies in supply chain management (SCM) is the lack of data collection from two or more stages along the supply chain. Rather, it is actually a strength of case study research to collect data at various stages and with a range of techniques, enabled by the flexibility in research design of case studies (Seuring, 2008), which is met by Paper 4 and 5 in combination.

In addition to the aforementioned critique of data collection in case studies, there are two major critiques. The first is the rigor of the research (Yin, 2009), which has been addressed by describing method selection, empirical context, the procedure of collecting evidence, the analysis procedure, as well as how validity and reliability has been ensured. The second critique about case studies involves generalisability (Eisenhardt and Graebner, 2007, Yin, 2009), a response to which has been elaborated in section 2.7.

2.3 Empirical context

The five appended papers to this thesis are based on five studies. In order to provide an understanding of the settings of each study, the empirical context is presented below. Also, providing the empirical context serves as part of the chain of evidence and ultimately facilitates an understanding of transferability of the results of this thesis. Firstly, the empirical context for the studies using interviews resulting in Paper 1, 4 and 5 is described in terms of how sampling of cases/interviewees has been done. Next the context for the conceptual paper resulting in Paper 2 is presented. Finally, the empirical context derived for the techno-economic study, resulting in Paper 3, is presented.

Sampling has in general been performed in accordance with Eisenhardt and Graebner (2007), who state that an important variant of theoretical sampling is polar sampling, in which cases are selected based on extremes in order to easily observe contrasting patterns among data. This advice is followed for the case study (Paper 4) as well as for the interview studies (Paper 1 and 5). In Paper 1, companies producing forest fuel differed mainly on where they were located. Companies performing transportation and handling were either hauliers (3), or companies providing haulier services for transport buyers (2). Transportation companies differed on where they operated, the scope of their business (only B2E or other types of goods as well) and the range of the number of activities in which they were involved, e.g., merely transportation or handling and storing as well. Companies producing energy differed as to location and the number of power plants used to produce energy. Due to proprietary reasons, the companies were ensured anonymity.

In Paper 4, four energy producers were selected to ensure diversity in key parameters in terms of location, potential amount of supply, storage ability, number of other production units producing energy and length of the energy production season (the number of months in which energy is produced). These parameters were deemed as relevant, given that the scope of the paper was coordination of activities and it was *a priori* assumed that case selection according to these parameters could illuminate different possibilities for means of

coordination. Companies were chosen so that diverse values was covered for each of these parameters

In Paper 5 the hauliers were polar in terms of their differences in size, chosen as this would affect the type and diversity of vehicles the haulier should and could have (ranging from having 1-5 trucks (small), 6-20 trucks (medium) and more than 20 trucks (large)). A second factor for sampling was whether they had dedicated trucks, used only for biomass, such as the combo truck, a truck with an integrated chipper. Thirdly, the companies differed as to location, from southern to northern Sweden, rendering different transport demand characteristics due to climate which influences the length of the supply season. At least two companies were interviewed with respect to variances in each factor. In total, nine companies were interviewed.

In order to establish a context for Paper 2, which was entirely conceptual, literature concerned with forest fuel, pellets and coal logistics was reviewed. This consists of different levels in the supply chain in terms of feedstock, supply systems, production, distribution systems and customers. For each level, it was described how different attributes influenced the operations at that level. Also, in order to provide support for how a framework can be developed, a review of SCM literature, with a focus on key terms such as structure, configuration and design was performed. The framework entailed three potential supply chains for TDB.

In Paper 3, the modelled supply chain ranges from source of feedstock to the gate of a CHP, see Figure 8.

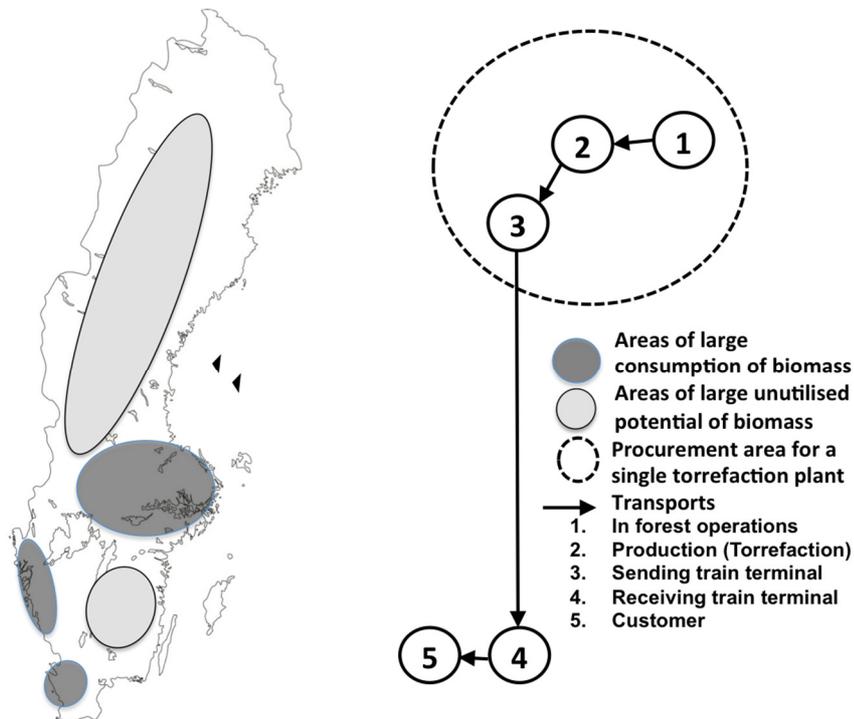


Figure 8: Areas of large unutilised potential of biomass and areas of large consumption, left-hand side, and a possible supply chain (not according to scale), right-hand side

The supply chain was modelled to be potentially representative in a Swedish perspective based on where there is a large unutilized potential of forest residues, and where the potential customers of TDB can be located. The distance between the torrefaction plants and customers had to be assumed, using current intermodal transport of unrefined forest fuel as a basis, but was evaluated in the sensitivity analysis. Also, in order to collect data to ensure that the model represented a potential real world system, interviews were performed with eight pellet producers and an energy producer, based on convenience sampling, cf. Bryman and Bell (2007). Also, tours at a power plant of the energy producer and four of the pellet plants was performed.

2.4 Collection of evidence

The two major sources of evidence used in this thesis are literature and interviews. Also, when the opportunity was given, observations and documents were used to collect additional data.

2.4.1 Literature review

The relevant literature can roughly be divided into two complementary bodies of knowledge. The first encompasses B2E logistics, which is almost exclusively published in energy- and biomass-oriented journals. The second encompass logistics in general, which is typically found in logistics-related journals, in which biomass as a good has received very little attention. These two groups of literature differ according to the focus of the journals, research approach and outcome (See Table 1).

Table 1: Characteristics of the research fields

	B2E	Logistics and supply chain management
Examples of journals	<i>Biomass and Bioenergy; Biofuels, Bioproducts and Biorefining; Bioresource Technology; and Energy</i>	<i>Supply Chain Management: An International Journal; and International Journal of Physical Distribution and Logistics Management</i>
Journal focus/Unit of analysis	Object (biomass and energy) and transformation of object	Research approach/perspective (supply chain perspective)
Research approach	Optimisation and simulation, techno-economic analysis	Vast types of different case studies (from cost to pure conceptual), surveys and interview studies
Research outcome	Numerical results, suggestions on specific configurations of supply chains, mathematical models	Theories, concepts, models

Literature addressing B2E includes papers that differ in terms of character of research, ranging from purely technical papers of chemical conversion of biomass to studies of technological development and different types of supply chain analysis. Papers regarding supply chains primarily use simulation, optimisation or techno-economic models as methods to evaluate different supply chain configurations (e.g., comparing direct with terminal supply) in specific

geographical regions. The outcome of the papers is often the model itself, though numerical results (e.g., the cost of producing energy from biomass) and how supply chains should be configured (e.g., location of terminals in a specific region) are also common. Hence, the useful parts for this thesis are arguably descriptions of important configuration/design issues in B2E supply chains

To complement the bioenergy literature, logistics and SCM journals were also reviewed (see right-hand side of Table 1). Common among papers published in these journals is the research approach, which usually takes an SCM or logistics perspective, making use of e.g. case studies, surveys and interviews in examining various types of supply chains. The major benefit of including this body of knowledge is that it offers theories regarding (1) how to approach supply chain design, (2) relevant aspects and principles within supply chain design, (3) important logistics concepts and (4) coordination as an approach for improving physical flow. As such, the two bodies of knowledge complement each other well in addressing the purpose of this thesis.

Hence, this thesis is underpinned by literature from both B2E-oriented journals and logistics-oriented journals. Scopus (www.scopus.com) and Google Scholar (www.google.com) has been used to identify relevant literature published in scientific journals for the three cornerstones in this thesis; supply chain attributes, pre-treatment technology and coordination. Firstly, in order to identify supply chain attributes, search strings such as 'biomass' in combination with 'logistics' and 'supply chains' were used. Secondly, in order to identify literature for process-technology, 'torrefaction' as well as 'pyrolysis', which is another pre-treatment technology, were used as search strings. However, journal papers on torrefaction cover mostly technical aspects, which create a need for a complementary body of knowledge in order to understand how to make use of technology in a supply chain perspective. Hence, literature reviews on 'supply chain design' as well as 'supply chain configuration' were used. Thirdly, 'coordination' and similar terms, such as 'collaboration', have been used to identify literature relevant for coordination. Finally, transport, a key activity in the physical flow, called for a literature review of 'transport efficiency' but also on 'bulk transport' and similar terms.

It not feasible to argue that all relevant papers have been found. One argument concerns the diversity in terminology for the same object. In this thesis, forest residue has been used as the term for the tops and branches (everything but the stem and the stump). However, in the literature, additional terms such as slash, forest waste, primary forest fuel and forest by-products are often used interchangeably with forest residues. For all three cornerstones, this thesis has tried to address these types of problems by applying snowballing in terms of following up relevant papers and authors frequently appearing in the reference lists. In sum, a number of search strings have been used to identify literature, which has been followed by snowballing to identify additional relevant literature for addressing the purpose of this thesis.

2.4.2 Interviews

In general, the papers that used interviews as a data collection method (1, 4 and 5) adhered to the following procedure. Initially, (1) a literature review resulted in (2) the development of interview guides. After that, (3) interview guides were evaluated by other researchers or pre-tested with interviewees from the industry. This rendered (4) minor re-working of the interview guides. That was followed by (5) performing the interviews (collecting the data) and (6) transcription shortly after the interviews. Finally (7) data was analysed which rendered potential (8) follow-up questions by mail or telephone when there were unclaritys.

A criteria for the selection of interviewees is that they should have the knowledge and experience to answer the questions (Flick, 2009). In general, interviewees at the different companies were logistics managers, e.g. at energy producers responsible for procurement and often for the internal material flow. Logistics managers at hauliers were in general responsible for scheduling of the vehicle fleet. Logistics managers at suppliers were responsible for activities such as purchasing of transport and the use of terminals for storage. In order to ensure that the interviewees had the proper knowledge and experience to answer the questions, background questions about education, occupation and experience were asked at the beginning of each interview.

Prior to conducting interviews, interview guides were constructed based on the frame of reference for each paper. In Papers 4 and 5, the guides were sent in advance to interviewees along with a description of the research studies that framed the interviews. The interview guides had been constructed to cover background questions, the main body of the interview and follow up-questions. The interviewees were given time to reflect and add additional perspectives towards the end of the interviews. The interviews that were conducted in person lasted for 1–2.5 hours and were recorded and transcribed shortly afterwards. Interviews held over the phone ranged between .5-1 hours and were also recorded and transcribed after the interviews, except for the first six interviews in Paper 1, which were typed during the interview. Transcription is beneficial as it allows researchers to not become distracted and enables prompting and probing, cf. Bryman and Bell (2007). In addition, transcription enables higher transparency and serves as a part of chain of evidence (ibid) and allows for using sophisticated tools such as coding to analyse the data (Maxwell, 2005). Hence, transcriptions have been beneficial for the research process.

2.4.3 Observations

Observations in case studies can range from formal to casual data collection (Yin, 2009). Observations can be preferable when technology is being studied, as it allows understanding of the actual use of the technology (ibid). Even though the technology (torrefaction) cannot be studied, potential contexts of the technology have been studied. In that sense, the less formal observations may consist of, for example, field visits (Yin, 2009), which were performed in Paper 4. Three visits to power plants for purposes of touring their internal material flow and riding with a truck of a haulier for half a day were performed. Similarly, four pellet plants were visited for Paper 3, which helped making assumptions in the development of the techno-economic modelling. During these observations, notes have been

taken. Hence, observations in this thesis has mainly been used to collect additional data when opportunities have been given.

2.4.4 Documents

A number of sources of documents have been used to gain knowledge of B2E supply chains, e.g. in terms of reports, company reports and company presentations. When interesting aspects were discovered, they were actively searched in scientific journals. In the end, the only documents used as evidence that were not able to be found elsewhere were a few documents on storage levels and storage costs handed by a manager of a power plant in Paper 4. Hence, documents have served mainly as source to gain a complementary understanding of B2E supply chains compared to the view given in scientific journals, but they have to a limited extent served as evidence in the papers.

A summary of the data collection with respect to number of interviews/observations/documents in each paper can be seen in Table 2.

Table 2: Data collection in the appended papers

Point of data collection/ Method of data collection	Number of suppliers	Number of transportation and handling companies	Number of energy producers	Number of pellet producers
Interviews				
Paper 1	5	5	5	
Paper 3			1	8
Paper 4	1	2	4	
Paper 5		9		
Observations				
Paper 3			1	4
Paper 4	1	1	3	
Documents				
Paper 4			3	

2.5 Evidence and analysis procedure

Yin (2009) states that case study analysis is difficult, as compared to statistical analysis; there is no fixed formula or cookbook recipes for guidance. One implication is that experienced researchers are likely to have advantages over novices (Yin, 2009). Reflecting on the research process, it can be observed that my skills in analysing data have improved significantly; I have moved from a novice towards a more skilled researcher. Data analysis was difficult in the first study. By comparison, when analysing data in the last study, I had developed stronger skills in coding, using a-priori literature derived framework and applying computing assisted tools for analysis (NVivo10). Furthermore, Maxwell (2005) states that there is no single way or formula for analysing qualitative data and for the strategies applied, there needs to be a fit with the data available and the research questions. With this in mind, the analysis of each paper and with respect to the three overall research questions is presented below.

2.5.1 Analysis of B2E supply chain attributes (RQ1)

From the literature review, a number of factors shaping configuration of the supply chain and the physical flow therein were identified. These can be grouped into two types: environmental and efficiency factors. First of all, some factors exist in the environment of B2E supply chains, in line with a systems approach, as proposed by Churchman (1981). These factors are very difficult or impossible to alter. For example, the dispersed geography of forests sets constraints for vehicle selection and therefore shape configuration of the physical flow. Secondly, for every stage along the supply chain, there are many decisions to make, and different factors influence either the cost or the efficiency of links, nodes and the overall network. Knowing that different trucks are preferable in different conditions, or that integrating operations can influence the efficiency of forwarding, can and should shape decisions concerning those activities. Thus, factors, such as distance to customers, are labelled as efficiency factors, influencing the efficiency of operations and should hence shape of how actors configure activities in the supply chain. Within the analysis of the interviews, the focus was placed on the argumentation of the interviewees, e.g., why they chose a certain vehicle or configuration of the transport network due to different elements in customer demand. Data was categorised in the same way as for the literature review.

In Paper 2, the analysis was entirely literature-based. In comparison to Paper 1, in which the scope was primary forest fuel primarily in terms of forest residue (biomass directly from forests), Paper 2 incorporated a wider scope. The assumption was that various types of feedstock could be consumed by different types of end-users, ranging from household use to large coal-fired power plants. The systems approach permeated this paper as well, as literature was analysed and categorised according to different stages in the supply chain. A number of attributes, describing the operations at each level, ranging from feedstock, supply system, production to distribution system were identified.

The material used for analysing RQ1, labelled as paper takeaways (see Figure 9) was (1) the identified factors that shape the configuration of the supply chain identified in Paper 1, (2) attributes of different stages identified in Paper 2 and (3) additional literature. In comparison to the terminology used in Paper 2, which discussed attributes in terms of each stage of the supply chain, attributes as used in RQ1 is with respect to general terms for an overall description of the entire supply chain. Hence, the approach for answering RQ1 has been to identify attributes that distinguish the B2E supply chains from other types of supply chains, which has been an ongoing activity throughout the entire research process. The result of the analysis is nine distinct attributes of B2E-supply chains. The attributes provide the lens for analysing RQ2 and RQ3, as represented by the curved arrows in Figure 9.

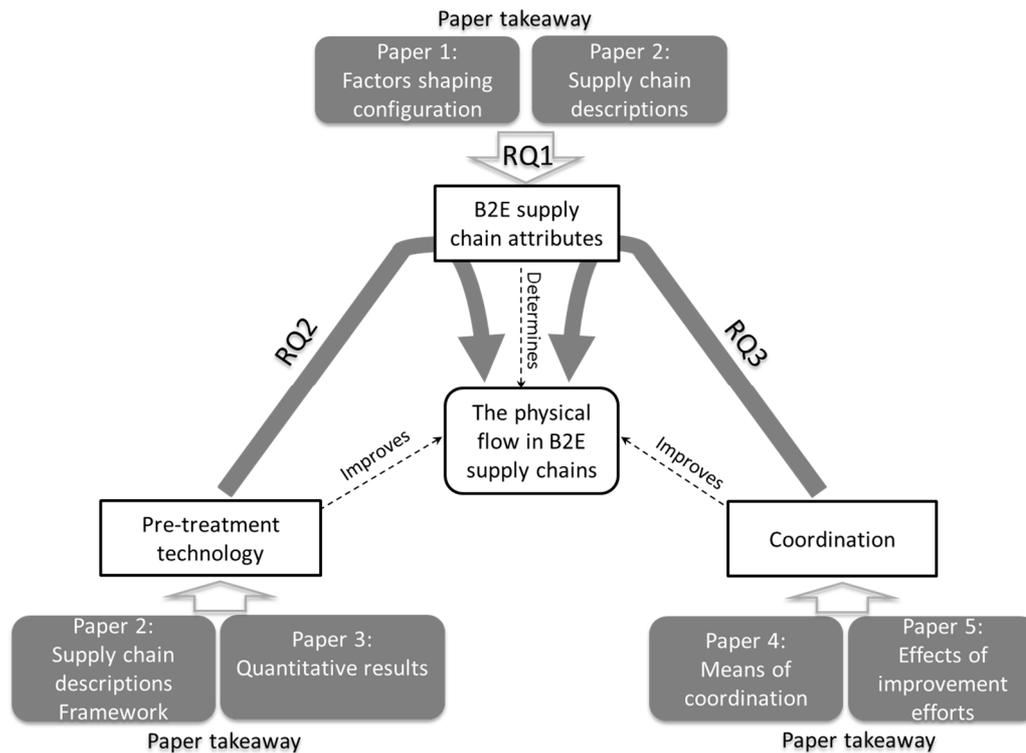


Figure 9: Analysis according to the research model

2.5.2 Analysis of pre-treatment technology (RQ2)

As earlier stated, Paper 2 is built upon a conceptual analysis, through which a number of attributes of different stages in the supply chain were identified. Based on these and prescriptions from SCM, a conceptual framework for configuration of a torrefaction supply chain was proposed. The purpose of the framework was to highlight that decisions makers' need to find a niche for the torrefaction plant, while at the same time understand the implications of their decisions upstream and downstream in the supply chain.

In Paper 3, the results of the techno-economic assessment were analysed with respect to system parts (supply system, production, and distribution system) but also with respect to activities within the system parts. Furthermore, a sensitivity analysis was performed to address the influence of a number of central variables on supply chain cost. The reasons for doing so are the (1) different decisions that can be made, for example, on vehicle selection and (2) uncertainties within the data. Also, in order to provide directions for transferability of results to other settings, variables such as biomass yield and moisture content were varied in the sensitivity analysis. Finally, the optimal size of torrefaction plants was analysed for a number of relevant parameters.

For RQ2, the materials used for analysis included (1) the attributes and the developed framework in Paper 2, (2) numerical results from Paper 3, and (3) additional literature. The analysis systematically investigated potential interplays between attributes, identified in RQ1 and torrefaction, as a means to gain an understanding of how the physical flow can be impacted by torrefaction, described further in section 6.2 and depicted in Figure 9.

2.5.3 Analysis of coordination (RQ3)

In Paper 4, the primary means of data analysis was coding, cf. Miles and Huberman (1994) using the commercial software NVivo 10. The first stage of coding consisted of descriptive coding cf. Saldaña (2012), which identified various means of coordination that improve supply chain performance, specifically by minimising coordination problems or by setting conditions for minimising impact of coordination problems. Subsequent coding linked data to the means of coordination and suggested additional categories. At this stage, it was observed that some actions at power plants are taken primarily for internal benefits, yet has positive upstream effect, and can hence be seen as means of coordination. For example, deploying a large storage area at the power plant enables supply security, perhaps regardless of the fact that it also induces positive, unintentional side effects upstream in the supply chain. Given the possibility of such discrepancies, these were divided into intentional and unintentional means of coordination, which also rendered a number of drivers for unintentional means of coordination. Furthermore, additional descriptive coding revealed multiple factors that both explain some coordination problems in B2E supply chains and describe important aspects of coordination. Finally, a comparative analysis was performed to identify differences among the energy producers

For Paper 5, coding was done according to the layered approach presented in the paper, primarily aiming at relating output and input (number of roundtrips, load amount, trucks, personnel and fuel) to improvement efforts. Hence, through coding, the potential effect that different improvement efforts have on transport efficiency was derived. In addition, based on a division of the interview questions, a comparative analysis was performed in order to analyse differences between the interviewees. Finally, a comparison with non-B2E logistics literature was made in order to position the findings in a wider context.

The material used for analysing RQ3 included the means of coordination and barriers towards coordination identified in Paper 4 as well as the potential effect that the different improvement efforts have on transport efficiency from Paper 5. Improvement efforts comprises means of coordination as well as a few efforts that do not lie within the domain of coordination, e.g., efforts in legislation. The analysis systematically investigated potential interplays between attributes, identified in RQ1 and coordination, to gain an understanding of how activities can be coordinated to improve the physical flow, described further in section 6.3.

All in all, a summary of the research, in terms of research questions, aims of each paper, evidence (literature and empirical data) and data analysis can be seen in Table 3.

Table 3: A summary of the research in each paper

Research question	P a p e r	Purpose/aim/objective of paper	Evidence	Data analysis
RQ1: What attributes characterise the physical flow in B2E supply chains?	1	To identify factors that shape the configuration of the B2E supply chain	Literature: Mainly from B2E journals. Empirical evidence: Interviews with actors within the industry (five with suppliers of forest fuel, five with transport and handling companies, and five with energy producers) complemented the current body of knowledge regarding factors shaping chain configuration	The literature and the empirical data were categorised according to different stages of the supply chain. The data was sub-categorised according to environmental factors and efficiency factors
RQ2: How can pre-treatment technology impact the physical flow in B2E supply chains?	2	To develop a framework for configuration of biomass-to-energy supply chains from the perspective of the torrefaction plant.	Literature: Mainly from B2E journals. Some papers on related research fields and some on supply chain design.	The literature findings were categorised according to attributes of different stages of the supply chain. The analysis developed of a framework for torrefaction configuration based on prescriptions derived from SCM
	3	To develop a techno-economic system model to address how logistics and torrefaction production parameters affect (1) the optimal size of the torrefaction plant and (2) the total cost of supplying torrefied biomass to an end user (a CHP)	Literature: From B2E as a foundation for model development. Empirical evidence: A techno-economic modelling, covering the entire supply chain, from forest to power plants	The results were analysed according to (1) system parts and (2) activities. A systematic sensitivity analysis on central parameters was performed
RQ3: How can activities be coordinated to improve the physical flow in B2E supply chains?	4	To identify means of coordination for activities within the physical flow of B2E supply chains.	Literature: B2E and coordination Empirical evidence: A multiple case study with four energy producers, using interviews, company documents and observations collect data. Furthermore, one interview with one supplier, one large forest haulier and one small forest haulier were performed.	The data was coded to identify means of coordination, but also identified barriers toward coordination as well as additional perspectives on coordination
	5	To explore how improvement efforts in B2E supply chains shape the transport efficiency of forest hauliers	Literature: B2E literature was used as a basis for deriving a framework for relating improvement efforts to transport efficiency, using a layered approach. General transportation literature was used in the analysis Empirical evidence: 9 interviews with forest hauliers.	The data was coded, primarily by relating improvement efforts to output and input of transport efficiency.

2.6 Validity and reliability

Validity can be defined as the ‘correctness or creditability of a description, conclusion, explanation, interpretation, or other sort of account’ (Maxwell, 2005, p. 122) or the ‘integrity of the conclusions that are generated from a piece of research’ (Bryman and Bell, 2007, p. 43). Common criteria of quality are often divided into internal validity, external validity, reliability and construct validity (Ellram, 1996, Mentzer and Kahn, 1995). In Table 4, tactics for ensuring validity and reliability according to Yin (2009) and tactics deployed in this thesis are listed.

Table 4: Tactics to ensure validity, adapted from Yin (2009) and tactics deployed in this thesis

Tests	Tactics suggested by Yin	Tactics deployed in this thesis
<p>Construct validity: Establish correct operational measures for the concepts being studied</p>	<ul style="list-style-type: none"> • Multiple sources of evidence • Establish chain of evidence • Review draft case study report 	<ul style="list-style-type: none"> • Triangulation - Multiple interviews in Papers 1, 4 and 5 • A documented chain of evidence in overall research and papers • Briefing of the interview: describing the studies to interviewees (content, unit of analysis, purpose) • Follow up questions with interviewees to sort out unclarities
<p>Internal validity: Explaining internal relations</p>	<ul style="list-style-type: none"> • Pattern matching • Explanation building • Address rival explanations • Use logic models 	<ul style="list-style-type: none"> • Pattern matching of developed frameworks in Papers 4 and 5 • Validation of techno-economic modelling • A comparative analysis of data in Papers 4 and 5
<p>External validity: Generalisability beyond the actual study</p>	<ul style="list-style-type: none"> • Use theory in single-case studies • Use replication logic in multiple cases 	<ul style="list-style-type: none"> • Theory derived frameworks in Papers 2, 4 and 5 • Documentation of unit of analysis and perspectives
<p>Reliability: Demonstrating that the operations of a study can be repeated, with the same results</p>	<ul style="list-style-type: none"> • Use case study protocol • Develop case study database 	<ul style="list-style-type: none"> • Documentation of: <ul style="list-style-type: none"> ○ research questions ○ unit of analysis ○ interview guides ○ interviewees ○ criteria for selecting interviewees ○ time and place of interviews ○ interview recordings ○ transcriptions ○ how analysis has been conducted.

2.6.1 Construct validity

Construct validity (also known as measurement validity) refers to if the actual measurement corresponds to what was intended to be measured (Karlsson, 2009, Bryman and Bell, 2007). Four ways to enhance construct validity has been deployed in this thesis. Firstly, construct validity can be enhanced by using multiple sources of evidence within data collection (Voss et al., 2002, Yin, 2009).

Secondly, a key tactic is to establish a chain of evidence (Yin, 2009). Thirdly, when using interviews as a data collection method, it is important to frame the interview through briefing before and at the beginning of the interview (Kvale, 1996). Finally, when there are unclarities during analysis of data, these need to be resolved, e.g. through follow-up interviews.

Data triangulation

Multiple sources of evidence within data collection can refer to (1) different types of data, e.g., interviews and observations and (2) data collection on the same issue with several respondents. Multiple respondents have been used to collect data on the same issues with multiple respondents in Papers 1, 4 and 5. In Paper 3, important quantitative data have been double checked with at least two sources.

Also, through questionnaires used in Paper 5, a number of the findings from Papers 1 and 4 were evaluated. In particular, factors, such as the importance of size of hauliers, the importance of transporting complementary goods when there is no season for B2E and queues at receiving stations were addressed from the perspective of the hauliers. Furthermore, the effect of the different means of coordination was evaluated. For example, it was noticed in Paper 4 that the length of the energy producing season can be extended, and hauliers were asked about the implication of this extended season on their operations in Paper 5.

Chain of evidence

Establishing a chain of evidence means that the reader should be able to trace steps from conclusions to initial research questions and vice versa (Yin, 2009). A chain of evidence has been established both for the individual papers as well as for the overall research. For Paper 2, the techno-economic models are available as well as documentation on sources from where data has been retrieved. The justification behind calculations is documented and all the numerical results are compiled in datasheets in Microsoft Excel. For Papers 4 and 5, research questions, interview guides, research framework and the coding paradigm have been described and justified. Recordings and transcriptions are available.

The logic and transparency behind the overall research model in this thesis serves as an overall chain of evidence. First of all, the B2E supply chain attributes were derived from interviews and literature. Secondly, these attributes both shaped how to study pre-treatment technology in the papers and the analysis in the kappa. Thirdly, the attributes helped to identify and frame how to study coordination and how to perform the analysis in the kappa.

Briefing

In order to frame the interviews, interviewees should be briefed about the study before the interview starts, e.g., explaining the purpose of the study, and debriefing afterwards (Kvale, 1996). For Papers 4 and 5, descriptions of the studies were sent to the interviewees prior to the interviews, explaining the purpose, unit of analysis and overall design of the studies. The studies were, furthermore, briefly explained at the beginning of each interview, and the interviewees were given time to reflect at the end of the interviews and asked if they had any information to add.

Follow-up

Finally, for all interviews, when there were unclarities during interpretation and analysis of data, follow-up questions were sent via e-mail or addressed during telephone calls.

2.6.2 Internal validity

Internal validity is mainly for explanatory case studies, when an investigator tries to explain why event x leads to event y (Yin, 2009). Internal validity is hence mainly for Paper 3, in the use of techno-economic modelling.

Validation of techno-economic modelling

The techno-economic model used in Paper 3 is a technique similar to simulation for which Banks et al. (2000) stated that validity can be ensured by (1) face validation, (2) validation of model assumption and (3) validating input-out transformations. First of all, face validity has been addressed through defending and discussing the overall system design and results during a seminar with industrial actors comprising energy producers, forest fuel companies and technology developers as well as external researchers. Face validity can also be enhanced by sensitivity analysis (Banks et al., 2000) and therefore, a sensitivity analysis was performed on a number of important parameters. Secondly, all important in-data to the model were double checked using multiple sources, either through literature or through interviews with industrial actors, e.g., technology developers or pellet producers. To assure validity of assumptions, the overall system design of the supply chain model has been discussed with several industrial actors, in meetings, on the telephone and during the aforementioned seminar. Thirdly, no complete validation of input-out transformation can be done as the system does not exist. Rather, tactics deployed have been to compare the results to those of similar studies in order to evaluate the feasibility of the results.

Pattern matching

Even though none of the studies was purely explanatory, some means have been applied to ensure internal validity. According to Yin (2009), pattern matching in terms of comparing an empirically based pattern with a predicted one can help strengthen internal validity if they coincide. This has been done, to some extent, for Paper 4, as a framework was derived before the study, and the results align with the proposed framework. Similarly, for Paper 5, the results fit well into the literature derived framework for transport efficiency.

Cross-case analysis

According to Voss et al. (2002), a cross-case analysis is a means to enhance internal validity. A cross-case analysis examines similarities and differences among cases. One technique is to use word tables that display the data according to some uniform framework (Yin, 2009). Less sophisticated techniques have been applied in this thesis, as a comparative analysis has been made in Papers 4 and 5 in terms of comparing the answers of the interviewees on different questions within the papers and on overlapping issues between the papers.

2.6.3 External validity

External validity refers to whether the results are valid in a similar setting outside the studied system (Karlsson, 2009, Bryman and Bell, 2007). There are two types of generalisations: analytical and statistical (Yin, 2009). Results in this thesis can only be analytically generalised, for which Yin (2009) proposes two tactics; theory in single case studies and replication logic in multiple case studies.

Theory in single-case studies

Theory has been used to underpin the theoretical framework developed in Paper 2. Prescriptions for supply chain configuration were borrowed from SCM and from B2E-logistics. In Paper 3, modelling is underpinned by theory, e.g. on economies of scale of technical processes and the dependence between different parts of systems. For Paper 4, the framework for the study was derived from coordination- and B2E-logistics literature, and complemented by a process perspective on supply chains. For Paper 5, the framework, a layered approach for transport efficiency was built on (1) common definitions of transport efficiency (2) Churchman's (1981) theories on systems approach, and (3) the concept of causal power. Hence, theory has been used to increase external validity, not only for the case study but for the other studies as well.

Analytical generalisation/transferability

Given that interviewee sampling in this thesis has followed the guidelines of polar sampling, cf. Eisenhardt and Graebner (2007), statistical generalisation is not feasible. In contrast to statistical generalisation, which is about enumerating frequencies, analytical generalisation is about finding domains into which the developed theory can be generalised (Yin, 2009). Also, there have been arguments for a move from generalisability to transferability, as this is more appropriate in qualitative research, cf. Halldórsson and Aastrup (2003). Such criteria allows for receivers/readers to determine applicability in other contexts. As a response, three aspects illuminate domains to which the results of this thesis could potentially be transferred:

First, the studies were performed in a Swedish context. For other parts of the world, forest geography and energy demands differ. Generalisability is likely to be higher in countries such as Canada and Finland, which in comparison to Sweden, have similar forest geography and a climate that renders similar energy demands from customers. Other forest-rich countries such as Brazil have a significantly higher growth rate and yield per area, and completely different energy demand patterns due to climate and weather. This calls for alternative configurations of the supply chains, implying that likeliness of generalisability of findings in this thesis is lower. Hence, B2E-supply chains in other national settings is a domain for which generalisability could be explored by readers of this thesis, but the degree of generalisability should be dependent upon the resemblance to a Swedish contextual setting.

Secondly, pre-treatment is not the only type of technology for increasing transport efficiency through altering the properties of the goods being transported. Rather, for other types of goods, packaging technology, which enables improvements to the shape in which goods is transported in, is another path for improving transport

efficiency. On that topic, a framework was developed in Paper 2 for a profile analysis of technology according to customer demand. It could be explored if the framework could be adapted to assess the role of packaging technology based on different types of demand. Hence, technology represents another domain into which findings of this thesis could be generalised.

Thirdly, the layered approach for transport efficiency developed in Paper 5 could be used to study transport efficiency for other types of goods. The analytical approach could be the same, as transport efficiency in general can be modelled as a ratio between output and input. This implies that the structure of the framework remains but the content could differ, as there are different improvement efforts for goods other than those identified in Paper 5 for B2E. Thus, transport in general is another domain into which findings of this thesis could potentially be generalised.

Finally, for transferability cf. da Mota Pedrosa et al. (2012), the perspectives and the unit of within each paper is documented in Table 5.

Table 5: Perspectives and units of analysis

	Perspective	Units of analysis
Paper 1	Supply chain	Physical flow
Paper 2	Primarily from viewpoint of torrefaction plant, but looking upstream as well as downstream	Physical flow, pre-treatment technology
Paper 3	A supply chain	Physical flow, pre-treatment technology
Paper 4	Departing from energy producer, but adding perspective from suppliers and forest hauliers as well.	Physical flow, means of coordination
Paper 5	From perspective of the hauliers	Physical flow, improvement efforts

2.6.4 Reliability

Reliability refers to what extent a study can be repeated with the same results (Voss et al., 2002). Yin (2009) argues that a prerequisite for an investigator to repeat an earlier case study is the documentation of the procedure followed. In response, the studies in this thesis have documented research questions, unit of analysis, interview guides, interviewees and the criteria for selecting interviewees, recordings, transcriptions and how analyses have been conducted. Reliability of observations is ensured by documentation of where and when observations have taken place. However, reliability cannot always be ensured, as observations were done at a certain period of time with certain people in the industry, which are settings that cannot always be replicated. Reliability is ensured for Paper 3 as the techno-economic model is available making it possible to achieve the exact same results.

The general research quality of papers is also enhanced through public scrutiny. The published papers were reviewed through peer-reviews and by external researchers prior to publication. The papers have also been presented at workshops and international research conferences. Paper 1 was presented and

defended in different versions at two international research conferences and at an international workshop on B2E-logistics. Paper 2 has also been read and commented upon by two experts on technical aspects of torrefaction and by one SCM-researcher. Paper 3 has also been presented and defended at a national workshop with industrial actors and discussed with several actors during model development. Papers 4 and 5 were presented at international research conferences. In general, the scrutiny has not called for any major changes, e.g., in terms of contradictions, errors or major changes in frameworks. Feedback has in general been positive and rather called for minor changes such as clarifications

2.7 Methodological standpoint

The conceptual framework is a key part of the research design going beyond a mere literature review, and consisting of the system of concepts, assumptions, expectations, beliefs, and theories that support and shape the research (Maxwell, 2005). Hence, below, some methodological standpoints that have shaped the research are stated.

2.7.1 Unit of analysis

This thesis has the physical flow in B2E supply chains as main unit of analysis depicted in Figure 10, using links and nodes.

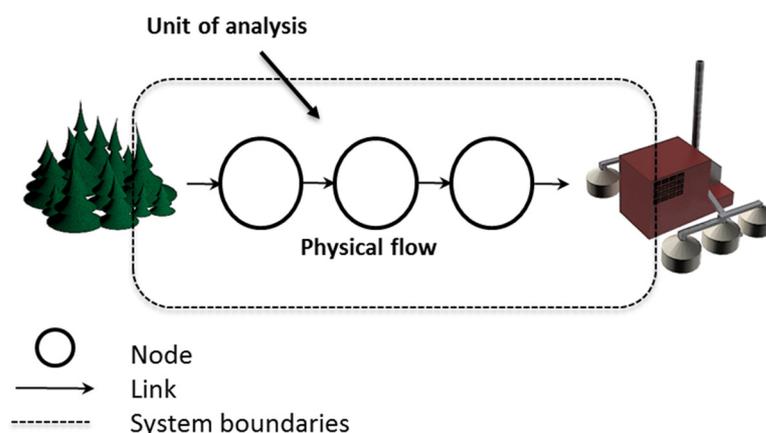


Figure 10: The unit of analysis in this thesis

Having the unit physical flow as unit of analysis research is in line with central theories in logistics. Arlbjörn and Halldorsson (2002) argue that for logistics, ‘the hard core may be formulated as follows: directed toward the flow of materials, information and services; along the vertical and horizontal value chain (or supply chain) that seeks to; coordinate the flows and is based on; system thinking (a holistic view), where; the unit of analysis essentially is the flow’ (p. 26). On a more detailed level, core dimensions in logistics are nodes, flows and networks (Hesse and Rodrigue, 2004) or similarly, just nodes and links (Lumsden, 2006). In the introduction it was argued that it is necessary to move biomass across space and among different places, hold it across time using storage so that it is available when in demand, and process it through existing energy infrastructure in order to access the untapped potential of renewable energy in biomass. These challenges align well with the physical flow as a unit of analysis

2.7.2 A systems approach

A key part in a researcher's conceptual framework is how the research is approached. Arbnor and Bjerke (1997) present three approaches: the analytical approach, the systems approach and the actors approach. Within the logistics discipline, the systems approach seems to have a somewhat central role (Lindskog, 2012, Gammelgaard, 2004). A systems approach is also the essence of supply chain management (see, e.g., Mentzer et al. (2001)). In line with this, the assumption behind this thesis is that a B2E supply chain is a system, and should be studied through a systems approach.

Within a systems approach it is often argued that the whole of a system differs from the sum of its parts (Churchman, 1981, Arbnor and Bjerke, 1997). This holds true for B2E supply chains as well. It can be exemplified by the interaction between torrefaction, which enhances product properties of biomass, and the supply system for feedstock, the input to the process. The torrefaction plant reaps advantages from economies of scale. However, given that biomass is a scattered resource, and the larger a plant is built, the longer the average transportation distance becomes, there is a diseconomy of scale in supplying large plants. Also, operational performance of the torrefaction plant is dependent upon the cost of biomass, and each part can therefore not be studied in isolation in order to identify optimal size of a plant, which hence justifies a systems approach.

The focal system in this thesis is the B2E supply chain, ranging from roadside to point of energy conversion. The entire B2E supply chain is not studied for two reasons. First of all, it is not feasible within a reasonable time to study the whole supply chain, or at least, such a study would only touch upon each part of the supply chain and would not allow for in-depth research. Including, for example, energy use in households would be too extensive. Secondly, different parts of the supply chain require a completely different set of skills and education, e.g., understanding how the product (biomass) is 'produced' and cultivation measures requires a background in forestry. On the other end of the supply chain, is energy distribution, which requires an understanding of how technology is incorporated behind the design of energy grids and the national/international trade of electricity. This is to some extent also motivated by the current research, e.g., in a review of biofuels research, An et al. (2011) showed that current papers almost exclusively look at the upstream part of the supply chain seen from the biofuel production. Hence, in order to have a feasible scope, the system boundaries are in general put at the roadside of forests and at the energy production process within a power plant. This is hence the scope of what in this thesis is referred to as a B2E supply chain. However, it has been argued that logistics systems are always open systems (Jonsson, 2008) and, similarly, each part of a system is part of a larger system (Arbnor and Bjerke, 1997). The implication is that it has to be explained how the environment outside the system influences the system, which is shown below using the model of Churchman (1981).

In order to describe the focal system in this thesis, the five considerations that must be kept in mind when thinking about the meaning of a system (Churchman, 1981) as the foundation. These are basically five aspects that define the focal system:

- The total system objective, and more specifically, the performance measures of the whole system
- The systems environment: the fixed constraints
- The resources of the system
- The components of the system, their activities, goals and measures of performance
- The management of the system

Even though Churchman (1981) argues that the objective is a logical place to begin in systems thinking, he does not precisely define what an objective is, whilst arguing for how difficult it is to determine the real objectives of a system. It is also stated that a scientist should try to move away from vague statements of objectives to more specific performance measures, which is a score of how well the system is doing. The environment makes up things that are fixed from the system point of view, outside the system's control, and something that determines in part how the system performs. The resources of a system are the means within the systems, used to do its jobs, e.g., in terms of money, man hours and equipment. Within the system, components take actions, using resources. According to Churchman, the term *component* is used interchangeably with subsystem or parts within management science. Finally, the management of a system has to generate plans for the system, whilst considering the four aforementioned aspects defining the term. Management involves making sure, often called controlling, that plans are carried out in accordance with the original ideas of the system (Churchman, 1981). However, given that Churchman's model was not developed for logistics, it has to be interpreted and slightly modified to be applicable to a systems description in logistics. Figure 11 shows a personal interpretation of how Churchman's view of systems can be described in a B2E context through depicting aspects of systems within links and nodes of a supply chain, which are central elements in physical flows (Hesse and Rodrigue, 2004, Lumsden, 2006).

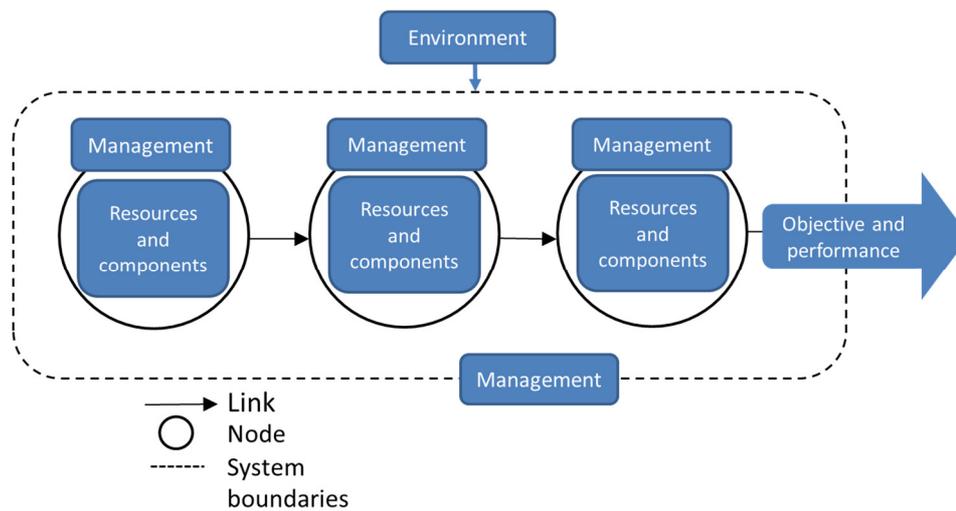


Figure 11: An interpretation of Churchman's view of systems in a supply chain context

2.7.3 The B2E supply chain as a system

Objectives of the overall energy system

As previously stated, all systems are part of larger systems, and before identifying the aspects defining the B2E supply chain, it is of importance to establish a context through glancing at the objectives of the larger system, which is energy systems in general. Within this thesis, an energy supply chain is viewed as a system, including all the processes involved in sourcing energy carriers and transforming them and distributing consumable forms of energy in terms of heat and electricity. The objectives of an energy system are dependent upon the applied perspective. From the view of the supply chain and the society, it is to ensure that energy is always available for households or industries. However, the actors within the supply chain have economic objectives, e.g. maximising profitability, but also other targets regarding sustainability in terms of reducing CO₂-emissions, sharing renewable energy production and energy efficiency (Vattenfall, 2012), or a sustainable regional (Gothenburg-area) society (GöteborgsEnergi, 2012). Within energy systems modelling, researchers often use economic objectives in combination with conflicting objectives, e.g., exergetic (Toffolo and Lazzaretto, 2002), environmental (CO₂-emissions) (Ren et al., 2010) or thermal and environmental (CO₂ and NO_x-emissions) (Li et al., 2006). Also, governments try to influence the objectives of energy systems through policies. Lund et al. (2010) noted that two general governmental objectives are decreasing CO₂-emissions and increasing the share of renewables. Governments can also have more specified objectives, e.g., the UK government has objectives for renewable energy regarding (1) emissions, (2) security, diversity, sustainability and competitiveness of energy supply, (3) stimulating new technologies, (4) helping industry to create jobs through exporting new technology and (5) making a contribution to rural development (van der Horst, 2005). Hence, there are different objectives for energy systems depending on which perspective is taken, but most of them are regarding economic, environmental and social sustainability.

Objectives and performance of the B2E supply chain

As previously argued, the B2E supply chain is part of overall energy systems, where goals involve economic and environmental objectives. Given that bioenergy is close to CO₂-neutral and contributes to local development, it does, per se, contribute to the overall objectives regarding sustainability of the overall energy system. Furthermore, within supply chain research, performance is often measured in terms of cost and/or a combination of customer responsiveness (Beamon, 1999). However, given that energy producers often have a responsibility to always be able to deliver electricity and especially heat throughout the year according to distribution contracts, responsiveness is not an issue to decide upon, e.g., more or less 100% delivery service is required, which implies that raw materials always have to be available for energy production. Rather, the best measure of performance is the cost of the supply chain in relation to the amount of goods delivered, which is also mirrored in B2E supply chain research, see e.g. Kanzian et al., 2009, Rauch et al., 2010 and Tahvanainen and Anttila (2011).

Environment

In B2E supply chains, there are a number of characteristics that describe the environment, such as weather (Gold and Seuring, 2011) and perishable product properties (Iakovou et al., 2010). Furthermore, fluctuating energy demand from e.g. households is a part of the environment, which is in line with the reasoning of Churchman, who states that even though demand can in some sense be influenced by advertising, pricing and the like, demand lies in the environment as it is a given by individuals outside the system and it influences system performance. Finally, it should also be noted that the aforementioned overall objectives of energy systems translates into the environment of the system. For example, governments try to influence the energy system through policies in terms of fixed prices, taxation, investment subsidies and green certificates (Thornley and Cooper, 2008). These can hence be regarded as ‘givens’, influencing systems in terms of the competitiveness compared to fossil fuels, e.g., dictating terms from which distances it is economically feasible to procure biomass.

Components and resources

In Figure 12, a division of components and resources in the B2E supply chain is depicted.

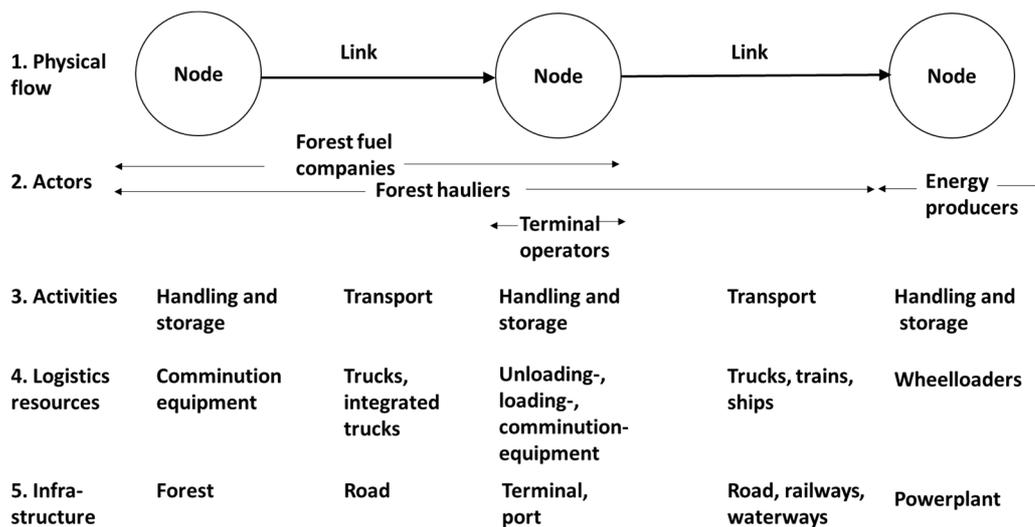


Figure 12: Physical flow, actors, activities, logistics resources and infrastructure of a B2E supply chain

As earlier indicated, the unit of analysis is the (1) physical flow, and it is hence helpful to make a subdivision of components and resources into actors, activities, logistics resources and infrastructure to provide a more thorough foundation regarding system description. A number of (2) actors (forest fuel companies, forest hauliers, terminal operators and energy producers) operate within the links and nodes of the system and have different scopes within different supply chains. In the supply chains there can be additional actors such as train transport companies or shipping companies. Within the nodes and links, the actors perform a number of (3) activities (handling, storage, comminution and transport) by using (4) logistics equipment (e.g., comminution equipment, trucks, unloading and loading equipment, trains, ships and wheelloaders) and operate on (5) infrastructure (forests, roads, terminals, ports, railways, watersways and power plant area).

Activities do not merit a separate category in Churchman's model, even though he, as earlier argues, states that the resources of a system are means within the systems used to do the jobs. Thus, jobs are important, which in this thesis is seen as the activities performed. Hence, including activities as a category, in describing the system is relevant, as it aligns well with the perspective of a physical flow as unit of analysis, consisting of activities such as handling and transportation.

Management of the system

The system is managed by the actors. Ultimately, it is the responsibility of the energy producer to ensure that energy is always available for distribution to households and industries. The actors manage the activities in the system to contribute to the overall system objective, yet also according to their self-interest. In order to avoid sub-optimisation of the system, it is important that the interdependence of activities is acknowledged.

2.7.4 Implications of a systems approach for this thesis

The systems approach has several implications for the kappa and the appended papers. Using the reasoning behind defining the objective of the systems helps ensure that the system modelled in Paper 3 represents a real world supply chain. Furthermore, as observed in Paper 4, the framework for a layered approach to relate improvement efforts to transport efficiency is built upon the assumptions in Churchman's model.

Furthermore, dividing the system into components (actors), resources and performance, helps to illustrate that different aspects of performance are relevant from perspectives of different actors and from the perspective of the system. This has, in particular, helped identify which measurements of performance to use in the papers. Furthermore, in this thesis, part of the purpose statement was to 'improve the physical flow'. 'Improving' is somewhat vague, and as a response, it is justified to shortly describe how each paper's use of performance relates to 'improvement'. As earlier argued, the best performance measure for the overall system is the cost of delivering biomass for energy production. This was followed in Paper 3, where the perspective was of the entire supply chain. However, the other papers had different perspectives, and did not use quantitative methods, which called for other approaches to handle performance. In general, performance measurements entail an analysis of both efficiency and effectiveness in accomplishing a goal (Mentzer and Konrad, 1991). This view is in line with how performance was addressed in the other papers. In Paper 1, performance was manifested in terms of identifying factors that influenced efficiency. In Paper 2, the focus was rather on effectiveness, in terms of identifying how to use torrefaction the correct way for different end users. In Paper 4, the departure was coordination problems that cause high supply chain costs. Finally, in Paper 5, the perspective was from the view of the hauliers, and performance was addressed in terms of their transport efficiency. In the framework developed, the definition of transport efficiency could be converted to performance through estimating the cost of output and input. Hence, there were different measurements of performance for the papers (see Table 6). Although each paper uses different perspectives and methods, all contribute to the overall purpose regarding improving the physical flow.

Table 6: Performance measurement in the papers

Paper	Performance Measurement
Paper 1	Efficiency
Paper 2	Effectiveness
Paper 3	Cost
Paper 4	Cost (as point of departure)
Paper 5	Efficiency

2.7.5 Epistemology and ontology

The epistemological debate concerns what can be regarded as acceptable knowledge within a discipline, and whether social sciences can be studied according to the same principles, procedures and ethos as the natural sciences (Bryman and Bell, 2007). The ontological debate is concerned with the nature of knowledge; in other words, the researcher's view of the world from an objective or subjective perspective (ibid.). The author's view of the world is that reality definitely exists, e.g., on a basic level the world is made up of atoms and molecules and everything could hypothetically be measured. On a more specific level the view is that there is 'a best' configuration for a B2E supply chain in a specific context if all variables are known. However, an optimal configuration cannot be identified given that the world cannot be fully understood due to complexity and comprehensiveness, only proposed or evaluated differently based on the author's knowledge of the world and the research field in particular. The best fit with textbook definitions on ontology and epistemology is the post-positivist view (cf. Guba (1990)). Within this, the view on ontology is that of the critical realist, where *'reality exists but can never be fully apprehended. It is driven by natural laws that can only be incompletely understood'*. The epistemological stance is modified objectivist where *'objectivity remains a regulatory ideal, but it can only be approximated, with special emphasis placed on external guardians such as the critical tradition and the critical community'* (ibid). An implication of post-positivism is methodological pluralism, as method selection should be driven by the research questions posed (Wildemuth, 1993, Lapid, 1989). Furthermore it has also been argued by that case study methodology as proposed Yin (2009) is based on post-positivism (Strang, 2015). Both suggestions are in line with earlier discussions on method selection in this thesis.

3 Frame of Reference

As part of this thesis's conceptual framework, the following frame of reference based on a review of relevant literature establishes a foundation for the research conducted in this thesis. This chapter offers insights into physical distribution, supply chain attributes, technology, coordination, as well as characterises the context of B2E supply chains.

To derive a frame of reference, this thesis makes use of literature from several fields, including logistics and bioenergy. Key areas addressed are physical distribution and transportation, supply chain design, technology and coordination, and B2E-logistics

3.1 Physical distribution and transportation

According to Lumsden (2006), transportation networks can be defined in terms of nodes and links (Figure 13). A *node* is a geographical position—for instance, a source of goods or a point for storage, processing, or transshipment of goods. *Links* connect nodes by involving vehicles and vessels to transfer goods using infrastructure. Generally, links and nodes can be arranged into different network types. For instance, Woxenius (2007) has suggested six distinct theoretical designs for transportation networks: direct links, corridors, hub-and-spoke designs, connected hubs, static routes, and dynamic routes.

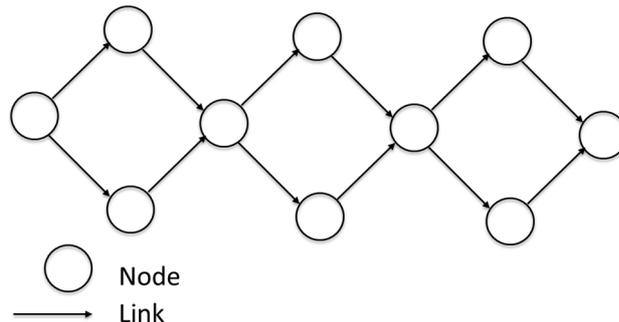


Figure 13: A model of a transportation network, adapted from Lumsden (2006)

Planning transportation networks occurs at strategic, tactical, and operational levels and shapes transport efficiency in terms of costs, environmental concerns, delivery time, frequency and quantity (Jonsson, 2008). Strategic planning involves decision-making that considers long time horizons, which can mean decisions affecting network structures, node location, traffic modes to link nodes, and the capacities of both links and nodes. By contrast, decisions made at the tactical and operational levels concern shorter time horizons and can involve delivery consolidation, the selection of distribution paths between terminals or directly between firms, aggregated transport quantities and frequencies on those paths, route planning, vehicle loading, vehicle scheduling, and the tracking and tracing of delivered goods (Jonsson, 2008).

In this thesis, the unit of analysis is the physical flow in B2E supply chains, in which the transport of goods per se is a central activity. To contribute to the

somewhat sparse literature addressing B2E transport (see Section 3.4), the following aspects help to establish the context of transports in general, but also shape how to study transport in a B2E context. First, vehicle utilisation influences transport efficiency. Second, understanding operational perspectives matters to identifying how transport efficiency can be improved. Third, uncertainty and flexibility impact transport costs and are of particular relevance in B2E contexts due to fluctuations in energy consumption. Fourth and lastly, several different means to increase transport efficiency exist within logistics.

First, a major determinant of transport efficiency is vehicle utilisation—for example, in terms of load factor, a weight-based measurement of space utilisation (McKinnon, 2007)—which is also essential to reducing CO₂ emissions during road transport (Léonardi and Baumgartner, 2004). McKinnon (2007) has argued that constraints upon vehicle utilisation include demand fluctuations, just-in-time delivery, the unreliability of delivery schedules, vehicle size and weight restrictions, handling requirements, the incompatibility of vehicles and products, health and safety regulations, capacity constraints at company premises, lack of knowledge of load consolidation opportunities, and poor coordination of purchasing, sales, and logistics functions. The constraints can be classified as market-related, regulatory, interfunctional, infrastructural, or equipment related (McKinnon, 2007). At the same time, structural factors can also determine vehicle utilisation—for instance, in terms of centralisation or with an altered transport network design (Piecnyk and McKinnon, 2010). However, biomass is a bulk commodity for which fill rate is an inadequate measurement of the capacity utilisation of the vehicle. Trucks are (almost) always full from either a weight or volume perspective, depending on the moisture content of biomass. Hence, the product properties sets conditions for transport efficiency. Therefore, vehicle utilisation should be measured in terms of amount of MWH, describing the load carried, in relation to the capacity of the truck, most frequently measured in m³.

Second, transportation efficiency has also been studied from an operational perspective. Simons et al. (2004) developed a new measurement—namely, overall vehicle effectiveness (OVE)—based on five losses in the lean paradigm: driver breaks, excess load time, fill loss, speed loss, and quantity delays. Later, Sternberg et al. (2012) developed a similar framework based on the seven classical sources of waste—overproduction, waiting, incorrect processing, unnecessary movement, defects, resource use, and uncovered assignments—from a lean approach and adapted it to study motor carrier operations. In that sense, transport efficiency involves not only exploiting vehicle capacity efficiently, but also using vehicles themselves efficiently. However, efficient use of vehicles depends not only upon hauliers, for losses can also depend upon how shippers and receivers of goods manage their processes.

Third, another major factor influencing transports is uncertainty. For this factor, Sanchez-Rodrigues et al. (2010) have developed a model consisting of five categories of uncertainty: supplier uncertainty, customer uncertainty, carrier uncertainty, uncertainty in the control system of the supply chain, and uncertainty of external factors. Uncertainty can be responded to with flexibility when providing transport services, which has implications for transport cost (ibid).

Internally, the types of flexibility relate to mode, fleet, vehicle, node, link, time, capacity, routing, and communication; by contrast, types of external flexibility include flexibility related to product, mix, volume, delivery and access (Naim et al., 2006). Understanding uncertainty and flexibility is of importance for actors in B2E supply chains, given the fluctuations in demand for biomass and its transports caused by fluctuating energy production to accommodate fluctuating energy consumption from households and industries.

Fourth and lastly, different means to improve transport efficiency have been identified in the literature, including factory gate pricing (Potter et al., 2007), supply chain pooling (Pan et al., 2013), different types of collaboration at either horizontal or vertical levels (Mason et al., 2007, Fugate et al., 2009, Lehoux et al., 2013), and weekend freight levelling (Humphrey et al., 2007). From the perspective of logistics service providers, means of improvement include differentiating services in terms of routine logistics, standard logistics, and customised logistics, all of which differ with respect to flexibility, collaboration, and information sharing (Naim et al., 2006). Improving information technology has also been confirmed as a means of improving transportation efficiency by reducing time spent with administrative actors and the associated wait times (Sternberg et al., 2014). Thus, technology and coordination are not the only ways to improve transportation, for several others exist within logistics.

3.2 Supply chain design

As argued in the introduction, the configuration of supply chains and of their physical flows falls into the domain of supply chain design. To further illustrate the importance of understanding supply chain attributes, this section presents an overview of six important works regarding supply chain design. A comparison of their purposes, their identified attributes and determinants of supply chain design, and their outcomes appears in Table 7.

To devise an effective supply chain strategy, Fisher (1997) considered the starting point to be the nature of the demand for the product. As that study explained, aspects of demand include product life cycle, contribution margin, product variety, average margin of error in forecast in at the time production is committed, average stockout rate, average forced end-of-season markdown as a percentage of full price, and lead time required for made-to-order products. According to these aspects, products can be grouped as either functional products with predictable demand or innovative products with unpredictable demand, two groups that together provide a basis for determining the supply chain strategy. The outcome of Fisher's (1997) paper was a framework in which a functional product aligns with a physically efficient supply chain, whereas innovative products align with a market responsive supply chain.

Pagh and Cooper (1998) examined supply chain strategies in terms of two concepts: postponement and speculation. Whereas *postponement* refers to performing differentiation at the latest possible point in time in the supply chain, *speculation* refers to performing differentiation at the earliest possible point, typically in order to avoid unnecessary costs. The result of their paper was a framework for profile analysis to assist managers in choosing between

postponement or speculation strategies based upon several determinants. As the authors stated, 'When selecting determinants, it is essential that the selection is based on each determinant's relevancy for choosing the best P/S [postponement/speculation] strategy' (p. 24). The chosen determinants fell within three categories—namely, product, market and demand, and manufacturing and logistics—and included life cycle (i.e., stage, volume, and cost–service strategy), product characteristics (i.e., product type and range), and value (i.e., value profile and monetary density). Market and demand encompassed relative delivery time, delivery frequency, and uncertainty of demand, while manufacturing and logistics included economies of scale and capabilities.

Sunil (2003) sought to describe a framework for designing the distribution network from suppliers to customers. The approach involved elucidating how performance factors influence the distribution network design, which can be described in terms of customer needs met and the cost of meeting them. As the author argued, though customer needs consist of many components, the focus of the study was measures influenced by the structure of the distribution network in terms of response time, product variety, product availability, customer experience, order visibility, and product returnability. Supply chain costs were defined as those affected by changing the distribution network—that is, inventories, transportation, facilities, and handling. The outcome of the paper was a discussion of design options considering the factors for six different distribution networks based on where products were delivered or picked up and whether the flow involved an intermediary.

Payne and Peters (2004) addressed supply chain design as a matter of selecting the best supply chain for achieving the right balance between the required levels of customer service and the total costs of supplying that level of service. To that end, companies need to match their products with the types of distribution channel for delivering them. In that sense, a critical decision regards where stock should be stored in terms of dispersed, centralised, or assemble-to-order models. The approach used in that study was a product characterisation model structured around key attributes determining supply chain design, including volume, volatility (i.e., demand variability), order line value, order line weight, order frequency, product substitutability, and number of customers of each product. Payne and Peters's (2004) outcome was a supply chain design matrix based upon key attributes for determining a supply chain strategy in terms of dispersed stock models, central stock models, or assemble-to-order models.

Christopher et al. (2006) addressed supply chain design for global operations, based upon product segmentation (i.e., standard or special), demand (i.e., stable or volatile) and replenishment lead times (i.e., short or long). The authors argued that it is possible to simplify the taxonomy to contain just two dimensions: predictability and replenishment lead times. The outcome of their paper was a framework entailing a 2×2 matrix, in which each cell corresponds to a specific supply chain strategy in terms of lean, agile, or so-called 'leagile' strategies.

Vonderembse et al. (2006) aimed to provide insights into organisations that design supply chains in order to manufacture discrete parts. To design a supply chain, it is generally essential to understand and differentiate products as standard,

innovative, or hybrid. Based on the stage in the product life cycle (i.e., introduction, growth, maturity, and decline), the authors proposed a framework for supply chain design consisting of strategies in terms of lean, agile, hybrid–lean, and hybrid supply chains.

Table 7: A comparison of six papers addressing supply chain design

Authors	Purpose	Attributes and determinants	Outcome
Fisher (1997)	To develop a framework for devising an effective supply chain strategy	Aspects of demand toward distinguishing functional from innovative products	A framework in which functional product aligns with a physically efficient supply chain, whereas innovative products align with a market-responsive supply chain
Pagh and Cooper (1998)	To examine supply chain strategies in terms of postponement and speculation	Determinants within product, market and demand, and manufacturing and logistics	A framework for profile analysis to assist managers in choosing either postponement or speculation strategies
Sunil (2003)	To describe a framework for designing a distribution network in a supply chain from suppliers to customers	Various factors in choosing distribution network (i.e., response time, product variety, product availability, customer experience, order visibility, and product returnability)	A description of design options for distribution based upon where products are delivered and whether flow involves an intermediary
Payne and Peters (2004)	To address supply chain design as a matter of dealing with the trade-of between cost and service level	Volume, volatility (i.e., demand variability), order line value, order line weight, order frequency, product substitutability, and each product’s number of customers	A design matrix using supply chain determinants to determine supply chain strategy in terms of dispersed stock models, central stock models, or assemble-to-order models
Christopher et al. (2006)	To examine supply chain design for global operations	Product (i.e., standard or special) demand (i.e., stable or volatile) and replenishment of lead times (i.e., short or long)	A framework for choosing among lean, agile, and so-called ‘leagile’ supply chain strategies
Vonderembse et al. (2006)	To provide a framework for designing supply chains	Product types (i.e., standard, innovative, or hybrid) and product life cycle (i.e., introduction, growth, maturity, and decline)	A framework for supply chain design in terms of lean, agile, hybrid–lean, and hybrid supply chains

A review of these papers highlights three major issues. First, as can be seen in Table 7, column 3, there are numerous approaches to describing supply chains

according to performance factors, product characteristics, decision determinants, or attributes, all determining supply chain design. To some extent, such difference concerns labelling and type of good, as well as depends on the objective of each paper. It is nevertheless important to identify attributes of supply chains encompassing the physical flow in order to understand how the flow can be improved. For example, using some aspects in these papers (e.g., product returns) would be not be fruitful in a B2E context, for there are no product returns in B2E supply chains. By extension, this circumstance further justifies RQ1, which aims to highlight the importance of identifying attributes in order to understand how physical flow can be improved.

Second, a drawback of the aforementioned papers is that many design determinants can be perceived as somewhat arbitrarily proposed as there are limitations to length of papers, thereby leaving readers to trust the design determinants presented. In response, to provide a valid, transparent foundation for improving physical flow, thoroughly addressing supply chain attributes with appropriate methods (e.g., using multiple sources of evidence) is desirable and justified. Ultimately, this reasoning additionally justifies the selection of the method for answering RQ1 (e.g., using both literature review and interviews to identify attributes) in order to assure readers that attributes identified are relevant and underpinned.

Third, the issue of supply design in these papers involves a wide range of scopes, from the entire supply chain to the distribution system to managing products according to demand, which justifies further specifying the scope of design in the thesis. To that end, *supply chain configuration*—that is, a subdomain within supply chain design—is used to describe the scope. In the literature, the term *configuration* seems to be used more narrowly than *supply chain design*. To further specify scope of this thesis, what follows defines and describes *supply chain configuration* as well as *coordination*.

By definition, *configuration* refers to the ‘arrangement of parts or elements in a particular form, figure, or combination’ (*Oxford English Dictionary*, 2015). Supply chain configuration treats a supply chain as a system of entities that can be managed, thereby suggesting that it is a supply chain management problem requiring that various aspects are addressed, including e.g. the location of supply chain facilities at different tiers, supplier selection, product allocation, and the definition of a facility’s capabilities (Chandra and Grabis, 2007). When it comes to physical flow, Graves and Willems (2005) treated supply chain configuration as a matter of locating inventory among nodes. Therefore, as these examples show, similar to supply chain design, supply chain configuration can comprise a wide scope. To provide clarity for this thesis, the three concepts of supply chain design, supply chain configuration, and physical flow configuration are in this thesis positioned along a narrowing continuum. In that sense, supply chain design is the widest concept, for it addresses which elements should be included in the supply chain—for example, which products should be produced—yet also the overall supply chain strategy. Further along the continuum, supply chain configuration is narrower and follows decisions regarding supply chain design, e.g. in terms of supplier selection. Along with supply chain design, supply chain

configuration also establishes conditions for the physical flow. Lastly, configuration of the physical flow is narrowest and, as stated earlier, concerns decisions on how links, nodes, and resources are used—for instance, which trucks are used for transport.

A central premise regarding supply chain configuration and supply chain design is that they both assume the contingency theory—briefly, that a company needs to adapt its strategy to the market (Hofer, 1975)—common in supply chain configuration (e.g., (Roh et al., 2011, Caridi et al., 2010). However, the contingency theory is not always explicitly stated; for example, Lee (2002) has argued that a supply chain strategy based on a one-size-fits-all model will fail, yet does not explicitly discuss contingency theory. In sum, no best configuration for a supply chain or its physical flow exists; instead, the ideal configuration depends upon circumstances of each supply chain—for instance, in terms of local or regional settings of the environment in which the supply chain is configured.

By contrast, *coordination* refers to ‘the process of organising people or groups so that they work well together’ (Merriam–Webster, 2015). Coordination is also part of the essence of supply chain management. According to the Council of Supply Chain Management Professionals (CSCMP, 2010), supply chain management ‘encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service-providers, and customers’. Although configuration and coordination involve similar issues (e.g., management of activities), coordination bears a far stronger emphasis upon activities that need to be aligned among actors. Accordingly, decisions about an activity (e.g., inventory level) can constitute both configuration and coordination, insofar as the latter is built upon the premise that the decision is made to accommodate the activities of other actors. For instance, decisions about inventory levels represent only configuration if it does not accommodate with e.g. the amounts in which suppliers want to make deliveries. However, if inventory levels suit is other actors, then the decisions represent coordination as well as configuration.

3.3 Technology

In this thesis, two approaches to improve the physical flow are via the use of pre-treatment technology and the coordination of activities. To situate these approaches among related literature and understand how they can be used, technology and the concept of coordination are presented in a wider context below.

3.3.1 Technology in a logistics context

When discussing technology in supply chain contexts, associations between the two often highlight information technology (IT). In describing the benefits of technology, Hesse and Rodrigue (2004), have asserted that ‘flexible order and supply behaviour is actually made possible by new technologies, primarily through the real-time exchange of information’ (p. 174). In the 1990s, IT was one of the most discussed topics in logistics (Closs et al. (1997), and it formed a major

barrier to effective collaboration within supply chains (Fawcett et al., 2008). Whereas IT concerns improving supply chains by communicating information, pre-treatment technology concerns managing products by altering their properties in order to improve the physical flow in the supply chain. Thus, both types of technology aim to improve the supply chain, though the scope of technology in this thesis differs from the vast majority of research addressing technology in supply chains. In that light, the focus of this thesis is not IT used to manage supply chains, but altering product properties within supply chains by means of process technology. As such, it is possible to combine pre-treatment technology and IT, though that topic is beyond the scope of this thesis.

3.3.2 Torrefaction: A pre-treatment technology

Torrefaction is often labelled as a pre-treatment process, given its use in altering product properties of biomass before converting it to heat, energy, or vehicle fuel. Torrefaction is a thermal pre-treatment process in which biomass material is subjected to a temperature of 250–350 °C for 20–60 min. Scientific literature often uses the term *torrefaction plants*, which however can be misinterpreted since torrefaction is not the only process in the plant.).

Compared to unrefined forest fuel, torrefied densified biomass (TDB)—exhibits superior product properties. Besides increasing transportation, handling, and storage efficiency, TDB's enhanced characteristics add value by allowing co-firing with coal, thereby rendering a superior fuel for combustion (Ciolkosz and Wallace, 2011), as well as for gasification and subsequent liquid fuel production. Torrefied pellets pose good storage possibilities due to their hydrophobic properties and far less storage loss, if any, due to biological breakdown (Bergman, 2005). Furthermore, compared to comminuted forest fuel, which is bulky and has low energy density (i.e., about 3–5 GJ/m³), as to traditional pellets (i.e., 8–12 GJ/m³), torrefied pellets have excellent transportation properties owing to their significantly higher energy density—roughly 14–18 GJ/m³ (Uslu et al., 2008).

Other than better transport and storage properties, several other potential benefits of torrefied biomass exist compared to unrefined forest fuel, including a lesser amount of energy required for grinding (Phanphanich and Mani, 2011) and the ease of feeding in subsequent processes (e.g., producing vehicle fuel via gasification). In sum, torrefaction is clearly both an important production process that adds value for end users and can improve the physical flow by posing logistical benefits (e.g., increased transportation properties). To describe how these benefits can be used in supply chains, relevant logistics concepts are presented below.

3.3.3 Torrefaction in a logistics context

Since torrefaction plants are physical sites where both transformation and storage occur, it is useful to view these plants as nodes in a supply chain, which invites the use of logistics concepts regarding nodes, terminals, distribution systems, utilities, and gaps. The function of storage at torrefaction plants can to some extent be compared to nodes in terms of terminals. Hultén (1997) has stated that nodes are used to bridge gaps between means of transport within the physical flow of products in terms of frequency, capacity, and time (Figure 14).

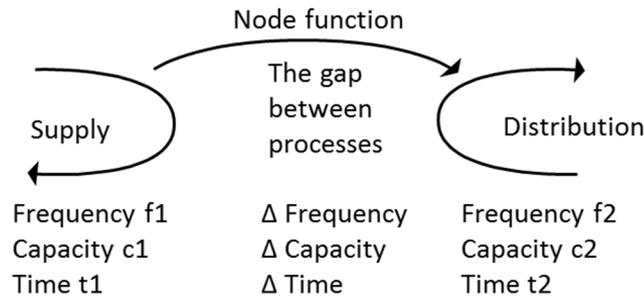


Figure 14: The function of terminals, adapted from Hultén (1997)

Jonsson (2008) has similarly argued that actors along the supply chain contribute to overcoming several gaps, the following of which are relevant to this thesis:

- The pace gap that arises because customers do not acquire or consume products at the same places, at the same times, or at the same intervals as manufacturing companies produce them;
- The distance gap that arises because producers are located in a few places, whereas customers are more numerous and widespread across the geographical area of the market; and
- The quantity gap that arises because companies, largely for financial reasons, produce and deliver in quantities during a given period that differ from how much individual customers purchase and consume.

In logistics contexts, Jonsson (2008) has defined utilities created in the supply chain to satisfy customers' needs:

- Form utility, which represents the added value created by refining input goods into finished products;
- Place utility, which represents the added value created by making products available for acquisition at the right place;
- Time utility, which represents the added value created by making products available for acquisition at the right time; and
- Ownership utility, which represents the added value created when ownership rights or the right to use a product delivered are transferred to customers.

3.4 Coordination

Coordination as a phenomenon has been addressed in different research fields. This thesis makes use primarily of theories of coordination in logistics research. In order to provide a frame of reference for coordination of activities in B2E supply chains, this section identifies central aspects of coordination as a concept whereas the next section (3.5) reviews the context: B2E supply chains.

This thesis follows Arshinder et al. (2008) who refers to Malone and Crowston (1994) and states that their definition of coordination: 'the act of managing dependencies between entities and the joint effort of entities working together towards mutually defined goals (p. 318), is that the most commonly accepted definition. In line with the description of the objective of the B2E supply chain as a system (see 2.7.4), the term *mutually defined goals* here indicates delivering biomass at a low cost to a power plant. *Managing dependencies* refers to how

different actors or entities adopt different *means of coordination*, which is to arrange an activity to suit activities of other actors in the supply chain (e.g., levelling demand patterns). Lastly, *dependencies* is a term referring to how a means of coordination relates to other activities within the supply chain.

In the context of supply chains, *coordination* is often used interchangeably with *cooperation*, *collaboration*, and *integration* (Jahre and Jensen, 2010). Skjoett-Larsen et al. (2003) have suggested that collaborative planning, for example, should be viewed as a general approach to coordinating processes among participants in supply chains. Accordingly, coordination and collaboration to some extent overlap and represent adjacent concepts, which allows for borrowing theories and terminology—for instance, regarding where to coordinate in the supply chain, what to coordinate, and what potential barriers to coordination are.

In the context of collaboration, Baratt (2004) has argued that among the important questions are when, where, why, and with whom to collaborate, while Romano (2003) has concluded that the most commonly coordinated flows in supply chains are those of information and physical material. Baratt (2004) has also proposed terminology for describing collaboration in terms of scope that distinguishes vertical (i.e., with suppliers), horizontal (i.e., with companies at the same level), and internal (i.e., within the company) collaboration. Coordination also involves a temporal dimension; as Jahre and Jensen (2010) have stated regarding humanitarian logistics, coordination occurs at operational, tactical, and strategic levels. In the light of these divisions, the scope of coordination in this thesis is the different activities in the supply chain that can be coordinated by actors, including hauliers, suppliers, and energy producers.

Different factors shape whether coordination can be applied. As Matopoulos et al. (2007) have demonstrated, trust, dependence, and risk and reward sharing are vital when determining the breadth and depth of collaboration. At the same time, Skjoett-Larsen et al. (2003) have argued that actors maintain different attitudes (i.e., negative, indifferent, and positive) toward different types of collaboration (e.g., on transport and production). It is thus suggested that attitudes and behaviour can serve as either prerequisites for or barriers to actors' applying the coordination of activities in B2E supply chains. However, other types of barriers also exist; for instance, technology can be required for collaboration (Whipple and Russell, 2007). On that topic, Baratt (2004) has argued that an obsession with technology can itself be a barrier to collaboration and that, in response, it is more important to decide with whom to collaborate and over what to collaborate at earlier stages. Plus, implementing collaboration also requires significant resources (Whipple and Russell, 2007), and organisations aiming to collaborate with too many customers and suppliers will not succeed (Baratt, 2004). Though collaboration is somewhat more comprehensive than coordination, these could be barriers for coordination as well. In short, several potential barriers to the coordination of activities exist within B2E supply chains.

Unsurprisingly, coordination in a supply chain does not happen spontaneously, but requires some sort of function to implement and ensure. One such function is coordination mechanisms that control the actions of individual supply chain members (Romano, 2003) and for which Xu and Beamon (2006) have argued are

constituted by different sets of methods applicable to manage interdependence among organisations. Adding that the suitability of these mechanisms depends on the coordination problem, Fugate et al. (2006) have presented three major groups of coordination mechanisms in terms of price coordination: quantity discount mechanisms, non-price coordination mechanisms (e.g., by quantifying flexibility), and flow coordination mechanisms (e.g., vendor-managed inventory). Earlier, Mintzberg (1979) divided coordination mechanisms into mutual adjustment, direct supervision, and four types of standardisation: work processes, outputs, norms, and skills. By some contrast, Arshinder et al. (2008) divided coordination mechanisms into the categories of contracts, IT, information sharing, and joint decision making. In any case, since a well-functioning coordination mechanism across the flow decreases costs and increases the level of service (Flygansvær et al., 2008), coordination mechanisms are needed to control how different means of coordination are managed—for instance, how contracts can distribute the cost and benefits of bartering volumes between suppliers and energy producers. Ultimately, since there are several different mechanisms from which to choose, selection should depend upon what exactly is being coordinated.

In sum, this section has defined and presented the scope of coordination in this thesis—the physical flow in B2E supply chains, which can be improved through means of coordination. However, there are barriers towards the use of means of coordination and coordination mechanisms that are needed for the means of coordination to be implemented.

3.5 B2E: The context of the focal product

The B2E supply chain can be subdivided into three parts—namely, the upstream, the midstream, and the downstream (An et al., 2011)—though Sandersson (1999) has alternatively identified upstream supply, conversion, and downstream provision. The upstream, which is the focal part of this thesis, is that which supplies B2E production; the midstream refers to energy conversion in power plants; and the downstream comprises energy distribution to consumers. As shown in Figure 15, forest biomass is generally separated in the forest into roundwood and forest residues, which are used to make different products and for different purposes. At the other end of the supply chain, there are different customers in terms of large (e.g. coal fired power plants) and small scale users of pellets (e.g. households), as well as conventional CHP plants using forest residues, for example. What follows is a summary of the current body of knowledge of the configuration of the supply chain and the physical flow of B2E, which to some extent overlaps with frame of references in Papers 1-5, appended to this thesis, but provides a more holistic, less detailed view. This review provides an understanding of the context of the physical flow, which pre-treatment technology and coordination of activities can improve.

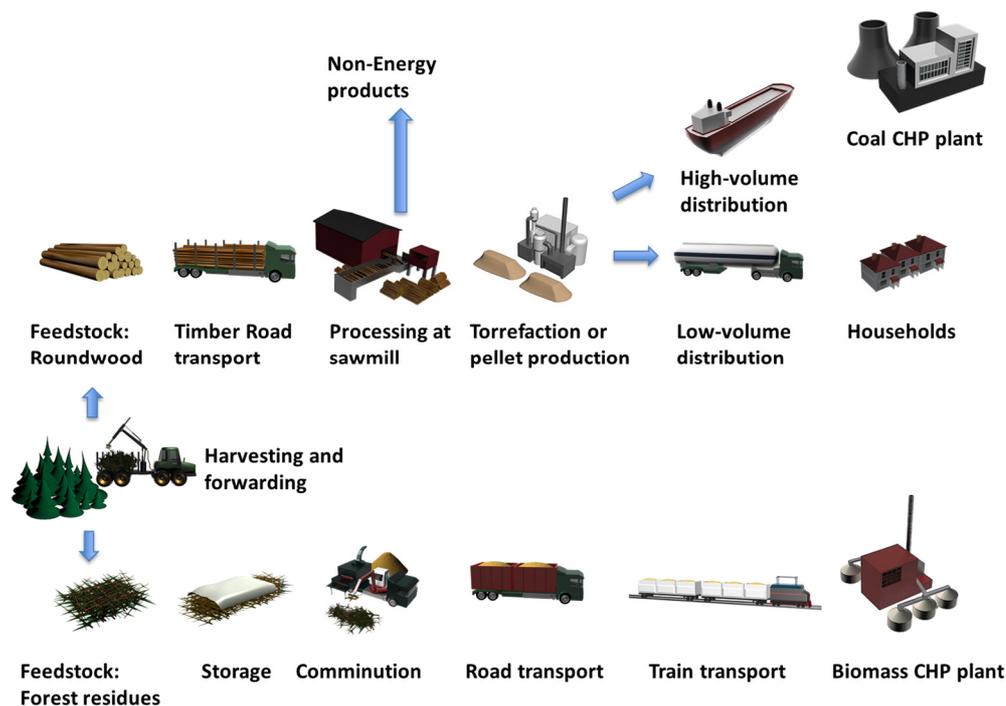


Figure 15: Stages in the physical flow in B2E supply chains

3.5.1 Feedstock

Though feedstock characteristics differ according to several aspects related to its type and location, in this thesis all feedstock originates in the forest. Actors in energy supply chains can procure biomass either directly from the forest (e.g., in forest residues) or from sawmills in the form of by-products (e.g., sawdust). Depending on the source, which can be described, for example, by geographical location or type, feedstock has numerous properties, all with implications for how suppliers organise the supply chain, as well as for procurement by operators of torrefaction plants and energy-producing companies.

Geography. Biomass can be classified in terms of geographical dispersion. Primary feedstock is acquired directly from the source—in this case, the forest—which complicates logistics (Möller, 2003, Gronalt and Rauch, 2007). Secondary feedstock in the form of by-products consists of refined biomass or return wood from sawmills, for example. The main logistical difference is that secondary feedstock is sourced from a single geographical point, whereas primary feedstock has a geographical spread and thus requires a different approach to sourcing and inventory control.

Ownership. Forests from which feedstock originates are owned and controlled by either large corporations or small private owners. Regarding accessibility to these resources, previous research has suggested that buyers should be highly active in their contact with private forest owners in order to convince them to sell biomass (Bohlin and Roos, 2002).

Competition and integration. In some cases, the wood fuel market is closely integrated with the forest sector, either via business relations or dependency on

supply feedstock from one sector to another (Roos et al., 1999). Feedstock can be used by several industries, which induces competition between pellet producers and CHP plants (Monteiro et al., 2012), yet also with non-energy sectors such as the particleboard industry (Selkimäki et al., 2010). Integration and competition are largest in countries where biomass use is well developed (e.g., in Europe), whereas in low-cost biomass countries, competition and integration are less important. Finnish pellet producers, for example, depend on the forest sector, for their lack of feedstock stems from the decreased number of sawmills, which has caused pellet plants to run at less than full capacity (Selkimäki et al., 2010).

Seasonality in supply. Seasonality in supply is more clearly accentuated for other types of biomass that do not originate from forests—for example, agricultural biomass (Wolfsmayr and Rauch, 2014). However, due to varying weather conditions, the period during which biomass can be supplied from forests can be limited (ibid). For instance, in Austria, forest roads cannot bear loaded trucks until snowmelt or after heavy rainfall (Gronalt and Rauch, 2007). Thus, storage might be needed in the supply chain as a means to manage seasonality in supply.

Cost. Feedstock cost influences varies, for example, on the national level due to competition (Trømborg et al., 2013). Feedstock cost can also differ significantly across regions and over time and is thus a major driver of international trade. The low cost of feedstock coupled with its large potential favours countries such as Canada and Brazil in producing and exporting refined biomass (Junginger et al., 2008, Heinimö and Junginger, 2009).

Quality for end users. Feedstock can also be segmented according to different quality parameters, including moisture content, contamination, and ash content. Some feedstock such as stumps is desirable only for some types of customers (e.g., large CHP plants that are flexible in receiving feedstock of fluctuating quality), yet not for customers unable to handle contaminations.

Quality for logistics operations. Lastly, feedstock quality differs, for instance, in terms of energy density, which is a function of moisture content and bulk volume. This trait poses implications for transportation and handling efficiency.

3.5.2 Harvesting and forwarding

Harvesting and forwarding (in-forest transport) can be arranged differently, and several factors affect the selection of forwarding equipment and the cost of forwarding.

Time constraints. Since the major share of a tree's economic value is its stem, which is purchased by pulp and paper industries, that sector has the greatest say on when trees should be harvested. Forest residues are seen as a by-product, and bioenergy production seldom exerts a major influence on decisions made in the forest (Richardson, 2002). From a logistical point of view, roundwood involves a pull system, whereas forest residues entail a push system; as a result, storage is required throughout the B2E supply chain in order to bridge the gap between supply and demand. Furthermore, when forests are harvested, forest residues are left to dry, generally for at least one summer, to increase the quality in terms of

calorific value and improve transportation properties due to decreased moisture content, as well as to ensure sustainability in the forests by letting needles fall off. In effect, these circumstances pose time constraints on the configuration of the physical flow.

Selecting forwarding equipment. Forest residues can be forwarded (i.e., transported in forests), comminuted (i.e., chipped into small pieces), uncomminuted, or bundled. Bundling improves transport efficiency in the forest and in some conditions can be more profitable for the entire supply chain of forest residues (Johansson et al., 2006). This circumstance, however, poses some requirements for supply chains, including customers' ability to perform cost-efficient comminution. In Finland, for example, Kärhä and Vartiamäki (2006) have shown that bundling is the most competitive method when transport distance exceeds 60 km. Bundling offers other logistical advantages besides increasing transport efficiency, including the ability to use conventional roundwood machines and trucks for transport to customers (Johansson et al., 2006).

3.5.3 Storage

Storage is most often required to bridge the gap between supply and demand. The configuration of storage poses implications for its cost, the quality of feedstock, and the cost of subsequent transport and handling.

Dimensions of storage. Biomass can be stored in forests, on roadsides, in terminals, or at power plants. Key parameters affecting storage costs are type of storage, duration of storage, volume to be stored (Gold and Seuring, 2011). The shape in which biomass is stored is significant, since comminuted forest chips can cause remarkable greenhouse gas emissions (Wihersaari, 2005). An important issue concerning storage is whether forest residues should be stored in covered storage on roadside, which comes at a cost, yet which generally improves the quality of biomass and enables more efficient transports downstream, by reducing moisture content.

3.5.4 Comminution

To increase its transport efficiency and prepare it for energy conversion, biomass is often comminuted. How, where, and when comminution is performed shapes cost and poses implications for subsequent transport and handling costs, as well as for the quality it bears upon reaching customers.

Configuring comminution. Two principally different technologies are available for comminution: chipping using knives and grinding using hammers. Spinelli et al. (2012) have compared the two techniques to show that chipping affords higher productivity and superior chip quality, whereas grinding should be used only when feedstock has high levels of contamination. Forest fuel can be comminuted in its terrain, on roadsides, in terminals, or at power plants. Scheduling vehicles used in B2E supply chains requires considering both time and place, for a trade-off exists among transportation, comminution timing, and storage efficiency, largely for three reasons. One, comminution equipment reaps benefits from economies of scale (Kanzian, 2009), which are most efficiently achieved at terminals. Two, early comminution in the supply chain (e.g., on roadsides) allows

efficient transportation. However, three, since biomass is a biological material, it suffers from biological breakdown and should thus be consumed as soon as possible after comminution (Wihersaari, 2005). Finally,

3.5.5 Road transportation

Since transportation cost accounts for a significant share of procurement costs, selecting transport trucks is important, as well as influenced by several factors.

Selecting trucks. Several different types of vehicles (trucks) are available for the transport of forest fuel, and for road transport, different ones are suitable in different conditions, which differs with respect to the type of load units as well as the form the biomass is transported in. When distances are short, for example, it can be profitable to transport loose residues (Ranta and Rinne, 2006, Asikainen, 2001), whereas for long-distance transport, a bundling system can be more profitable (Johansson et al., 2006). Choosing vehicles is not only a matter of operational efficiency, for cases exist in which external reasons affect the choice. For instance, container systems can be used to avoid spreading too much forest chip content along roadsides in urban areas (Björheden, 2000).

Cost of transportation. In their review, Gold and Seuring (2011) identified mass, volume and energy density of biomass, travel time, distance, speed, road properties, and infrastructure as major factors of road transport cost. Optimising travel routes is one way to reduce transportation costs (Flisberg et al, 2012), for which it is essential to schedule trucks according to the number of round trips that they can make each day (cf. Rogers and Brammer (2009). The utilisation rate of trucks is also significant, for instance, due to factors such as the possibility of backhaul (Rauch and Gronalt, 2011).

3.5.6 Transport network configuration

In transport network configuration, a key factor shaping overall cost is structure—that is, how links and nodes are managed to constitute supply chains; see Figure 16 for several possible setups. Transport network configuration is also a function of numerous aspects and needs to be adapted to the specific case.

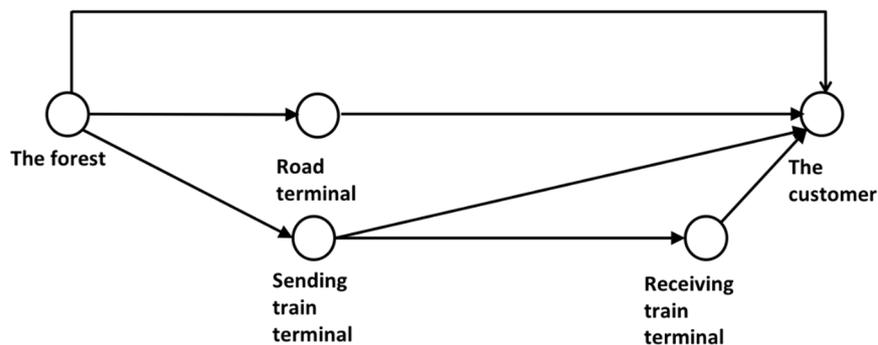


Figure 16: Alternative supply chain routes

Transport network structure. In the context of transport network structure, a critical decision is whether to use direct supply from roadsides to power plants or use handling via terminals. For forest fuel, system configuration should be as

simple as possible, which can be achieved, for example, by minimising the number of handling steps (Eriksson and Björheden, 1989, Hall et al., 2001, Kanzian, 2009), since each additional operation is associated with an additional cost. It is therefore important to adopt a systems perspective, which considers transport and processes at the same time, in order to understand the wider implications of decisions made at each stage of the supply chain. When configuring a supply chain, site-specific matters such as the regional characteristics of resources and infrastructure have to be taken into account (Ranta, 2005). It can also be necessary to use various systems in order to ensure supply throughout the year; such a setup often uses a combination of direct supply and intermediate storage (Allen, 1998).

Drivers for using terminal supply. A few reasons for choosing terminals have been identified. The major benefit of using terminals is that forest fuel can be stored to mitigate the gap between supply and demand that occurs throughout the year (Gunnarsson et al., 2004). Yet, since terminals are often required to impose a minimum capacity for storing forest fuels in order to hedge against variability in demand, costs are often higher as a result (ibid). Nevertheless, transporting via terminals can be advantageous since larger, central chipping machines reap operational advantages due to economies of scale. At the same time, terminals can be used to mix raw material into a uniform fuel (Björheden, 2000).

Multiple transport modes. Transporting forest fuels offers advantages by using a combination of transport modes, though the distance needs to exceed a certain length in order to overcome the fixed components of dual transport modes and transshipment costs. In North American settings, it is profitable to transport forest chips with a combination of trains and trucks when the distance exceeds 145 km (Mahmudi and Flynn, 2006) and, in Finland, when it exceeds 150 km (Tahvanainen and Anttila, 2011). However, these rates stem from a theoretical viewpoint, meaning that local infrastructure also needs to be taken into account (Mahmudi and Flynn, 2006). This finding is consistent with the conclusion that rail transportation in Finland is hampered by a lack of railway terminals and terminals at energy plants (Tahvanainen and Anttila, 2011). The break-even distances for these B2E transports is rather short compared to, for example, that of non-bulk goods transported via intermodal terminals, the distance of which generally needs to exceed 500 km in order to be viable (Flodén, 2007). However, if the supply chain requires a buffer, then rail transportation poses greater potential, even if distances are less than 100 km (Tahvanainen and Anttila, 2011).

Finally, major factors of the cost of rail transportation are the cost of electricity to operate trains and the cost of investing in the engine (Flodén, 2011). As such, the utilisation rate of trains is crucial, and using the train year-round and achieving backhaul can lower the cost significantly. Other factors likely to influence rail transportation are the structure of the transportation network, the time period, the cycle length, and the size of the train units (Osleeb and Ratick, 2010).

3.5.7 Refinement of biomass by pelletising and/or torrefaction

Biomass can be refined in different types of units, including pellet plants or torrefaction plants, and several decisions made at the plant pose wider implications for supply chains.

Plant configuration. Common to bioenergy plants using geographically spread feedstock is the trade-off of economies of scale in plants themselves (i.e., cost of production) and the diseconomies of acquiring large volumes of feedstock from distant locations (i.e., cost of inventory and transportation). The logistical constraint relates to feedstock as a distributed resource that can, for example, imply low volumes at scattered locations. The larger a plant, the longer the average transportation distance and hence the greater the haulage cost (Cundiff et al., 2009).

Location and integration. Pellet production can reap economic and environmental advantages from integration with CHP plants (Wahlund et al., 2002, Song et al., 2011). Smaller pellet plants using by-products for pellet production are often co-located with their suppliers in order to minimise transportation costs (Selkimäki et al., 2010). Besides co-location's capacity to induce logistical benefits, two other major advantages can be reaped by integrating plants that produce different kinds of products; by sharing existing structures, investment costs are lowered, while via energy and material exchange between processes in the plants and by using the same personnel and equipment, operating costs can be lowered as well. Integration can also be a concern for torrefaction plants, which can, for instance, lower production cost via integration with other industries such as sawmills or CHP plants. Due to variation in outdoor temperature, the demand for district heating varies throughout the year, which often implies unused capacity during the summer months (Starfelt et al., 2015). Nonetheless, the performance of torrefaction requires extensive individual assessment for each plant, since operating conditions can differ significantly (e.g., Sermyagina et al 2015).

Operational decisions. Pellet quality is a function of not only feedstock selection, but also choice of process. Shang et al. (2012) have identified a relationship between choice of process and pellet quality, by showing that high torrefaction temperature results in greater weight and energy losses, as well as negative relationships between pellet temperature and durability. Traditional pellets are grouped into three categories (i.e., A1, A2, and B), the quality of which is contingent upon parameters such as ash content, heating value, and net calorific value, which in turn affect the final energy conversion process and maintenance of boilers. The quality parameters of torrefied pellets are important to supply chain configuration for at least three reasons: durability, which affects handling and storage; the degree of hydrophobicity, which affects storage; and energy density, which affects transport efficiency.

Cost of refinement plants. Among factors affecting costs at bioenergy plants are the size of pellet plants (Nilsson et al., 2011) and CHP plants (Flynn et al., 2003), both of which reap benefits from economies of scale. Large-scale plants enjoy advantages from the high utilisation rate of equipment and more efficient use of personnel (Nilsson et al., 2011, Sultana et al., 2010). For large-scale plants, the

costs of feedstock and energy account for the largest share, whereas personnel and capital have a smaller share (Nilsson et al., 2011). For a pellet plant to achieve long-term success, it is important to sustain the combination of a secure market of large-scale customers with low profitability and a nearby small-scale market of customers posing high profitability (Wolf et al., 2006). However, increasing the scope of customers requires investment in different logistical resources—that is, bulk-handling systems for large customers and plastic bags for smaller ones.

Cost of torrefaction plants. A few recent studies have assessed the cost of constructing and operating torrefaction plants. The cost of investing in torrefaction poses significant advantages due to economies of scale and should exceed 40 MW_{th} (Uslu et al., 2008). Operating availability is also a significant parameter affecting production costs (Shah et al., 2012, Uslu et al., 2008), though moisture content is also critical (Shah et al., 2012). Another important parameter affecting torrefaction costs is torrefaction severity (Shah et al., 2012).

3.5.8 Distribution of refined products

Two generic distribution systems of refined products exist—namely, high- and low-volume distribution—for which several factors have been identified that influence operators of and operations at pellet or torrefaction plants.

High-volume distribution

Transportation. For trucks, loading capacity can be as low as 35% for TDB based on how well the carrier is adapted to volume or weight and how the load is arranged on the trucks. Rail transportation is to a far lesser extent limited by weight and offers a 70–80% fill rate for TDB. Whereas road and rail transport are hampered by restrictions, sea shipping reaches or is close to 100%, depending on the design of the vessel. Distribution to large-scale users often involves intercontinental shipping with Panamax or handymax vessels and uses ports for storing up to 200,000 tonnes, whereas the end user provides storage for up to 10,000 tonnes (Sikkema et al., 2011).

Contracts. Trading pellets depends greatly upon transportation costs, which play a significant role in transoceanic supply chains (Sikkema et al., 2010) and are sensitive to price fluctuations in freight transport. For instance, there have been cases in which the transatlantic trade of pellets has been hampered by price fluctuations in freight rates (Junginger et al., 2008). The type of chartering contract is also important, for some suppliers have long-term contracts that render them immune to price roller coasters (ibid)

Market dynamics. Pellets are a dry bulk commodity subject to seasonal fluctuations in freight spot rate for bulk goods. Freight rates have been found to vary from -18.2–15.3% in individual months within a year, which can affect tactical shipping operations, including the timing of dry-docking, chartering strategies, and switching between freight markets (Kavussanos and Alizadeh-M, 2001)

Infrastructure. A major barrier to increased trading is infrastructure, both in sending and receiving countries (Junginger et al., 2008). Some end users of pellets

such as coal-fired CHP plants are capable of receiving large vessels, whereas other plants require transshipment either with smaller barges or with road–rail transport due to infrastructural factors, which thus places additional requirements on the supply chain configuration in terms of intermediate storage. Capacity within transportation corridors can also pose problems, for inland waterways limit the size to small ships, while some railway corridors are congested (van Dam et al., 2009).

Low-volume distribution

For small-scale users (i.e., of bulk or plastic bags), transportation is performed by truck, primarily from smaller domestic plants, and distributed via retailers or via direct supply from plants to households based on annual delivery schemes. Given the low value of biomass, distribution is limited to a maximum distance on road—for example, 300 km in Finland (Selkimäki et al., 2010). A barrier to intercontinental distribution for small-scale users is the infrastructure required in receiving countries (Junginger et al., 2008). It has also been shown that time negatively impacts the durability of white pellets stored in plastic bags (Lehtikangas, 2000), though such effects on TDB have yet to be shown.

3.5.9 Energy production

In this context of this thesis, energy producers range from households with small-scale boilers to large coal-fired power plants, as well as differ in terms of numerous parameters that shape how the supply chain is configured. Household users have a marginal role in this thesis and the focus is rather on describing different aspects of large-scale users, primarily in terms of conventional biomass-fired CHP plants.

Size and technology. As argued earlier, all bioenergy plants that source scattered biomass need to negotiate a trade-off between economies of scale in producing energy and diseconomies of scale within transport of biomass to the plants. Furthermore, technology used for energy conversion determines which assortments can be used for energy production, which in turn affects routes in the physical flow. Trømborg et al. (2013) shown that energy producers using technologies that can use various biomass assortments can benefit from shorter distances, which implies lower cost, and are also less vulnerable to price increases.

Energy production pattern. Energy producers have different energy production patterns (i.e., base-, mid-, or peak loads) in terms of how they produce energy throughout the year—for instance, due to the length of the energy production season. Some plants are operated for roughly the same loads throughout nearly the entire year, often use forest residues or household waste, and are generally defined as base-load plants. Other plants use pellets, for example, and are operated for part of the year, meaning that minimum, average, and maximum energy production differ throughout the year, called mid-load plants. To prepare for certain spikes in demand, smaller plants—for example, with oil boilers—are used and often defined as peak load-plants. These plants require different supply systems to satisfy demand—for instance, when it comes to the storage of biomass.

In summary, the frame of reference has provided a foundation for investigating how the physical flow can be improved. Two particular approaches, pre-treatment technology and coordination, have been described, and these provide the foundation for addressing RQ2 and RQ3, respectively. However, as the main unit of analysis of this thesis—the physical flow—is important, relevant logistics aspects such as physical distribution and transportation in particular, as well as supply chain design and supply chain configuration have also been presented. Finally, as the context is equally important, a thorough description of B2E supply chains have been presented, which also plays a part in addressing RQ1.

4 Summary of appended papers

This chapter summarises the five appended papers with respect to approach, findings and contribution.

4.1 Paper 1 – ‘Factors shaping biomass-to-energy supply chain configuration – The case of forest fuel’

Approach:

Understanding which factors shape an effective and efficient configuration of B2E supply chains is important if B2E is to be made cost competitive in comparison to fossil fuel. Identifying factors that the industry perceives as important provides a platform for configuration of future supply chains, in terms of understanding how to make use of different paths for improvement, e.g., technological or managerial developments. The aim of this paper was to identify factors that shape the configuration of the B2E supply chain. This was done through a literature review and through interviews with actors in B2E supply chains: producers of forest fuel, transportation and handling companies, and energy producers.

Findings:

The results of the literature review are summarised in Table 8. These can be grouped into two types of factors shaping supply chain configuration. First, there are factors inherent in the environment of B2E supply chains, in line with systems theory as proposed by (Churchman, 1981); these factors are impossible to influence. For example, dispersed geography sets constraints for the vehicles that can be used, and climate dictates the terms of transportation routes. These are environmental factors (see the second column in Table 8). Secondly, it is also noted that there is no one size fits all solution for supply chain configuration. In every stage along the supply chain, there are many choices that can be made, and different factors influence either the cost or the efficiency of an activity. Knowing which trucks are preferable under various conditions, or understanding that integration of operations can influence efficiency of forwarding, should help to shape the decisions about these activities. Therefore, the factors shaping these decisions are labelled as efficiency factors (see the third column in Table 8).

Table 8: A summary of literature derived factors shaping supply chain configuration

	Environmental factors	Efficiency factors
Harvesting and collection	<ul style="list-style-type: none"> • Supply is often of a push type • Time constraints influence the timing of forwarding • Forest geography characteristics (e.g., tree species, terrain, topography, season, load size, stack volume, distance between stands, volume per hectare, forwarding distance, and landing type) shape forwarding costs • Safety issues shape the selection of machinery 	<ul style="list-style-type: none"> • Integration can lower costs • Shape (i.e., bundled versus unbundled) can lower forwarding costs
Comminution	<ul style="list-style-type: none"> • Customer ability to comminute dictates terms for upstream comminution • Weather, local environment, and type of forest chips produced shape efficiency of comminution 	<ul style="list-style-type: none"> • Comminution type (i.e., grinding or crushing) influences efficiency • Location of comminution sets conditions for scale that shape efficiency • Assortment, organisational setup, operators, harvest conditions, roadside landing capacities, and availability of production machinery shape the efficiency of comminution • Storage time shapes the productivity of comminution
Storage	<ul style="list-style-type: none"> • Storage is required to bridge the gap between supply and demand • Climate and weather influence whether covered storage is preferable 	<ul style="list-style-type: none"> • The shape in which biomass is stored (i.e., comminuted or uncomminuted), type, and duration influence storage efficiency
Transport	<ul style="list-style-type: none"> • Infrastructure and road properties are preconditions for a well-functioning supply chain • Distance to customers shapes both selection of transport modes and vehicles within each mode • Stakeholder preferences can shape vehicle selection • Cost of energy influences efficiency of different transport modes (e.g., increased energy costs can suggest a shift) • Available infrastructure shapes decisions about transport mode 	<ul style="list-style-type: none"> • Product properties in terms of shape and moisture content influence transport efficiency • Truck type influences transport efficiency
Network design	<ul style="list-style-type: none"> • Terminals can be needed as a place for storage in order to manage supply and demand • Infrastructure, phytosanitary risks, noise emissions, accessibility, construction costs, water protection, land use category, and nature protection determine the location of terminals • Powerplant scale and location shape to where transports are routed 	<ul style="list-style-type: none"> • The number of handling steps influences the cost of supply • Terminals can be used to enhance quality of biomass • Transport cost determines the locations of terminals • Competition among powerplants and procurement strategy shape how the flow is routed • Relationship management is important in order to secure nearby supply

In a similar way, empirical evidence from interviews was analysed and grouped into the same categories, see Table 9. There were no major contradictions between the factors identified in the literature and the interviewees' views. Rather, a number of factors were the same, and additional examples from the interviews strengthen the results of the literature review. In particular, both bodies of knowledge acknowledge that (1) it is important to select vehicles according to local circumstances; (2) an important decision is to deal with the trade-offs in efficiency, storage, transport, and comminution; and, (3) terminals are acknowledged as a necessary evil, often implying extra costs. Also, the interviews do provide a good complement to the existing literature, by identifying a number of additional categories of factors in terms personal beliefs, differing priorities, and a number of business reasons, that shape supply chain configuration.

Table 9: A summary of interview derived factors shaping supply chain configuration

Activity	Environmental factors	Efficiency factors
Harvesting and collection	<ul style="list-style-type: none"> Stakeholder preferences can shape vehicle selection 	<ul style="list-style-type: none"> Shape (i.e., green or non-green) influences administrative cost (i.e., scheduling of vehicles)
Comminution		<ul style="list-style-type: none"> If biomass can be sold year-round, as enabled by lowering the price, then the utilisation rate of equipment can be increased
Storage		<ul style="list-style-type: none"> There is an important trade-off between storage and comminution efficiency
Transport	<ul style="list-style-type: none"> The length of the supply season influences transport efficiency Weather can dictate terms for vehicle selection 	<ul style="list-style-type: none"> The ability of vehicles to perform both comminution and transport influences supply chain efficiency The scale of transportation companies sets conditions for vehicle selection The ability to transport other types of goods is important for transport efficiency
Network design	<ul style="list-style-type: none"> Fluctuations in demand shape terminal use Accessibility of forest roads due to weather creates a need for terminals Low investment cost shapes terminal location The diversity of customers in terms of energy production patterns, flexibility in fuel use, and ability to store and comminute shape the routing of flows 	<ul style="list-style-type: none"> Segmenting assortments when routing via terminals is important to lowering costs Forest residues need to share fixed and operating costs of terminals with other product flows Business reasons such as future expansions shape terminal locations Energy producers' interests in managing their own terminals shape how the flow is routed Energy producers' need for supply security shapes storage in the supply chain

Contribution:

The identified factors could have implications both for future research and for the industry. Academic contributions include:

- Some of the factors can be incorporated into and evaluated through mathematical models. For example, interaction with other types of supply chains could be evaluated through optimisation models.
- The identified factors comprise a vast list that can serve as a starting point for making delimitations in optimisation models.

For industry, the contribution is:

- The factors provide an overview for actors within B2E supply chains that can be used as a starting point for actors to understand each other's operations and to avoid system sub optimisation.

4.2 Paper 2 – ‘Supply chain configuration for biomass-to-energy: The case of torrefaction’

Approach:

Torrefaction offers a range of potentially beneficial logistics properties, but the actual benefits depend upon how the supply chain is configured to address various elements of customer demand. Therefore, the aim of this paper was to develop a framework for configuration of biomass-to-energy supply chains from the perspective of the torrefaction plant. The paper was underpinned by a literature review of torrefaction, related research fields such as unrefined forest fuel, pellets, and coal logistics, and prescriptions for configuration derived from SCM.

Findings:

Five major steps within the supply chain were identified: (1) feedstock, (2) supply system, (3) production (torrefaction), (4) distribution system, and (5) customer demand. For each of the steps, a number of attributes that had implications for supply chain configuration were identified. Based on the identified attributes and a conceptual argumentation, a framework for *torrefaction configuration* was proposed, see Figure 17. Torrefaction configuration refers to decisions on the organisation of production as well as upstream and downstream activities. The framework was exemplified for three distinct types of customers, which mainly differ in size, energy production pattern, and quality demand. They range from large coal-fired power plants, to medium-sized combined heat and power plants and district heating, to household consumption of pellets. Based on prescriptions for linking supply and demand from SCM, three configurations were proposed. For these, it was argued that important torrefaction decisions comprise torrefaction plant configuration, product characteristics, feedstock characteristics, and distribution system. Also, two general propositions were derived in the paper:

P1: Depending on type of demand, torrefaction will serve several functions by bridging different types of “gaps” in terms of time, place, quality and ownership.

P2: The production strategy of the torrefaction plant needs to be aligned with the distribution system according to the relative importance of different quality parameters (energy density, durability and hydrophobicity) that in turn influence the supply chain efficiency for different types of customers.

Supply chain attributes		Type of customer		
		1. Large coal-fired powerplants	2. Medium sized bioenergy plants	3. Households
Demand	Quality	Low	↔	High
	Energy production pattern	Base-load	Fluctuating	Fluctuating
	Size of customer	Large	↔	Small
Torrefaction plant configuration	Location driver	Close to cheap feedstock	↔	Close to low cost production
	Plant Size	Large	↔	Small
	Function of process	Bridge gap in distance	Bridge gap in time	Bridge gaps in quality and ownership
Product characteristic	Main quality parameters	High energy density	Trade off between high energy density, durability and degree of hydrophobicity	Durability
Feedstock characteristic	Parameter affecting feedstock selection	Low cost	↔	High quality
	Feedstock competition and integration	Low	↔	High
	Feedstock location	Low cost country	↔	Close to market
Distribution system configuration	Inventory strategy	Minimise	Hold stock to bridge fluctuations	Hold stock for speculation
	Transportation mode	Large ships	Small ships, trains, trucks	Trucks
	Trading flexibility	Low	↔	High
	Network design	Physically efficient	Responsive	Responsive
	Lead time focus	Shorten as long as it doesn't increase cost	Invest to reduce lead-time	Invest to reduce lead-time

Figure 17: A framework for torrefaction configuration

Contribution:

The key contributions for academia are:

- The framework that explicates how different elements in demand serve as a starting point for the torrefaction configuration. The proposed

framework entails three configurations, but this requires further development through empirical studies using complementary methods, such as interviews or surveys, and quantification through techno-economical or optimisation models.

- The framework could contribute to the logistics and SCM research communities as well. Even though the framework was developed for the B2E context, it could provide insight into how to make use of other types of technology, which alters product properties, to increase transport efficiency for other types of goods as well.

The key contribution for the industry is:

- The framework, which has the purpose to inform operators to find a niche for the torrefaction plants, and at the same time understand the upstream and downstream implications of their decisions.

4.3 Paper 3 – ‘Analysing biomass torrefaction supply chain costs’

Approach:

In order to assist operators of torrefaction plants involved in torrefaction supply chain configuration, it is important to identify parameters influencing cost in the supply chain. Hence, the objective of the paper was to develop a techno-economic system model to address how logistics and torrefaction production parameters affect (1) the optimal size of the torrefaction plant and (2) the total cost of supplying torrefied biomass to an end user (a CHP). This was done through a literature review of related research fields to identify possible parameters influence costs in a torrefaction supply chain. This served as the basis for constructing a techno-economic model of the entire supply chain, ranging from feedstock to the gate of an end-user. The model consists of four sub-models: (1) a supply system, (2) a complete energy and mass balance of drying, torrefaction, and densification, (3) investment and operating costs of a green-field, stand-alone torrefaction pellet plant, and (4) a distribution system to the gate of an end user such as a power plant.

Findings:

The results show that the torrefaction supply chain reaps major advantages from economies of scale for torrefaction plants up to 150-200 kton_{DS}/year and that the cost curve of TDB at the gate of an end user then flattens out (see Figure 18). For the 200 kton_{DS}/year torrefaction plant, the cost for the entire supply chain sums up to 31.8 €/MWh_{LHV}, where the supply system (including biomass premium) accounts for 59.5% of the system cost, the production cost to pellets accounts for 31.0%, and the distribution system accounts for only 9.48%. There are economies of scale for both the torrefaction plant and for the distribution system. When the torrefaction plant size is increased from 25 kton_{DS}/year to 200 kton_{DS}/year, the production cost decreases from 19.8 to 9.88 €/MWh_{LHV} (a 50% reduction) but the distribution cost only drops from 3.62 €/MWh_{LHV} to 3.02 €/MWh_{LHV} (a 16.5% reduction). There are also smaller diseconomies of scale of supplying larger plants, and when plant size increases from 25 to 200 kton_{DS}/year, supply cost increases from 16.7 €/MWh_{LHV} to 18.9 €/MWh_{LHV} (a 13.2% increase).

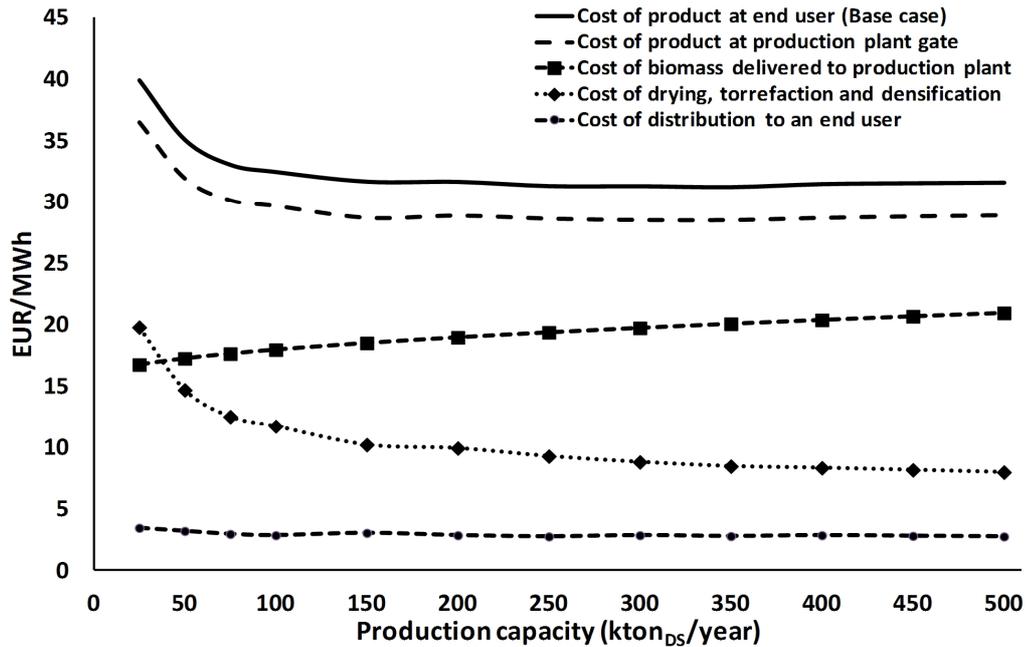


Figure 18: Cost for the torrefaction supply chain

For a 200 kton_{DS}/year torrefaction plant, the activities in the system that account for the largest share of the total costs (31.8 €/MWh_{LHV}) are in the biomass supply system (in total 18.9 €/MWh_{LHV}), which are: biomass premium at 4.40 €/MWh_{LHV}; comminution at 3.98 €/MWh_{LHV}; road transport to torrefaction plant at 3.86 €/MWh_{LHV}; and forwarding cost of 3.37 €/MWh_{LHV}; see Figure 19. The costs for activities within the distribution systems are rather low, explained by the fact that TDB has a very high energy density in combination with efficient rail transport, which keeps transportation and handling costs low. Still, the full potential advantages of TDB biomass cannot be realised due to weight restrictions in road transports, which result in the containers only having a fill rate of about 71% of total volume and also limits the number of containers to 2 instead of 3 on a truck.

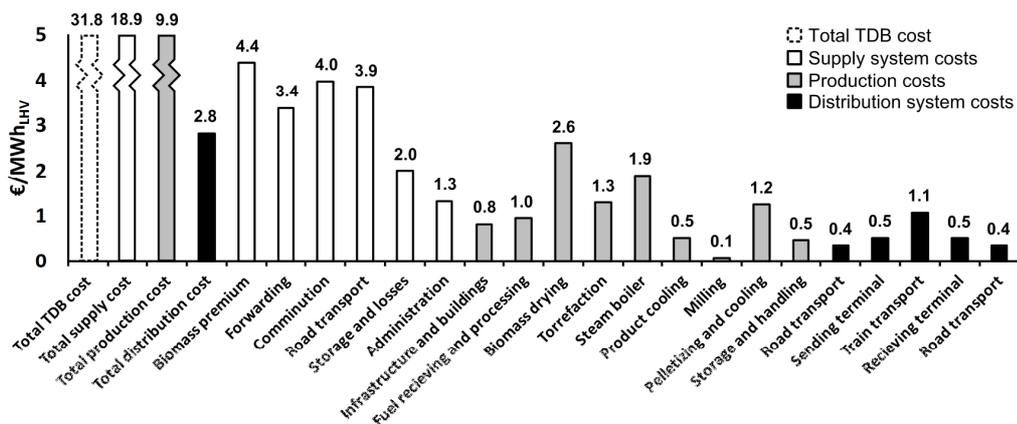


Figure 19: Costs for different activities

A vast number of parameters, both technical and logistical, were evaluated in a sensitivity analysis. The parameters with the highest impact included amount of

biomass, biomass premium, cost of forwarding, comminution and transport equipment, biomass moisture content, drying technology, torrefaction mass yield, and pellet plant capital expenditures. In relation, none of the factors within the distribution system had a significant impact, e.g., increasing the rail distance by 50% only increases total cost by 1.7%. Hence, given that distribution of TDB accounts for such a small share of the cost and that train transport is not sensitive to distance, it is suggested that torrefaction plants should be located far upstream in the supply chain.

A final sensitivity analysis on plant size showed that the amount of biomass available and type of transport vehicle had a major impact on the optimal size of plants. High amounts of biomass and low cost of transport shifts the optimal size to larger plants whereas when transport cost increases and amount of biomass decreases, optimal size is achieved at a smaller span (see Figure 20).

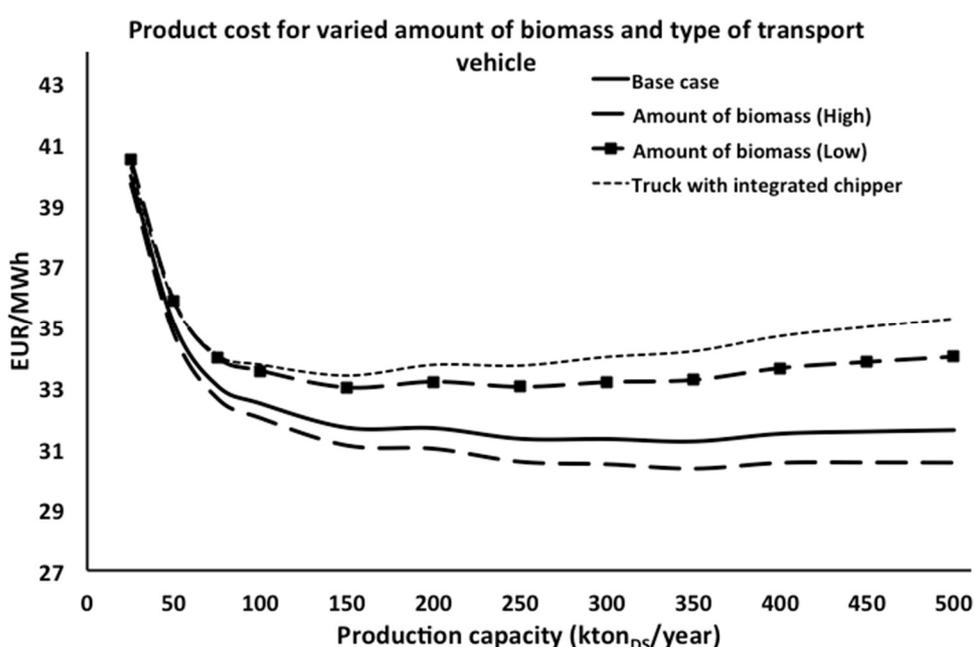


Figure 20: Optimal size of torrefaction plant for amount of available biomass and type of truck

Contribution:

The main contribution for academia is:

- The identification of cost for central parameters, providing direction for future research, in terms of where research on torrefaction is most needed.

The contribution to industry includes:

- The calculation of total cost of producing and distributing TDB to end users and the identification of central parameters influencing cost.
- The suggestions on scale (adapting to amount of available biomass) and location of torrefaction plants (far upstream in the supply chain and in areas with an abundance of biomass).

4.4 Paper 4 – ‘Coordination of activities in the physical flow of forest biomass’

Approach:

There is the potential to reduced cost of B2E supply chains by coordinating activities within the physical flow. In particular, energy producers can make decisions concerning the activities in their processes, e.g., regarding their internal material flow, which has implications for the activities in the upstream physical flow. The aim of this paper is to identify means of coordination for activities within the physical flow of B2E supply chains. The paper employed a multiple case study as a research method, using interviews as the main data collection source.

Findings:

In the paper, several means of coordination that improve the physical flow were identified and summarized in Table 10. The two most important means for actors upstream in the supply chain are the movement of activities, primarily of storage, from upstream in the supply chain to power plants, and different arrangements by energy producers that increase the length of the energy production season. A handful of means of coordination regarding the information flow, the supply process, and the internal material flow were additionally identified. A number of barriers towards applying different means of coordination were also identified.

Table 10: Different means of coordination

Means of coordination \ Coordination problems	<i>Storage</i>	<i>Terminals</i>	<i>Comminution</i>	<i>Transport distance</i>	<i>Transport queues</i>	<i>Utilisation of trucks</i>
Moving storage to power plant	+	+	+	+		+
Moving comminution to power plant			+		-	+/-
Extending energy production	+	+	+			+
Price				+		+/-
Bartering volumes				+		
Segmenting trucks					+	+
Extending open hours					+	+

Contribution:

The contributions for academia are:

- The identified means of coordination ought to inspire further research, especially in terms cost/benefit analysis.
- Even though not fully quantified yet, it is conceptually interesting that when IT companies locate server halls, this has implications for the regional forest hauliers. Similar means of coordination requiring a multi-tier approach is an interesting path for future research.
- In the paper, it was shown that moving storage downstream has potential benefits for both energy producers and forest hauliers. Moving storage downstream goes against much conventional logistics theory and should be evaluated for other types of goods as well.

The key contributions for the industry are:

- The identified means of coordination form a shortlist of options for energy producers, whereas the identified barriers form a list of obstacles that need to be overcome if different means of coordination are to be explored.
- Coordination of the physical flow cannot be achieved overnight. Rather, logistics need to be considered early in the process before the construction of the power plant, as this shapes future storage strategies.
- Managers at power plants need to be aware that how they manage their processes can have unintentional upstream impacts that could lower supply costs and thus justify lower biomass prices. In this context, two key aspects are thorough total cost models and transparency in the communication of costs.

4.5 Paper 5 – ‘Biomass-to-energy transport efficiency: hauliers’ perspectives on potential improvement efforts’

Approach:

In order to understand how to improve transport efficiency, the context in which the haulier operates needs to be understood. The paper articulated four basic premises. First, trucks are not only resources that perform activities, but they also constitute part of the physical flow in a supply chain. The implication is that other actors contribute to shaping transport efficiency as well. Second, transport efficiency is shaped in the context in which hauliers operate, which in a B2E context, implying that supply chain attributes in terms of fluctuations in demand set the conditions for transport efficiency. Third, the product itself dictates the terms for how to study transport efficiency. This implies that B2E transport efficiency cannot be understood through the same set of theoretical lenses as less-than-truckload transport, as conventional concepts such as fill rate are not applicable for bulk goods such as B2E. Fourth, the concept of transport efficiency differs depending on the perspective taken, which in B2E supply chains can be that of transport buyers, hauliers, and more broadly, the system itself. In response, the aim of this paper was to explore how improvement efforts in B2E supply chains shape the transport efficiency of forest hauliers.

A literature review helped to develop a framework for studying transport efficiency through a layered approach (see Figure 21). This framework relates improvement efforts to transport efficiency. The framework was used as a basis for constructing the interview guide and subsequently to analyse the data.

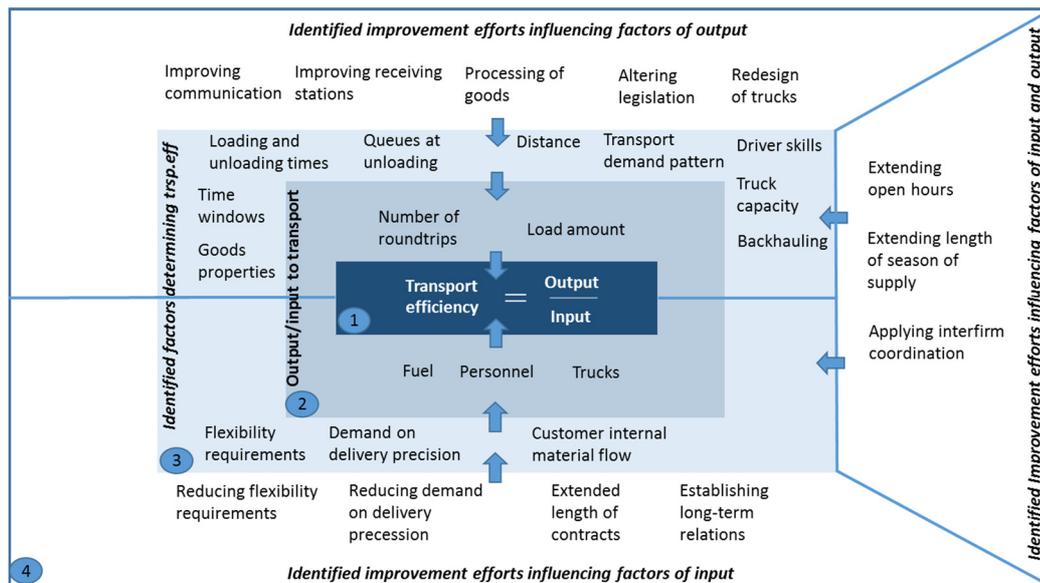


Figure 21: A layered approach for transport efficiency

Findings:

The paper explored how different improvement efforts shape transport efficiency, where the results can be seen in Table 11. In particular, it was shown that improvement efforts could contribute to increased utilisation rate of personnel and trucks on both short- and long-time horizons, as well as to avoiding detours. Furthermore, it is clear that the perspectives of hauliers and shippers differ; e.g., when it comes to the implementation of longer and heavier vehicles (LHV), several of the interviewees were opposed, arguing it leads to lower utilisation rates of trucks and less flexibility in taking assignments. Also, B2E poses a first mile problem, where communication to reduce pick-up failures is an important improvement effort. Finally, key aspects of transport efficiency include keeping skilled personnel and avoiding a cascading effect of delays.

Contribution:

The contributions for academia are:

- The developed framework (a layered approach for transport efficiency) could be used as an approach to improve transport efficiency for energy supply chains in other contexts and as well as for other types of goods.

The contributions for industry are:

- First, the results are important to communicate among actors, particularly regarding improvement efforts and their potential effects, which then justifies greater coordination or collaboration of actors along B2E supply chains.
- The framework serves as a method that could be used by hauliers to communicate with upstream and downstream actors in the supply chain about how improvement efforts can lead to increased transport efficiency. In turn, this can render lower costs—thereby enabling a lower price—for transports.

Table 11: How different improvement efforts shape outputs and inputs of transport

Improvement effort	Potential effect on factors determining output and input	Variable of output and input affected
1. Energy producers		
Extending open hours -allowing weekday night deliveries/allowing weekend deliveries	Extends the time window for transportation	Number of round trips
	Shortens distances by minimising detours, e.g. due to delays	Number of round trips
	Requires less planning for scheduling transport	Personnel (planning)
Improving receiving stations	Reduces queues at unloading	Number of round trips
	Prevents cascading effects in terms of unnecessary transport distances	Fuel
Improving communication with energy producers	Prevents queues, which minimises wait times at receiving stations	Number of round trips
	Reduces need for overcapacity to meet flexibility requirements due to disturbances	Personnel and trucks
Reducing demands on delivery precision from daily to weekly/ to between two weeks	Reduces transport distance by requiring less repositioning of trucks	Fuel
	Reduces administration in terms of scheduling transport	Personnel
	Reduces need for overcapacity to meet flexibility requirements	Personnel and trucks
Extending length of supply season from e.g. 6-9/ 9-12 months	Makes it easier to keep skilled personnel between seasons	Personnel
	Increases utilisation rate	Personnel and trucks
2. Forest fuel suppliers		
Reducing demands on volume flexibility	Reduces the need for overcapacity	Personnel and trucks
Extending length of contracts	Shapes fleet management as an incentive for risk and acquiring loans to invest in new trucks with better engines or lighter ones to increase load amounts, or both	Trucks Load amount Fuel
Establishing long-term relationships	Enables a greater extent of backhauling	Number of round trips
	Enables drivers to learn road properties in order to avoid pick-up failures, thereby reducing unnecessary driving distances and potential towing	Number of round trips
	Enables improved fleet management in terms of trucks better adapted and specialised to assignments	Trucks
Processing of goods in terms of covered storage at roadside	Accelerates loading of trucks, especially in snowy conditions	Number of round trips
	Improves properties of goods	Load amount
Improving communication with suppliers	Enables avoiding pick-up failure and thus unnecessary driving	Number of round trips
	Enables adapting trucks to be more efficient for often harsh forest road conditions	Trucks
Applying interfirm coordination in terms of bartering of volumes	Shortens transport distances	Fuel
3. Government		
Altering legislation in terms of allowing longer and heavier trucks	Increases the load of each truck, though if all factors remain the same, the utilisation rates of the truck and driver decrease as the number of round trips increases	Load amount Number of round trips
	Not all actors can receive or dispatch heavier trucks, which implies longer repositioning distances	Fuel

5 Analysis

This chapter synthesises the findings of the papers and analyses them with respect to the research questions.

The following sections analyse the findings of the five appended papers in relation to the research questions, as diagrammed in Figure 22. This chapter also makes use of literature, for two reasons in particular. First, because the research fields of B2E-logistics and torrefaction has progressed since Papers 2 and 3 were published, making use of additional literature allows for more well-founded, updated answers to RQ1 and RQ2. Second, using literature also affords a clear distinction between its contributions and the contributions of the appended papers, with respect to answering the research questions. This chapter takes a step back to better analyse findings in the appended papers, namely by imbricating divergent perspectives of actors in the papers from a holistic perspective, all according to the research model that, in this chapter, serves as an analytical model (Figure 22). As the curved arrows in Figure 22 illustrate, RQ1 identifies nine distinct attributes of B2E supply chains, which are then used as a lens for analysing RQ2 and RQ3.

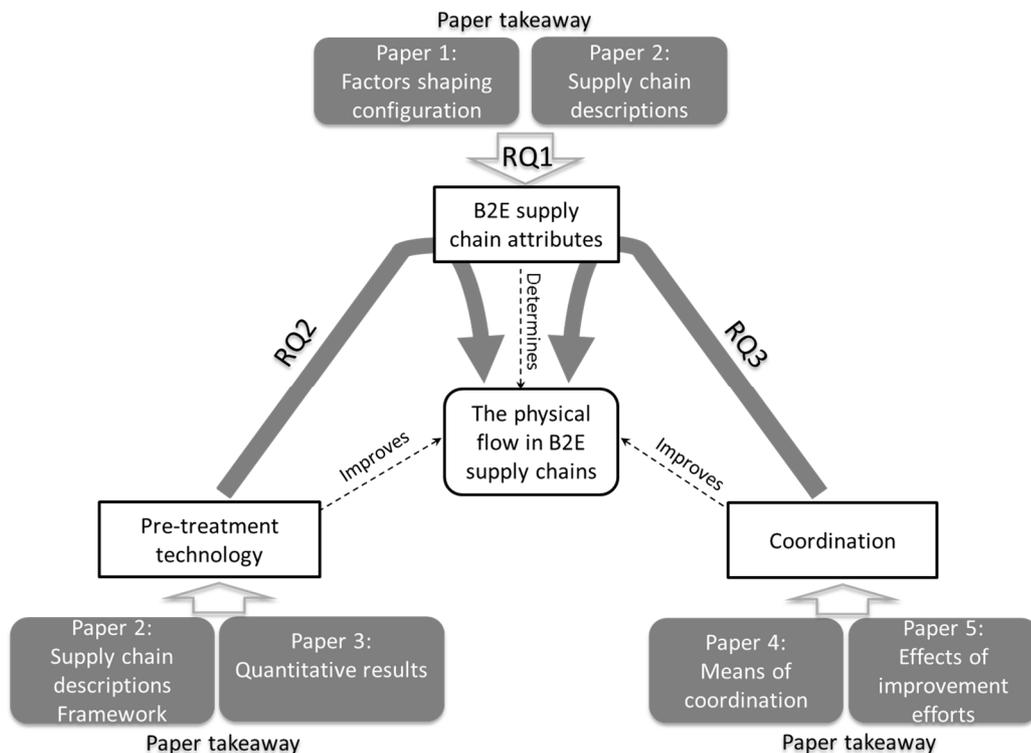


Figure 22: The overall research model as an analytical model

5.1 B2E supply chain attributes

As argued in the introduction and frame of reference, since no one-size-fits-all solution exists for physical flows in B2E supply chains, understanding how to improve physical flow first requires an understanding of the unique context of supply chains, described by their attributes. Also, attributes of supply chains determine the configuration of the supply chain and the physical flow therein and,

in turn, the performance of the flow, which can be quantified in terms of supply chain costs. In response, RQ1 was phrased as:

RQ1: What attributes characterise the physical flow in B2E supply chains?

RQ1 has been analysed based on findings from both the literature and the appended papers—primarily Papers 1 and 2, although a few findings from Papers 4 and 5 strengthen the analysis. Factors that shape the configuration of forest fuel supply chains, derived both from the literature and interviews, constitute the main takeaways of Paper 1. By contrast, literature-derived attributes, describing different stages of supply chains are the main takeaway of Paper 2. A few findings from Papers 4 and 5 also contribute to supporting the analysis of RQ1. The nine distinct attributes of B2E supply chains are defined as follows.

A1: Perishability. When biomass is comminuted into forest chips, it becomes subject to biological degradation and thus sensitive to time (Wihersaari, 2005), which justifies perishability as an attribute. In fact, Wihersaari (2005) has argued that forest chips should not be stored for more than a week before combustion in powerplants. Due to the perishability of biomass, the physical flow needs to be configured in order to reduce losses in substance and quality. Consequently, actors along the supply chain must strike a balance among the aspects of storage, comminution, and transport efficiency by making operational decisions regarding when and where to perform comminution (Paper 1). At the same time, since the perishability of biomass also constrains both transport lead times and acceptable storage times (Iakovou et al., 2010), a supply chains approach is necessary, primarily because these activities cannot be planned in isolation (Halldórsson and Svanberg, 2013). Biomass’s attribute of perishability therefore affects several operations and actors along the supply chain and shapes the configuration of the physical flow.

A2: Shape of goods. Biomass is characterised by high bulk volume and low energy density (Gold and Seuring, 2011), which makes its transport properties poor and thus circumscribes the economically feasible procurement area for a customer (Paper 1). In response, actors along a B2E supply chain can to some extent alter the shape of goods. When placed in covered storage at roadsides, biomass’s moisture content can be reduced, which raises its energy density (Sosa et al., 2015), which induces better transport properties and thus greater transport efficiency. Furthermore, governments can enact legislation to partially improve transport efficiency by allowing heavier trucks, which in enabling greater truck payloads benefits transport buyers, particularly from a systems perspective, though at the cost of risking lower revenues for hauliers (Paper 5). In all, the physical shape of biomass dictates terms for configuring the physical flow in supply chains and shapes transport efficiency.

A3: Geographical spread. Primary forest fuel is scattered in small amounts across large areas. Compared to forest byproducts such as sawdust that are produced at single points (e.g., sawmills), primary forest fuel requires a different approach for sourcing and inventory control (Paper 2). Due to the low volume available at each roadside location, economies of scale are difficult to achieve with vehicles before consolidation can occur—for example, in terminals

(Halldórsson and Svanberg, 2013). Since flows need to converge to reach customers, their consolidation becomes a vital task—one which underscores the fact that different activities cannot be planned in isolation (*ibid*).

To reduce the impact of poor transport properties and geographical spread, hauliers need to have certain sized vehicles in their fleets to ensure that they have the right truck for the right assignment as often as possible (Paper 1). For example, depending on the distance to powerplants, different trucks are preferable (Flisberg et al., 2015). For short distances, a combo truck—that is, one with an integrated chipper—could be preferable (Paper 1), whereas longer distances recommend a bundling system or (Johansson et al., 2006) or chip truck transportation (Tahvanainen and Anttila, 2011). Furthermore, there is a diversity in geographical spread in terms of amount of biomass per unit of area (Dymond et al., 2010), which influences the optimal size of powerplants and thus the cost of producing energy (Kumar et al., 2003). Accordingly, geographical spread not only poses a challenge for hauliers by influencing transport efficiency in the physical flow, but also affects other actors (e.g., energy producers) by influencing the production economy at powerplants.

A4: Weather and climate. Weather and climate clearly affect the quality of biomass. For example, snow and rain increase biomass's moisture content (Wihersaari, 2005). Of course, the factors of weather and climate differ around the world, thereby implying that storage used to guard against weather affords greater benefits in wet regions such as Finland and Ireland, yet nearly no effects in dry regions such as Italy (Erber et al., 2012). Furthermore, and also depending upon the location, weather and climate can pose constraints upon supply chain configuration; for instance, waterways can freeze, and roads can become temporarily inaccessible due to soil frost thawing (Paper 1). To be prepared for setbacks such as these, additional inventory is required to serve as safety stock. Finally, compared to fossil fuel, pellet product quality needs to be more closely controlled throughout the supply chain, e.g. through covered storage as it is a major issue for sustainability and viability (Selkimäki et al., 2010). As such, the two factors of weather and climate impact both the quality of biomass and thus the configuration of the physical flow.

A5: Customer diversity. Customers (i.e., energy producers) of biomass differ in several aspects, including type, size, and location of plants (Paper 1). Furthermore, storage differs at powerplants; some have only silos to keep biomass for a few days, whereas others have large fields on their property or in the vicinity (Ranta and Korpinen, 2011). Powerplants can also be characterised as either baseload plants, which operate for nearly the entire year, or as mid- or peak-load plants, which operate for only parts of the year (Paper 2). From another angle, powerplants differ in terms of demands put upon biomass quality; to produce second-generation biofuels, if the conversion technology allows a varied quality of biomass, then the cost of biomass at the gates of powerplants can be reduced (Trømborg et al., 2013). The implication of customer diversity for configuring supply chains and physical flows is that no one size fits all; on the contrary, a mix is necessary.

A6: Fluctuations in demand. The demand for energy from household and industries fluctuates, both along short- and long-term horizons, largely due to seasonal and short-term shifts in weather. Since energy (e.g., heat and electricity) is difficult to store, energy production fluctuates, which translates into fluctuating demand for biomass and its transport upstream in supply chains. In effect, this dynamic poses consequences for configuring the physical flow, notably in terms of requirements for deploying buffers in terminals or elsewhere (Paper 2). Safety stock can also be required, which implies an additional cost for the supply chain (Gunnarsson et al., 2004). As a result of these fluctuations, actors within the physical flow could be required to use a combination of supply systems, such as those directly from roadside to powerplants, and supply via intermediate storage (Allen, 1998). For hauliers, fluctuations in demand mean that logistics resources need to be available to manage the fluctuations in demand for transport (Paper 1). Altogether, fluctuations in demand pose constraints both for storage and the use of logistics resources within the physical flow.

A7: Time gaps between supply and demand. Since biomass is not made available at the same pace as demand, numerous time gaps exist within B2E supply chains. These gaps also occur due to connections with other supply chains, time constraints in the supply chain, customer preferences (Paper 1), material's being pushed into the supply chain, forest road accessibility, and disturbances (Paper 4). In response, suppliers need to manage the flow in order to overcome time gaps, which they can do by deploying storage at the right place, whereas hauliers need to retain an (over)capacity of logistics resources in order to cover transport peaks during periods of high demand (Paper 5). In effect, both of these necessary tasks pose additional costs in the physical flow.

A8: System openness. System openness also characterises B2E supply chains, which involve multiple interactions with other types of products, industries, and supply chains. For a high-performing physical flow, synergies and dependencies therefore need to be managed. In forests, residues are separated from the stems of the trees, which compared with the residues have major economic value, given their higher volume and quality. In fact, forest residues are merely a byproduct and seldom influence decisions in the forest concerning, for instance, when to harvest trees (Richardson, 2006). However, actors along the supply chain can benefit from integration, for example, by using the same vehicles (Björheden, 2000) or sharing the fixed costs of terminals for transshipment (Paper 1). To promote the cost-efficiency of logistics resources, it is important to transport complementary goods when demand for B2E transport drops, despite the difficulty of finding such assignments (Paper 5). In sum, B2E supply chains are characterised by system openness, and the cost-efficiency of the physical flow depends upon how synergies and dependencies concerning flows of other products are managed.

A9: Interorganisational relationships. Actors involved in configuring supply chains need to be aware of the preferences of other actors and stakeholders, which shape decisions in terms of, for example, accommodating environmental conditions, not merely cost alone (Paper 1). At the same time, links within the supply chain must be managed both vertically and horizontally (Halldórsson and

Svanberg, 2013) e.g. in terms of competition and integration (Paper 2). These circumstances open up possibilities for interaction between different flows—for example, trading energy vertically between producers (Paper 4). However, such setup create fluctuations in the demand for biomass, which is not preferable for hauliers, since it decreases the utilisation rate of vehicles and implies higher costs of supply within the physical flow. In short, how interorganisational relationships are manged shapes the performance of the physical flow.

A comparative view

When compared, and as shown in Figure 23, the nine attributes of B2E supply chains are clearly diverse in nature. The first two—perishability (A1) and the shape of goods (A2)—depend on the product, yet invariably pose implications for supply chain configuration. By contrast, geographical spread (A3) and weather and climate (A4) are two environment-bound attributes that cannot be altered and are thus classified in line with Churchman’s (1981) explanation of how the environment influences systems. Meanwhile, customer diversity (A5) relates to energy producers, whereas fluctuations in demand (A6) relates to how energy producers accommodate end users (e.g., households and industries) in the supply chain. They thus pose constraints primarily for supply chain configuration as a consequence of fulfilling system objectives—that is, to produce energy when required at the lowest possible cost—which also aligns with Churchman’s (1981) view of the objectives of a system. Lastly, time gaps between supply and demand (A7), system openness (A8), and interorganisational relationships (A9) are three attributes highlighting that different actors exist along supply chains, all with their own sets of goals, which together shape the configuration of the physical flow. In sum, and as shown in Figure 23, the nine attributes are diverse in nature and related to the goods, the environment, customers, or other actors in the supply chain.

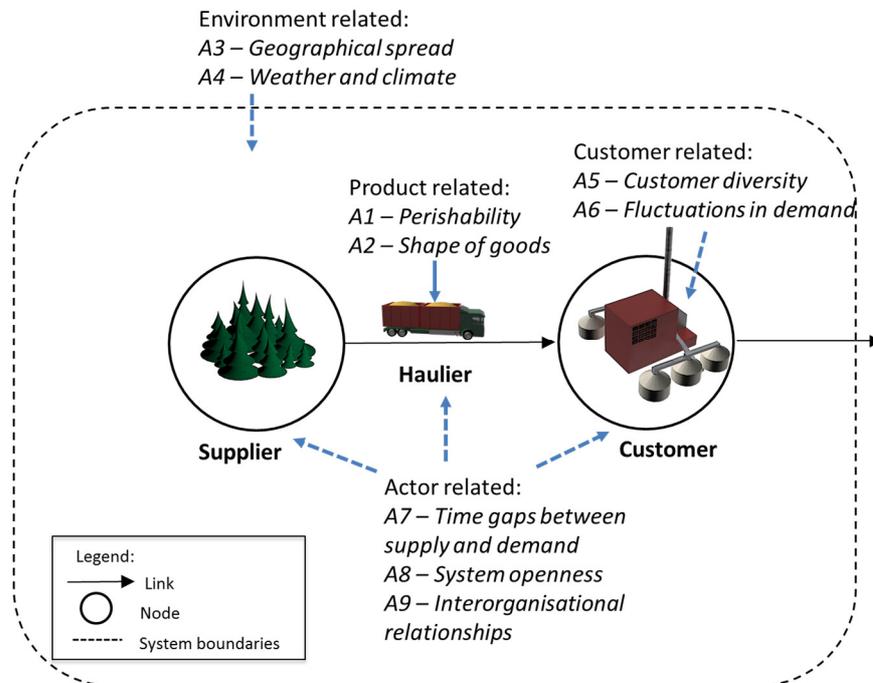


Figure 23: B2E supply chain attributes

It is also suggested that attributes have three different types of interplay with the configuration of the supply chain and the physical flow. First, some of the nine attributes can be altered. For instance, the shape of goods (A2) can be altered via processing (e.g., comminution) or covered storage. Second, the relative importance that the attributes exert on the physical flow can be reduced. Timing comminution from a supply chain perspective can reduce perishability (A1), for example. Third, environment-related attributes determine configuration, as when geographical spread (A3) and weather and climate shape how flows are routed (A4). Finally, as argued in the frame of reference, coordination is a specific way of managing configuration that indeed overlaps with configuration when decisions made internally suit actors in the supply chain. Similarly, technology can be managed differently in different configurations. Thus, the suggested interplays can be used to investigate how technology impacts the physical flow and how activities can be coordinated, as further described in the sections below. Lastly, the attributes are dynamic; e.g. geographical spread (A3) can vary between regions and interorganisational relationships (A9) can be managed differently depending what suits actors in different supply chains.

5.2 Pre-treatment technology and B2E supply chain attributes

One approach for improving physical flow in B2E supply chains involves introducing pre-treatment technology into the supply chain—in this thesis, torrefaction technology. How torrefaction influences the physical flow, needs to be understood by acknowledging the attributes of B2E supply chains. Accordingly, this section examines the interplay among torrefaction, supply chain attributes, and physical flow, all in the light of the second research question:

RQ2: How can pre-treatment technology impact the physical flow in B2E supply chains?

Detailed descriptions of different stages of torrefaction supply chains and the framework developed for configuration of torrefaction supply chains are the main takeaways from Paper 2, whereas the takeaways from Paper 3 are the quantitative results of torrefaction supply chain costs. To answer RQ2, the findings from RQ1 are used as a foundation. As established in the frame of reference, there is no one-size-fits-all for torrefaction, and when torrefaction is implemented in supply chains, it is a part of the supply chain configuration. As such, instead of an interplay between attributes and the configuration of the supply chain and the physical flow (RQ1), this section investigates the interplay between attributes and torrefaction, which in turn, as shown in the analysis below, informs how the physical flow can be impacted by torrefaction. Hence, the suggested interplay from RQ1 is operationalised into three questions, used to systematically analyse the evidence feeding into RQ3:

1. Can torrefaction alter the attribute (Table 12, Column 2)?
2. Can torrefaction reduce an attribute's impact upon the performance of physical flow (Table 12, Column 3)?
3. Does the attribute influence the configuration of torrefaction in a supply chain (Table 12, Column 4)?

Table 12: The interplay between B2E supply chain attributes and torrefaction

Attribute	Torrefaction alters	Torrefaction reduces impact of	Torrefaction is influenced by
(A1) Perishability	Torrefaction reduces perishability, which enables more efficient storage, improves the physical flow, and increases safety for actors		
(A2) Shape of goods	Torrefaction improves the shape of goods, which enables up to seven times better transport and handling efficiency in the physical flow.		
(A3) Geographical spread			Geographical spread shapes the availability of biomass, which influences the optimal size and location of the torrefaction plant and costs of delivering TDB to end users.
(A4) Weather and climate		Torrefaction improves hydrophobic properties, which can reduce storage costs.	
(A5) Customer diversity	Torrefaction expands the range of potential end users, for whom the production strategy and physical flow must be aligned.		
(A6) Fluctuations in demand		Torrefaction enables a levelled demand of upstream transports, which reduces the impact of fluctuations in demand upon transport efficiency.	
(A7) Time gaps between supply and demand	Not observed		
(A8) System openness			Connections to other supply chains shape the location of torrefaction plants and the distribution of TDB.
(A9) Inter-organisational relationships			Managing relations is important to securing local biomass supply in order to produce TDB at a lower cost.

The following sections provide an analysis of the interplay between torrefaction and B2E supply chain attributes. This list of attributes is not exhaustive, but instead based on evidence from Papers 2 and 3 and related literature.

Torrefaction and perishability. Given its relatively low microbiological activity, torrefied densified biomass (TDB) is far less perishable than unrefined biomass (Shankar Tumuluru et al., 2011). However, the advantage of less perishability varies according to the length of storage within the supply chain. When long storage times are necessary—for instance, when large volumes are required to bridge fluctuations in supply and demand—the advantage of altering perishability is greatest. Perishability moreover poses implications for more than simply supply chain cost. As a case in point, conventional wood pellets are safe when shipped in bags, but classified as hazardous material when shipped in bulk, due to the off-gassing of CO, CO₂, and CH₄ and the subsequent risk of spontaneous combustion (Searcy et al., 2014). In fact, with conventional pellets, at least eight confirmed fatalities have occurred since 2009, both in households and aboard ships, and numerous similar cases could may not been reported (Svedberg and Knutsson, 2011). By comparison, TDB’s storage risks such as off-gassing and self-heating may be insignificant (Shankar Tumuluru et al., 2011), which highlights its advantage in terms of safety, yet may need further research for verification. In all, the perishability of biomass wanes with torrefaction, which not only enables a more cost-efficient physical flow, but can also bolster the safety of actors involved in shipping and storing TDB.

Torrefaction and the shape of goods. Torrefaction improves the physical shape of biomass as a good by yielding a product with up to seven times higher energy density than primary forest fuel, which translates into greater efficiency in both transport and handling. As a result, the economically viable distance for transporting biomass is significantly longer than for primary forest fuel or conventional pellets. However, a trade-off does exist between torrefaction cost (i.e., cost of producing TDB) and reduced distribution cost due to improved product properties. The sensitivity analysis in Paper 3 revealed that improving product properties by making decisions regarding torrefaction severity beyond a certain point is too costly, since increased production costs outweigh the gains had by lower distribution costs. It should be noted, however, that those findings emerged in a Swedish case with rather short distribution distances. Since the benefits of torrefaction depend upon distance, it is nevertheless possible for a higher degree of torrefaction severity to benefit other supply chains (e.g., transatlantic supply chains). Furthermore, since different vehicles have different capacities, some trucks may be unable to exploit the full benefits of torrefied pellets due to weight restrictions. All told, torrefaction improves the shape of biomass as a good, though the production strategy needs to align with distribution downstream by considering vehicles used for transportation and the distance to customers.

Torrefaction and geographical spread. The scale of torrefaction plants matters greatly to the cost-efficiency of delivering TDB to customers. As a function of both diseconomies of scale (i.e., due to increased supply distance) and operational economies of scale in the given torrefaction plant, an optimal size for the

torrefaction plant can be determined (Paper 3). At the same time, the geographical spread of forests is not homogenous and creates variances in density due to the amount of biomass available per hectare in different regions. The actual amount available for a single actor furthermore depends on other factors such as competition (Rauch et al., 2010). Altogether, the dynamics of these factors influence the availability of biomass and potentially its price, which as shown in paper 3 affects the cost of supplying end users with TDB. For all of those reasons, the geographical spread of forests shapes the availability of biomass and dictates terms for the location and scale of torrefaction plants, as well as for the cost of producing and distributing TDB to customers.

Torrefaction and weather and climate. As a product, TDB exhibits better hydrophobic properties than unrefined forest fuel (Strandberg et al., 2015), which makes it more suitable for storage (van der Stelt et al., 2011). Still, its hydrophobic properties—for instance, with the outdoor storage of large quantities of TDB—needs be further verified. If possible to store outdoors without a significant loss in quality, TDB can benefit from reduced storage costs. Yet, the benefits of these hydrophobic properties depend on the distribution system, which should be aligned to customers' needs (Paper 2). To illustrate, if distributed to household customers in plastic bags, then TDB's moisture uptake is not a major issue. By contrast, if shipped in bulk and stored outdoors at port, then TDB can offer major benefits compared to conventional pellets. The climate also shapes the torrefaction strategy. For example, Chai and Saffron (2016) has shown that humid regions justify more severe torrefaction, whereas dry climates support less severe torrefaction. Torrefaction plants could therefore need to negotiate the trade-off not only among different product parameters (e.g., hydrophobicity and energy density), but also against the cost of torrefaction (Paper 3). In that light, torrefaction can reduce biomass's risk of quality loss in storage due to weather, though its actual benefits remain unquantified.

Torrefaction and customer diversity. TDB's properties appeal to a variety of end users, including households and powerplants using pellets or coal, as well as users seeking to produce vehicle fuel. The diversity of potential TDB customers implies that any torrefaction plant needs to develop a production strategy in which different elements of demand (e.g., demand pattern and quality demands) serve as starting points for further aligning the strategy with the supply chain (Paper 2). A profile analysis can help operators of torrefaction plants to find a niche for torrefaction plants, particularly with respect to different end users, though also with the upstream supply of biomass (Paper 2). Torrefaction thus allows for an even greater diversity of customers, which in turn yields new physical flows with which the production strategy needs to align.

Torrefaction and fluctuations in demand. Compared to transports along all of the different stages of the supply chain, trucks are most specialised earliest in the chain. When transporting from roadsides, transport efficiency can benefit from using combo trucks dedicated to B2E supply chains. Further down the supply chain—for example, from terminals to end users—conventional container trucks designed to carry a range of other goods can be used. Though particularly true for combo trucks, which cannot be used for other types of goods, the utilisation rate

of trucks in any case greatly impacts transport efficiency (Paper 5). Meanwhile, given the influence of the operating window upon the torrefaction production economy (Pirraglia et al., 2013), torrefaction plants are likely to operate for extended periods throughout the year. As a result, demand for upstream transport becomes more levelled, meaning greater utilisation rates for specialised vehicles (e.g., combo trucks and comminution equipment) in these supply chains than in those for primary forest fuel, which generally benefits hauliers. Further downstream, conventional trucks can be used for distribution, which also more easily can perform other tasks when demand for TDB and its transport wane. In short, torrefaction reduces the effects of fluctuations in demand upon transport efficiency by enabling greater utilisation rate use of vehicles within the physical flow.

Torrefaction and system openness. For the supply chain modelled in Paper 3, the greatest cost of torrefaction comes with drying. As an antidote, the industrial symbiosis of torrefaction with large heat producers can offer significant benefits (Sermiyagina et al., 2015). In that sense, production economy poses implications upon the location of torrefaction plants, which in turn influences how the physical flow is routed. At the same time, scale is an important factor of the performance of torrefaction plants (Paper 3), since the cost of producing TDB can represent a function of how well the torrefaction plant, in a way similar to a conventional powerplant, makes use of both primary and secondary forest fuel. Since forest fuel cannot bear the cost of train terminals and supply chains involving TDB likely cannot either, torrefaction plants should be located so that the distribution system can use the existing logistics infrastructure to enable a cost-efficient distribution of TDB. In that light, torrefaction supply chains should be open systems, in which the practice of co-location, the use of existing infrastructure, and multiple assortments can effectively reduce supply chain costs and dictate terms for supply chain configuration

Torrefaction and interorganisational relationships. Since the train transport of TDB is not affected by distance to any great extent (Paper 3), torrefaction plants should be located in areas with less competition for biomass so that they can procure large amounts of cheap biomass. Yet, once located in any area, a plant invariably depends upon local suppliers, and long-term relations become necessary to securing future supply. Since plants should also be located in areas previously abundant with unused biomass, forest owners who have not sold biomass need to be convinced to sell. To that end, wood fuel buyers need to be highly active in contacting forest owners in order to convince them to sell their biomass (Bohlin and Roos, 2002). Because procuring local biomass is necessary to produce TDB at low costs, interorganisational relationship management matters greatly to the performance of the torrefaction supply chain, particularly for plant operators.

Summary

The analysis suggests an interplay between the technology (i.e., torrefaction) and the context (i.e., B2E supply chains) into which it could be introduced. First, one feature of torrefaction is its potential to improve the physical flow by altering some B2E supply chain attributes. Notably, torrefaction reduces perishability

(A1), which improves the physical flow by reducing substance losses in storage. Torrefaction also alters the shape of goods (A2), which allows transport across longer distances and thus the use of untapped reserves of biomass, thereby making B2E more competitive among energy sources. Torrefaction furthermore expands the diversity of end users (A5) to include coal-fired powerplants and producers of vehicle fuel seeking to tap biomass's potential. In exploiting any of these possibilities, torrefaction plants' production strategies need to be aligned to accommodate a variety of end users.

Second, torrefaction can also reduce the relative importance of some supply chain attributes and reduce their impact on the physical flow. For instance, the impact of fluctuations in demand (A6) can be curbed by creating a more levelled demand of biomass and transports in the upstream in the supply chain, which enables hauliers to increase transport efficiency and suppliers to reduce storage volumes.

Third and lastly, attributes influence the configuration of torrefaction from a supply chain perspective. In particular, the geographical spread (A3) of forest shapes the availability of biomass by imposing conditions upon the optimal size of a torrefaction plant. Similarly, system openness (A8)—for instance, in terms of connections with other supply chains—impacts the location of torrefaction plants and thus the distribution cost of TDB.

5.3 Coordination and B2E supply chain attributes

Another approach to improve the physical flow of B2E supply chains involves the coordination of activities. In general, coordination is not necessarily binary, and different degrees of coordination are already applied within today's industry. For example, the open hours of receiving stations to some extent accommodate hauliers. In that sense, and for readability, in what follows *coordination* is best interpreted to mean *better coordination*, since activities are already coordinated to some extent. Yet, coordination requires further investigation in order to understand its potential. The third research question is:

RQ3: How can activities be coordinated to improve the physical flow in B2E supply chains?

In terms of the main takeaways, evidence for answering RQ3 comes from Papers 4 and 5. Paper 4 identified the *whats*—that is, the means of coordination—whereas the main takeaways from Paper 5 were the potential effects of improvement efforts, of which means of coordination constitute the vast majority, thereby comprising the actual improvement of the physical flow. To provide a more holistic view, and a foundation for how to use means of coordination to improve the physical flow, the context in which coordination occurs needs to be understood. Accordingly RQ3 refers to what can be done and the potential effects on the physical flow, but also to how the context sets conditions for doing so.

As argued in the frame of reference, coordination is a specific way of managing configuration, overlapping when decisions made internally suit actors in the supply chain. Consequently, instead of investigating the interplay between attributes and the configuration of the physical flow (RQ1), this section

investigates the interplay between attributes and coordination, to show how the coordination of activities can improve the physical flow. The evidence used to answer RQ3 has been systematically analysed in terms of the three interplays, operationalised as:

1. Can coordination alter the attribute (Table 13, Column 2)?
2. Can coordination reduce the attribute's impact on the performance of physical flow (Table 13, Column 3)?
3. Does the attribute influence coordination (Table 13, Column 4)?

Table 13: The interplay between B2E supply chain attributes and coordination

Attribute	Coordination alters	Coordination reduces impact of	Coordination is influenced by
<i>(A1) Perishability</i>		Prolonging the energy production season or moving storage downstream reduces impact of perishability.	
<i>(A2) Shape of goods</i>		Applying different means of coordination can improve the transport efficiency of trucks in the physical flow, which reduces the importance of the shape of goods.	
<i>(A3) Geographical spread</i>		Improving receiving capacity can lessen the impact of geographical spread upon physical flow.	
<i>(A4) Weather and climate</i>			Climate can motivate unintentional coordination, which improves transport efficiency and reduces storage costs.
<i>(A5) Customer diversity</i>			Some customers embrace coordination, whereas other do not.
<i>(A6) Fluctuations in demand</i>		Using bioenergy combines can reduce impact of fluctuations in demand.	
<i>(A7) Time gaps between supply and demand</i>		Moving storage downstream reduces impact of the time gap by enabling higher utilisation rates of vehicles and more specialised vehicles.	
<i>(A8) System openness</i>			System openness can be a barrier towards coordination or enable coordination.
<i>(A9) Inter-organisational relationships</i>	Long-term relationships and contracts can improve the physical flow.		Multiple relationships need to be managed in order to coordinate activities.

The following provides a non-exhaustive list of relationships identified between coordination and B2E supply chain attributes.

Coordination and perishability. An important means of coordination involves moving storage downstream, to the powerplant, which can allow energy producers to use assortments that suffer most from perishability in the short term—for example, bark during the summer—and store assortments that suffer less (Paper 4). Another, albeit unintentional means of coordination that can reduce perishability is prolonging the energy production season (Paper 4), which can be achieved by implementing bioenergy combines that produce electricity throughout the year, produce heat during the winter, and use excess heat to produce a complementary product (e.g., pellets) during the summer (cf. Wahlund et al. (2002)). In that way, bioenergy combines have better production economy than conventional CHP plants. The unintentional effect of bioenergy combines on the upstream supply chain is a result of a levelled procurement of biomass throughout the year, which allows reduced inventory levels and shorter storage times for suppliers, which in turn lowers marginal losses due to perishability. Altogether, both intentional and unintentional means of coordination can reduce the degree of perishability, thereby enabling a more cost-efficient physical flow of biomass.

Coordination and the shape of goods. Although the shape of goods cannot be altered by coordinating activities, different means of coordination can reduce transport costs, thus also reducing the relative importance of the shape of goods. In the interface between energy producers and hauliers, such means of coordination include e.g. (1) extending open hours, (2) improving receiving stations, (3) improving communication, (4) lessening demands upon delivery flexibility and precision and (5) prolonging the season in which biomass is supplied (see Paper 5 for a more comprehensive list as well as details on the potential effects). All of those means enable more efficient utilisation of trucks and personnel and/or reduced amounts of detours, which enables increased transport efficiency. By extension, decreased transport costs for hauliers can enable reduced prices for transport buyers, meaning larger economically feasible procurement areas for energy producers. Ultimately, it becomes more economically attractive for energy producers to improve of capacity of existing power plants or to build new ones, in either case to exploit the untapped potential of biomass. In all, coordinating activities reduces the impact shape of goods have on the physical flow, which makes B2E more competitive in terms of the cost of supply therein.

Coordination and geographical spread. In the short term, very little can be done to alter the geographical spread of forests. They are where they are, and cultivation measures are generally taken on long time horizons. Nevertheless, some means of coordination can reduce the impact of this attribute. Given the geographical spread of forests, logistics companies need to move their logistics resources around, according to where forests are being harvested. Flexibility in receiving stations at powerplants becomes a means of coordination in order to better allow logistics companies to finish operations in the region before moving on (Paper 4). In effect, this practice helps to prevent costly detours for trucks within the physical flow

(Paper 5). Altogether, coordinating activities can reduce the impact of geographical spread upon the performance of the physical flow.

Coordination, weather, and climate. Climate not only imposes constraints upon the physical flow, but can also incentivise unintentional coordination. For example, as Paper 4 has shown, climate has motivated the location of server halls in northern Sweden, where they make use of natural cooling during the winter, yet need energy for cooling during the summer. This energy demand pattern runs counter to the demand of district heating, which makes it possible for a CHP plant with customers such as server halls to operate for longer periods during the year. The implication for upstream actors is thus that a levelled demand of biomass and of transports, as previously argued, can reduce storage costs and increase transport efficiency within the physical flow.

Coordination and customer diversity. As indicated in Paper 4, energy producers can have highly different approaches and attitudes toward coordinating activities. For example, open hours differ among producers; in fact, one company reported that its receiving stations were open at night in order to accommodate delivery and thereby prevent the loss of future supply. The study also revealed that large customers seem to be less interested in coordinating activities with hauliers. Interestingly, one supplier reported that in emergency situations involving supply shortages, deliveries are routed to energy producers without large storage areas, thereby ensuring that all producers have biomass for energy production (Paper 4). This practice implies that, at least from the perspective of multiple suppliers and multiple customers, a mix of good and bad customers can nevertheless be sustained toward maintaining a cost-efficient flow with sufficient delivery service. However, one haulier argued that given sudden peaks in demand, transports are provided to energy producers with the most generous open hours. Clearly, different views exist regarding whether a system should allow for both bad and good customers in order to maintain a cost-efficient flow with sufficient delivery service. As a result, the different attitudes of energy producers can be a barrier towards the coordination of activities in the physical flow and in turn reduce its performance.

Coordination and fluctuations in demand. As posited earlier, another unintentional means of coordination is prolonging the energy production season by using bioenergy combines, which not only affects storage and perishability upstream, but is also important for hauliers. A levelled production of energy induces a levelled demand for transport of biomass, meaning that hauliers can increase their use of capacity on long time horizons and skilled drivers can be retained between seasons, both of which are essential for transport efficiency (Paper 5). Plus, experienced skilled drivers acquainted with forest roads perform transport more efficiently and are more likely to avoid pick-up failures, which also increases transport efficiency (Paper 5). In sum, bioenergy combines do not alter fluctuations in end users' demands, but do reduce fluctuations in energy production. For the physical flow, this dynamic unintentionally reduces fluctuations in demand, of both biomass and its transport, thereby affording a more levelled flow characterised by better use of vehicles and keeping personnel. A similar effect can be attained by moving storage downstream (Paper 5).

Coordination and time gaps between supply and demand. Moving storage downstream reduces not only perishability, but moreover the impact of time gaps between supply and demand upon the physical flow. By moving storage downstream, biomass can be supplied for longer periods throughout the year, which enables the greater utilisation rate of trucks so important for hauliers (Paper 5). It also enables the use of more specialised trucks, which are typically more efficient than multipurpose ones (Paper 1). Moving storage downstream also facilitates managing the flow of biomass pushed, e.g. into the supply chain—for instance, biomass cleared from building sites—which otherwise may need to be transported via terminals, thereby adding transport costs (Paper 4). All in all, this attribute's impact lessens with the coordination of activities, thereby increasing the performance of the physical flow, both by increasing the utilisation rates of multipurpose and specialised trucks and by facilitating transport routing.

Coordination and system openness. The connections that actors in B2E supply chains sustain with other energy producers, products, industries, and supply chains can be a barrier towards the coordination of activities as well as enable coordination (Paper 4). For example, the production economy of connected energy-producing units controlled by either themselves or other energy producers determine where and when energy is produced. This situation can induce large fluctuations in demand for biomass and its transport, which in turn lowers the efficiency of B2E's physical flow. Thus, since B2E energy supply chains are open systems, interconnected energy production units can both be a barrier towards and enable coordination and, in either case, poses consequences for the cost-efficiency of the physical flow.

Coordination and interorganisational relationships. One empirically observed means of coordination in terms of interorganisational relationships is establishing long-term relations between transport buyers and hauliers. For one, these relationships enable truck drivers to become acquainted with the quality of local forest roads, which is essential for transport efficiency (Paper 5). Moreover, long-term relationships manifested in long-term contracts are vital to enable for hauliers to invest in new vehicles with greater capacities and more energy-efficient engines (Paper 5). Thus, altering the interorganisational relationships by extending the length of relations and contracts affects the efficiency of transport within the physical flow.

Having multiple suppliers of biomass in one region is common, often their geographical areas overlap. Therefore, energy producers need to maintain relationships with multiple suppliers in order to ensure supply, which often results in road transport distances that are far from optimal (Rauch et al., 2010). In response, one means of coordination can be for producers to barter volumes, which can often shorten transport distances and lessen the impact of geographical spread upon transport efficiency within the physical flow (Paper 5). However, since it could be impossible to manage relationships with all energy producers in an area with many producers, managing relations with a few producers is more realistic (Rauch et al., 2010). All told, coordinating activities can reduce costs in the physical flow, though interorganisational relations need to be managed in order to achieve such coordination.

Summary

The answer to RQ3 suggests three types of interplays between coordination and B2E supply chain attributes. First, coordinating activities can reduce several attributes' impact upon the performance of the physical flow, thereby reducing their relative importance. In particular, moving storage downstream can lessen the impact of perishability (A1) and fluctuations (A6) in demand upon the flow. At the same time, prolonging the energy production season by introducing bioenergy combines can constitute an important means of coordination, albeit unintentionally, by minimising the fluctuation in demand of transports and thus allowing the more efficient utilisation of trucks and personnel. Levelled flows are also important for hauliers to retain skilled drivers between seasons, which is vital to transport efficiency. Furthermore, there are numerous means of coordination that can reduce the impact that shape of goods (A2) have upon the physical flow.

Second, B2E supply chain attributes shape how the means of coordination are used. The customer diversity (A5)—some of which approve coordination, whereas others do not care much about what happens outside their gates—can moreover pose barriers to using some means of coordination that could improve the physical flow. Also, a B2E supply chain's system openness (A8) can both be a barrier and enable the use of means of coordination to improve the physical flow.

Third and lastly, the sole attribute that can be altered by means of coordination is interorganisational relations, which can be made more long-term, which can be manifested in long-term contracts. Such extensions improve hauliers' transport efficiency, thereby enabling for them to invest in newer trucks with better engines and higher capacities, both of which improves transport efficiency. When compared (Table 14), torrefaction alters attributes to a greater extent than coordination, whereas coordination reduces the impact of attributes, thereby diminishing their relative importance.

Table 14: The interplay between attributes in B2E supply chains and torrefaction and coordination

Attribute	Alters	Reduces impact of	Influenced by
<i>Perishability</i>	T	C	
<i>Shape of goods</i>	T	C	
<i>Geographical spread</i>		C	T
<i>Weather and climate</i>		T	C
<i>Customer diversity</i>	T		C
<i>Fluctuations in demand</i>		T, C	
<i>Time gaps between supply and demand</i>		C	
<i>System openness</i>			T, C
<i>Interorganisational relationships</i>	C		T, C

Note. T = Torrefaction; C = Coordination

6 Discussion

To discuss the findings of the five papers and their analysis, this chapter presents five normative propositions for improving the physical flow in B2E supply chains, as well as explains the relationship of each proposition to relevant literature.

To discuss the significance of the results of the thesis—mostly from the foregoing analysis—this chapter presents five normative propositions that address ways to improve the physical flow in B2E supply chains (Table 15, Column 1). Each proposition is justified by discussing the significance for each actor in terms of how the actor benefits (Table 15, Column 4) and is discussed in the context of relevant literature, in terms of whether they confirm, expand, or challenge current understandings (Table 15, Column 5). These propositions draw upon findings from answering RQ1—that is, attributes determining the physical flow—in order to solidify their relevance to B2E supply chains (Table 15, Column 3). They also derive from the suggested interplay among B2E supply chain attributes and torrefaction addressed in answering RQ2 and the coordination of activities addressing in answering RQ3. First, to a far greater extent than the coordination of activities, torrefaction can alter different attributes of B2E supply chains. For instance, enhancing the shape of goods via torrefaction can render improved physical flow. Second, coordinating activities, can reduce the relative importance of attributes. For example, as illustrated in the previous chapter, moving storage downstream reduces the relative importance and impact of geographical spread. Third, attributes of B2E supply chains influence both the use of torrefaction and the coordination of activities. A clear example of this interplay is that geographical spread influences the optimal size of torrefaction plants. To further strengthen the five propositions, results from the appended papers (Table 15, Column 2) and a few concepts from the frame of reference are both included as support.

Propositions 1 and 2 are general propositions, derived from the relevance of B2E supply chain attributes, and build upon the assumption that supply chains can be configured or coordinated by different actors therein. By contrast, Proposition 3 addresses pre-treatment technology and provides suggestions for achieving economically viable torrefaction plants. Lastly, Propositions 4 and 5 elaborate on the means of coordination. As the following sections show, not all findings in the analysis are discussed, rather those that comprise the most distinct results, are not entirely straightforward, or add to, confirm, or challenge related literature in significant ways are discussed. Also, using this chapter to present distinct ways to improve the physical flow in B2E supply chains aligns well with the purpose of the thesis.

In sum, the propositions are derived from a discussion of the thesis's results and those of the appended papers and have the potential to improve the physical flow, either by making handling, transportation, and storage more efficient or by making the energy conversion more cost-efficient.

Table 15: Five propositions for improved physical flow in B2E supply chains

Proposition	Support from Papers 1–5	Relevant attributes	Benefits	Relation to literature
Proposition 1: Actors in energy supply chains should be reconceptualised as energy service providers.	<ul style="list-style-type: none"> • Bioenergy combines (Paper 4) • Customer demands (Paper 4) • Overcapacity in transport (Paper 5) 	<ul style="list-style-type: none"> • Perishability (A1) • Shape of goods (A2) • Fluctuations in demand (A6) 	<p>Energy producers: Better production economy by expanding operations according to utilities</p> <p>Hauliers: Improved transport efficiency by categorising service offerings according to utilities created</p>	<ul style="list-style-type: none"> • Challenges labelling an energy supply chain by its different parts • Prompts logistics researchers to study B2E supply chains
Proposition 2: Actors must acknowledge three structural elements of transport networks that facilitate efficient and effective supply chain configuration	<ul style="list-style-type: none"> • Pick-up failures (Paper 5) • Reduced downstream costs (Paper 3) • Shared fixed and operating costs at terminals (Paper 1) • Truck and personnel sharing (Paper 5) 	<ul style="list-style-type: none"> • Perishability (A1) • Shape of goods (A2) • Geographical spread (A3) • Customer diversity (A5) • Fluctuations in demand (A6) • System openness (A8) 	<p>Suppliers: Efficient, effective supply chain configuration by recognising the total structure of transport networks</p> <p>Terminal operators: Increased competition by diversifying nodes</p> <p>Hauliers: Increased use of capacity by considering other product flows</p>	<ul style="list-style-type: none"> • Adds to the structure of transport networks to allow theory borrowing • Adds that other product flows affect capacity use
Proposition 3: Operators of torrefaction plants must consider location, scale, and production strategy as key aspects of economic viability	<ul style="list-style-type: none"> • Efficient TDB transport (Paper 3) • Relation between scale and location (Paper 3) • Production costs (Paper 3) • Gaps (Paper 2) • Torrefaction adapted to customers (Paper 2) 	<ul style="list-style-type: none"> • Shape of goods (A2) • Geographical spread (A3) • Customer diversity (A5) • Fluctuations in demand (A6) • System openness (A8) 	<p>Torrefaction plant operators: Economically viable torrefaction plants by considering multiple criteria for plant location, by the relation among plant scale, biomass availability, and efficiency of logistics resources, and by adapting production strategies to customers</p>	<ul style="list-style-type: none"> • Confirms B2E literature on location, scale and logistics resources • Confirms configuration starting with different elements in demand
Proposition 4: Actors in the supply chain can benefit from moving storage downstream.	<ul style="list-style-type: none"> • Managing fluctuation (Paper 1) • Supply security (Paper 4) • Quality issues (Paper 4) • Utilisation rate of vehicles and personnel (Paper 5) 	<ul style="list-style-type: none"> • Perishability (A1) • Geographical spread (A3) • Fluctuations in demand (A6) • Time gaps between supply and demand (A7) • System openness (A8) 	<p>Energy producers: Improved quality, supply security, spot purchases, and biomass prices with downstream storage</p> <p>Hauliers: More efficient transport by levelling transport demand</p> <p>Suppliers: Lower inventory carrying costs by reducing storage volumes at terminals</p>	<ul style="list-style-type: none"> • Challenges norms of storage location • Adds that downstream storage can benefit logistics
Proposition 5: Actors in the supply chain can benefit from long-term relationships.	<ul style="list-style-type: none"> • Biomass availability shape transport cost (Paper 3) • Supply security (Paper 4) • Vehicle selection (Paper 5) 	<ul style="list-style-type: none"> • Shape of goods (A2) • Geographical spread (A3) • System openness (A8) • Inter-organisational relationships (A9) 	<p>Energy producers: Supply security and lower costs</p> <p>Hauliers: Increased transport efficiency with better vehicles</p>	<ul style="list-style-type: none"> • Confirms merit of long-term relations and contracts in a new context

6.1 Proposition 1: Actors in energy supply chains should be reconceptualised as energy service providers

Proposition 1 suggests that actors in energy supply chains—in the case of B2E, forest fuel suppliers, hauliers, and energy producers—can benefit from being reconceptualised as energy service providers. As with goods in general, energy carriers need to be provided in the right quantity and condition to the right customers at the right place and at the right time. As an energy carrier, forest fuel is sourced in forests throughout the year, yet subsequently needs to be transformed and provided to end users—for instance, transformed into heat for distribution via district heating to households on cold winter days. To manage energy provision for end users, supply chains need to create the utilities of time, place, possession, and form (Halldórsson and Svanberg, 2013), all of which actors along a supply chain need to know how, when, and where to create.

To that end, Proposition 1 suggests that actors can benefit by shifting focus from minimising the cost of operations to reconsidering what kinds of energy services they provide and could be providing, in terms of what types of utilities that they can create. As a result, actors can better understand how they could expand or adapt operations, if not both. Put differently, if the right activity is performed by the right actor while creating the right utility, then the physical flow can be more cost-effective. However, Proposition 1 rests upon the assumption that a supply chain can possibly be managed in such a way. To clarify that possibility, actors need to understand their (potential) coordinating role, in terms of how they can coordinate the supply chain by creating utilities. In that sense, an actor's coordinating role is slightly different than the coordination of activities, which has been a focus of this thesis.

6.1.1 Justification and significance for actors

For energy producers: Expanded operations improve the production economy

In Paper 4, a bioenergy combine operator's justification for building the combine was to improve the production economy, as has also been argued in the context of other bioenergy combines, including Skellefteå's (Wahlund et al., 2002). Another company with the same goals is Uddevalla Energi, whose representatives have argued that 'by using excess heat produced during the summer from burning waste to make dry sawdust compacted to pellets, we are moving energy from summer to winter, when it has use' (Uddevalla Energi, 2016). Though both arguments are similar, the former concerns production economy, whereas the latter concerns production as well as logistics, through using the terms *moving* and *use* (i.e., utility) common in logistics. In that sense, the logistics perspective focuses more on the service that can be provided by moving energy carriers across time, thereby creating the utility of time. In turn, this perspective helps the company to identify ways to expand their operations, which can yield a better production economy. Though these companies have not used the term *energy service provider*, they seem to understand—especially Uddevalla Energi—that they create not only the utility of form by transforming biomass to electricity and heat, but also the utility of time by making energy carriers available according to fluctuations in demand (A6), which in this case also improves the production economy. Such a setup can

moreover benefit the upstream physical flow, since there is less demand on hauliers to create the utility of time, which can require the overcapacity of logistics resources in order to negotiate fluctuations in demand for transport, which as shown in Paper 5 is costly. Plus, as argued earlier, bioenergy combines constitute a means of coordination that can partly reduce the impact of perishability (A1) and fluctuations in demand (A6) upon the physical flow. These benefits can yield additional economic benefits for actors upstream in the supply chain and ultimately justify reducing the price of biomass for energy producers. Altogether, through a reconceptualisation into energy service providers, and by thinking in terms of utilities that are and can be created, energy producers can expand or adapt processes toward improving the production economy, which can also enable a more cost-efficient physical flow of biomass.

For hauliers: Categorising transport service offerings according to utilities can increase profitability or improve transport efficiency

Hauliers need to recognise that they create not only the utility of place by moving biomass, but also the utility of form when comminuting it, both of which alters the shape the goods (A2) and trigger perishability (A1). More importantly, they also contribute to creating the utility of time, particularly by helping to manage fluctuations in demand for energy (A6), which they do by providing transport for biomass when needed for energy production. However, such utility of time needs to be provided not only to manage fluctuations in demand for energy, but moreover to meet energy producers' demands in terms of delivery precision. On that topic and for goods in general, Naim et al. (2006) has posited that hauliers in general should diversify their service offerings, in terms of a routine logistics service, a standard logistics service, and a customised logistics service, to accommodate customers' demands on flexibility. Such categorisation highlights the need for different approaches to planning, collaboration, and information sharing (Naim et al. (2006)). In that sense, forest hauliers should aim for a similar approach as well as categorise and price their service offerings according to the utilities they create—especially that of time—both to make planning more efficient and boost profitability. In the end, doing so can double as a means of illustrating to energy producers the inefficiencies of transport. That consequence is clearly relevant; as highlighted by a haulier in Paper 4, energy producers should reconsider whether they actually need to impose all of their demands upon delivery precision, since those demands invariably makes transport costlier. By revising those demands, transport efficiency can be increased. In sum, hauliers need to recognise that they are not only moving biomass, instead they are providing a number of services by e.g. providing form and in particular time utility in the energy supply chain, thereby justifying their reconceptualisation into energy service providers. By identifying the utilities a haulier creates for energy producers, as a means to plan operations effectively and offer their services accordingly, profitability for hauliers can be increased and the and the physical flow improved.

6.1.2 Relation to the literature

To a certain extent, Proposition 1 challenges current divisions of supply chains into their different parts. For example, Sandersson (1999) divides energy supply chains into upstream supply, conversion, and downstream, though such division

risks misleading actors and researchers into thinking that, for example, conversion occurs only in conversion units (e.g., powerplants). From an alternative perspective, conversion is a gradual process that occurs at several stages along the supply chain. To illustrate, different activities in the chain (e.g., harvesting, comminution, and storage) alter the shape of biomass (A2) in terms of size and moisture content. As such, these activities create the utility of form by preparing the material for its transformation from solid biomass to electricity and heat. In effect, understanding that utilities are created along the supply chain is essential for actors to be able to identify ways to improve their operations. Along those lines, a more appropriate labelling of the different parts of the supply chain recognises the upstream, the midstream, and the downstream (An et al. (2011), which can prevent assumptions about at which point utilities are created in supply chains.

The reconceptualisation of energy producers could also attract logistics researchers to study logistics in B2E contexts. On that note, Altman et al. (2007) have stated, ‘The biomass and bioenergy industries face important organizational and strategic challenges, but there is so far little literature applying organizational economics to the industry’ (p. 15). More recently, Svanberg (2013) has similarly concluded that research addressing B2E supply chains is almost entirely neglected in logistics oriented journals, despite that concepts such as (energy) service provision and utilities are common terms in the field. Similar reconceptualisations in other contexts have occurred by relabelling actors in supply chains to *logistics service providers*. Though difficult to trace its inventor, this term appeared somewhere 25 years ago, for example, when Stock (1990) discussed the development of warehouses through the use of information technology, concluding that, ‘In essence, the firm is no longer a public warehouse; rather it is a logistics service provider’ (p. 137). Since that time, the amount of research on logistics service providers has increased significantly in literature addressing logistics and supply chain management. Therefore, by reconceptualising energy producers and hauliers as energy service providers, logistics researchers are encouraged to study B2E supply chains to a greater extent.

6.2 Proposition 2: Actors must acknowledge three structural elements of transport networks that facilitate efficient and effective supply chain configuration

Proposition 2 consists of three structural elements that facilitate for actors in B2E supply chains to achieve efficient, effective supply chain configurations that ultimately induce a cost-efficient physical flow. The first element describes the overall structure of the transport network, the second describes how to use nodes to overcome gaps in the physical flow, and the third describes how to manage logistical resources in links and nodes, primarily by acknowledging that other product flows interact with the B2E supply chain. Assuming that a supply chain as a whole can be configured and coordinated in the first place, Proposition 2 primarily targets suppliers and hauliers that manage the physical flow and who use combinations of links, nodes, and logistics resources to supply energy producers with B2E.

6.2.1 Justification and significance for actors

Understanding overall transport network structure is essential for suppliers to achieve efficient and effective supply chain configuration

In general, forest fuel companies (i.e., suppliers) have the power to configure the supply chain in order to satisfy the demands of energy producers. Suppliers are responsible for using their own or third-party terminals for storage and for contracting hauliers to perform transport when needed. As such, to achieve an effective and efficient supply chain configuration, it is important that they understand the overall structure of the transport network. To illustrate, a supply chain can consist of several levels, as depicted along the left-hand side of Figure 24. The specific transport cost is greatest in the early stages of the supply chain, as the right-hand side of Figure 24 shows, particularly in the forest, given the poor shape of goods (A2) and the poor infrastructure. As Paper 5 has demonstrated, transports are costly in the early stages of the supply chain as well—for example, because pick-up failures can occur on roadsides. At stages further along the supply chain, specific transport costs can be reduced as product properties can be improved, as illustrated on the right-hand side of Figure 24.

Due to geographical spread (A3), the physical flow needs to be consolidated in nodes. For example, flows can be consolidated at terminals or transports can be routed directly from the roadside to customers, as the centre of Figure 24 shows. By switching transport modes in the nodes—for instance, from trucks to trains—specific transport costs can be lowered. The high cost of initial transportation justifies the term *first-mile problem* that describes the logistics phenomenon and the transportation network term *first-mile network*.

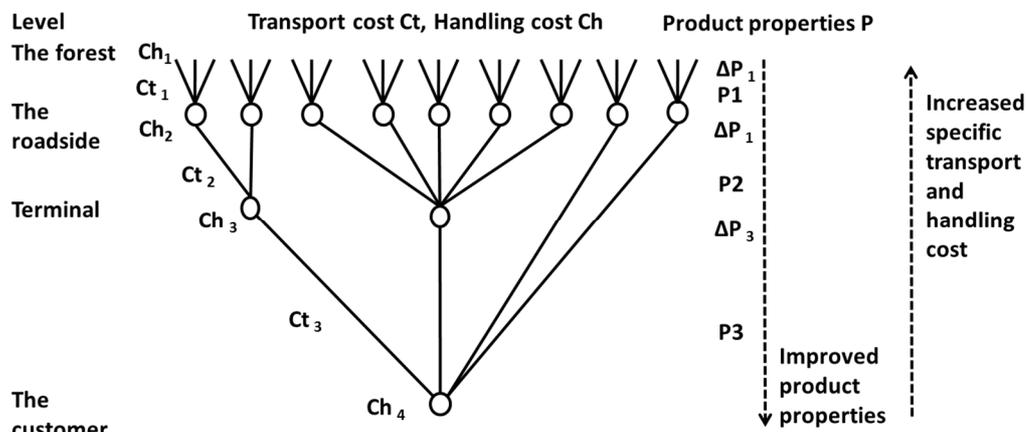


Figure 24: The first-mile network

Understanding the overall transport network structure affords three benefits. First, it provides directions for how to use nodes to bridge gaps and increase transport efficiency. Second, it provides an understanding of how to use vehicles that serve links and nodes toward achieving transport and handling efficiency. Third and lastly, a characterisation of the physical flow promotes borrowing theories that address improving the physical flow from other fields.

Correctly managing nodes is essential for cost-efficiency

An important node is the terminal, managed by suppliers themselves, hauliers, or other third-party terminal operators. Central to the physical flow, nodes function by overcoming gaps between ingoing and outgoing flows in terms of frequency, time, capacity, product properties, and infrastructure, a conceptualisation that extends Hultén (1997) previous definition of *node function* (Figure 25). That model primarily intended to describe how terminals enable different means of transport to operate independently toward achieving efficiency. Based on the findings of this thesis, the model showed in Figure 25 has been extended and adapted to the physical flow in B2E supply chains and used to describe how different processes are needed to bridge gaps between suppliers and customers.

Nodes can serve different functions. First, they overcome fluctuations in demand (A6) and, second, bridge the time gaps between supply and demand (A7). These functions align well with Hultén’s (1997) suggestion that nodes can overcome gaps in frequency and the time of both upstream and downstream processes. Third, nodes can also be used to bridge gaps in capacity between upstream and downstream processes, and fourth, to alter the shape of goods (A2). As shown in Paper 3, processing (e.g., comminution or torrefaction) increases the energy density of biomass, which implies lower costs in downstream distribution than in upstream supply. Lastly, and as Hultén (1997) briefly noted yet omitted from his model, nodes are required as physical places that can bridge the gap in infrastructure—for example, between road and rail or road and sea—which can in turn improve transport efficiency.

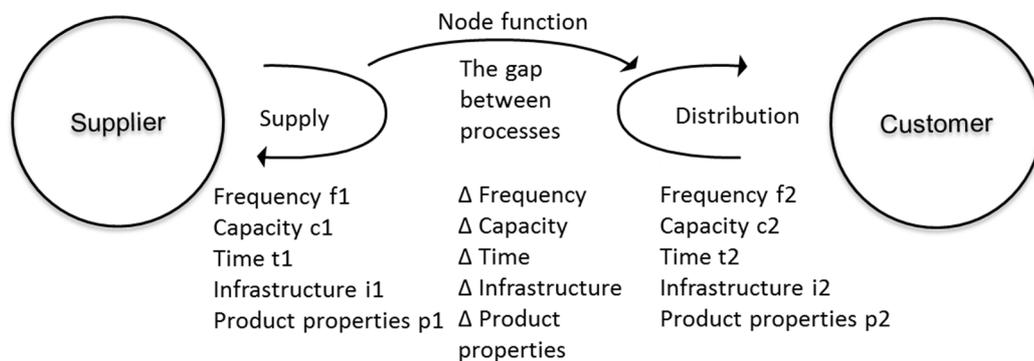


Figure 25: Node function, adapted from Hultén (1997)

As argued in Paper 1, however, no one-size-fits-all solutions are available for nodes; some should be used only for transshipments (e.g., when distances are long), whereas others should be used to bridge fluctuations (e.g., when fluctuations in energy production at powerplants are significant). Furthermore, nodes need to accommodate customer diversity (A5)—for instance, because some customers have their own storage, whereas others require storage upstream. Thus, acknowledging the diverse functions that nodes can provide and using the right node for the right function in the supply chain is vital for terminal operators to be competitive, to minimise costs, and to improve the physical flow.

Understanding that B2E supply chains are open systems allows terminal operators and hauliers to improve the efficiency of logistics resources

Given the system openness (A8) of B2E supply chains and as shown in Figure 26, there are numerous other types of flows—for example, of other non-energy products (e.g., forest products) and alternative fuels—that interact with the flow of forest fuel. These other flows need to be considered so that hauliers can increase the utilisation rate of vehicles and for terminal operators to increase the utilisation rate of handling equipment. Efficient transport and handling are critical to reducing the impact that attributes such as shape of goods (A2) exert upon the physical flow. Examples empirically observed in this thesis include the following:

1. As Paper 5 shows, hauliers can transport a wide range of different types of complementary goods (e.g., asphalt and scrap metal) when demand for biomass wanes, though such assignments are not always easy to secure and depend on the regional context;
2. As argued in Paper 1, having other types of goods pass through terminals is crucial, because both fixed and operating costs at terminals need to be shared, primarily since forest fuel alone can seldom bear the cost of a terminal; and
3. As revealed in Paper 5, hauliers can borrow and lend out both trucks and personnel to other companies that perform B2E transport, as well as lend out personnel for other purposes when demand for B2E transport is low.

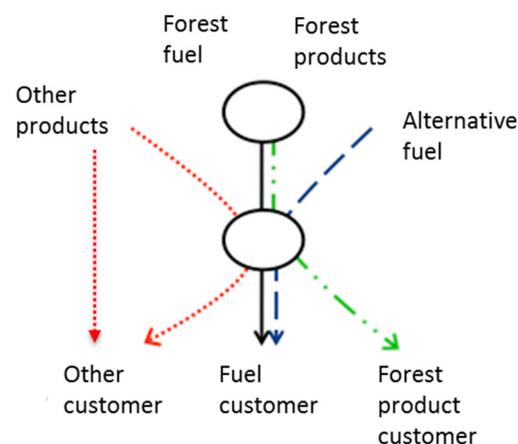


Figure 26: Interaction of flows of B2E and other products

Against this background, two suggestions can be made. First, interorganisational relationships (A8) are important in order for actors to find other types of goods to transport when demand for biomass transport is low. Relationships also need to be managed so that both trucks and drivers can be lent and borrowed. Second, hauliers and terminal operators need to strike an appropriate balance between efficient logistics resources dedicated to B2E if there is a high utilisation rate, as well as multipurpose equipment available for that can be used for other assignments as well (e.g., other types of goods).

6.2.2 Relation to the literature

In related literature, defining transport networks according to different structures is nothing new. For goods in general, Woxenius (2007) has identified six distinct

configurations of transportation networks: direct links, corridors, hub-and-spoke designs, connected hubs, static routes, and dynamic routes. Nevertheless, theoretical constructs concerning biomass supply chain configuration remain sparse, and since supply chains for forest residues share few characteristics with Woxenius (2007) configurations, defining an alternative transportation network is necessary. Within B2E logistics, Sharma et al. (2013) have reviewed how studies of B2E conceive the structure (i.e., convergent, divergent, conjoined, and network) of supply chains, noting that most studies have described them as network structures and that only three studied have deemed them to be convergent. However, it should be recognised that the result depends upon how many conversion plants are considered in modelling supply chains. On that point, this thesis advocates conceiving the flow to be convergent, which can capture the structure of the flow most distinctly, since each individual plant's flow is convergent in the first place.

Furthermore, as argued in Paper 5, considering B2E supply chains to constitute first-mile problems illuminates the application of theories from last-mile transport networks. Though first-mile problems do not mirror last-mile problems exactly, they do nevertheless allow the application of both theories and current knowledge concerning last-mile problems. In e-commerce, for example Lee and Whang (2001) argues that a key factor for 'winning the last mile' is information (p. 61), which in B2E supply chains means determining what information is necessary (e.g., road properties), by whom it should be collected, how it should be collected, and how it can be communicated. In sum, acknowledging that the transport network has first-mile characteristics enables the application of theories from research in other contexts.

In B2E logistics research, flows of other types of products are often neglected, though not entirely. Wolfsmayr and Rauch (2014b) have mentioned introducing seasonal commodities such as beets and grain in order to increase the use of capacity. Another example involves using conventional logging trucks to transport bundled forest residues (Johansson et al., 2006). Beyond that, however, research remains silent on the topic, thereby suggesting that Proposition 2 complements current knowledge of B2E and indicating a question for future research: How can other product flows be exploited to increase the use of the capacity of logistics resources for supplying B2E and clarifying what types of business models should be applied?

6.3 Proposition 3: Operators of torrefaction plants must consider location, scale, and production strategy as key aspects of economic viability

As emphasised earlier in this thesis, and in line with contingency theory, no one size fits all for torrefaction plants, at least from a supply chain perspective. For operators of torrefaction plants, this circumstance implies that plant operators need to understand and adapt to local circumstances in order to achieve long-term economic viability, which is vital to improving B2E's physical flow via torrefaction. Among aspects of local circumstances that shape the viability of torrefaction plants, first there are multiple factors at different levels that serve as criteria for the location of torrefaction plants. Second, the relationship between

biomass availability and the size of torrefaction plants influences the cost of producing torrefied densified biomass (TDB). Third, different elements in demand should shape the production strategy to reduce costs in terms of overproduction and distribution. As such, compared to the other four propositions in this thesis, Proposition 3 is primarily directed toward torrefaction plant operators.

6.3.1 Justification and significance for actors

To achieve economic viability, operators of torrefaction plants should consider multiple criteria at several levels for effective location

Regarding the location of torrefaction plants, numerous factors at different levels shape a plant's economic viability. First, addressing the international level, Smith and Junginger (2011) have argued that factors affecting the viability of conventional pellet plants include feedstock (e.g., availability, competition, and pricing), investment climate, electricity prices, market potential, and logistics, all of which should be valid criteria for the location of torrefaction plants as well. In particular, the price of biomass is important for the location of the large-scale production of TDB (Paper 2). In particular, countries such as Brazil and Canada with vast amounts of cheap, unutilised biomass, are favoured for conventional pellet production (Heinimö and Junginger, 2009), also due given that the wood fuel market is far from integrated in terms of cost of feedstock between regions (Olsson et al., 2012).

Second, feedstock availability can vary significantly at the national level and shapes the price of biomass. Furthermore, as Paper 3 has shown, TDB can be cost-competitively transported across great distances, since the shape of goods (A2) improves by way of torrefaction. Together, this imply the preferability of locating torrefaction plants in areas with an abundance of biomass.

Third, factors at the regional level should also shape decisions concerning plant location. In particular, as revealed in Paper 3, a major share of production costs stems from the drying process in the plants, yet can be significantly lowered by integration with existing powerplants or energy-intense industries. In that light, since the B2E supply chain is characterised by system openness (A8), existing industries into which the efficient integration of flows of energy and raw material can be made constitute an important criterion for plant location at the regional level. In short, no universal solution for locating plants is available; instead, location should consider multiple criteria at different levels that shape to what extent a torrefaction plant achieves long-term economic viability.

Assessing torrefaction plant size from a systems perspective minimises production costs

The optimal size of a torrefaction plant depends on its location, for regional variances exist within the geographical spread (A3) of forests. For example, in the context of the supply chain studied in Paper 3, large volumes available locally recommended the construction of a large torrefaction plant, and when available volumes are small, a smaller plant is more appropriate. Yet, size also bears implications for the upstream logistics system, as Paper 3 has also shown. In that study, a truck with an integrated chipper performed similarly to a conventional

truck at a small-scale torrefaction plant (<25,000 tonnes/year), yet at larger-scale plants—meaning longer transport distances—conventional chip trucks were more cost-efficient. Thus, the relationship among scale, the availability of biomass, and the choice of logistics resources stresses the value of taking a systems perspective in order to minimise the cost of TDB, which is, after all, the sum of all logistics and production costs.

Adapting production strategies to accommodate end users and distribution systems is essential to the competitiveness of torrefaction plants

Given the potential diversity of TDB's end users (A5), Paper 2 has concluded that a torrefaction plant ought to play correspondingly diverse roles. For instance, depending on the type of demand, torrefaction can serve several functions by bridging different types of gaps in terms of time (A7), place, quality, and ownership. In effect, to be competitive in terms of cost, the plant's production strategy should be aligned with both end users and the distribution system used. Torrefaction plant operators must particularly assess the relative importance of TDB's product quality parameters, including its energy density, durability, and hydrophobicity, all of which can pose trade-offs with cost and thus impact supply chain efficiency for different types of customers. Ultimately, to minimise costs caused by overproduction or the optimisation of the wrong parameters, the plant's distribution system and customers should serve as starting points for determining and optimising production strategies.

6.3.2 Relation to the literature

Adapting the size of torrefaction plants to the availability of biomass aligns with earlier recommendations for bioenergy facilities in general (Searcy and Flynn, 2009), powerplants (Kumar et al., 2003), and pellet plants (Sultana et al., 2010). Selecting vehicles according to the distance to plants is similarly consistent with earlier findings that it can be profitable, for example, to transport uncomminuted forest fuel over short distances, though chip truck transportation should be used when distances are long (Tahvanainen and Anttila, 2011).

When determining the function of a torrefaction plant, it is essential for demand to constitute a point of departure; indeed, demand has served as a starting point for designing supply chains for other types of goods (cf. (Christopher and Towill, 2002, Fisher, 1997, Lee, 2002)). Given the diversity of TDB customers, Paper 3 has suggested using profile analysis to identify compatibility and any possible niches for the torrefaction plant according to the supply chain and different elements of demand. This approach aligns with recommendations by (Pagh and Cooper, 1998), who have suggested using profile analysis for choosing between postponement and speculation strategies. Lastly, and as argued earlier, a torrefaction plant could play different roles in different supply chains, a view that aligns with the functions of terminals in distribution systems. More specifically, Roso et al. (2009) have differentiated dry ports based on scale and functions—for instance, in terms of making rail viable from a cost perspective or offering a buffer for containers to relieve seaport stacking areas. Altogether, the findings of Proposition 3 align well with those in the literature, or more precisely, its contribution shows that the above theories hold true in B2E contexts as well.

6.4 Proposition 4: Actors in the supply chain can benefit from moving storage downstream

When storage of biomass is needed in supply chains, Proposition 4 suggests that such storage should be moved downstream—namely, to powerplants—to benefit energy producers, hauliers, and suppliers. In this thesis, *moving the storage of biomass* is used as a term to describe how inventory should be kept at a powerplant instead of upstream in the supply chain. To that end, energy producers with limited storage capacities—for example, those with silos only, each offering just a few days of storage—need to expand their storage capacities. The feasible way to achieve such expansion is to invest in outdoor storage areas next to the powerplants, which enable holding inventory for significantly longer times (e.g., 1–2 months). Proposition 4 is particularly relevant when there are large fluctuations in demand (A6) or when large shares of supply are handled via terminals instead of via direct supply from roadsides. Empirical support for Proposition 4 is particularly drawn from Paper 4, in which two case companies had large storage areas, whereas another two were keen to develop some, yet were hindered by limited space next to their powerplants. As Papers 4 and 5 have shown in combination, moving storage downstream is a means of coordination that poses several advantages for energy producers, hauliers, and suppliers.

6.4.1 Justification and significance for actors

For energy producers: Improved quality and supply security, lower biomass prices, and spot purchasing

Keeping inventory at powerplants implies an extra cost for energy producers, largely due to increased inventory carrying costs, which consist of capital holding costs, storage costs, and uncertainty costs in terms of quality losses as a result of perishability (A2). However, for these same energy producers, there are also benefits of maintaining storage areas for holding inventory that could outweigh the costs: improved quality, greater supply security, potentially lower prices of biomass, and the possibility of making spot purchases. First, as Paper 4 has demonstrated, keeping inventory at powerplants allows not only using the right assortment at the right time as a way to reduce losses in quality, but also searching within piles of biomass to find the right quality of biomass to meet boiler specifications. Second, as interviewees in Paper 4 argued, storage areas can be used to keep inventory at powerplants in order to ensure supply security. Evidence in Paper 1 also supports that claim, by showing that, for one energy producer, supply security was ensured by routing all biomass flows via terminals. This measure was taken in response to large fluctuations in demand (A6), which precluded direct supply from roadsides. In such cases, it is preferable to maintain storage at powerplants instead of at terminals in order to achieve supply security. Third, moving storage to powerplants helps to reduce the number of handling steps, which in turn lowers supply costs for both hauliers and suppliers, thereby justifying a lower price of biomass for energy producers. Fourth and lastly, since system openness (A8) characterises B2E supply chains, having a storage area enables energy producers to benefit by making spot purchases and procuring assortments other than primary biomass. An example of this possibility emerged in Paper 4, in which one case company spot purchased bark, which would have been impossible had it lacked a storage area. In that sense, there are several

potential benefits of keeping inventory at powerplants, but also of having unutilised storage space at powerplants.

For hauliers: An increased utilisation rate of vehicles and personnel improves transport efficiency

For hauliers, the benefits gained by energy producers' keeping inventory at powerplants is a more levelled supply, which implies a better utilisation rate of both trucks and personnel on long time horizons, but also to more easily keeping skilled personnel between seasons. As Paper 5 has illustrated, the utilisation rates of vehicles and personnel pose important challenges for hauliers, and skilled truck drivers are essential in order to maintain transport efficiency.

For suppliers: Reduced inventory implies lower inventory carrying costs

If inventory is relocated to energy producers, then suppliers can reduce their inventory and benefit from lower inventory carrying costs. This approach is one way to manage interorganisational relationships (A9) differently, as an interviewee in Paper 4 eloquently expressed: 'One of the suppliers doesn't even have a terminal of its own; we are its terminal'. In that light, moving storage downstream, to keep inventory at powerplants enables suppliers to reduce their inventory, as well as the number of handling steps upstream in the supply chain, both of which yield a more efficient physical flow.

6.4.2 Relation to the literature

Proposition 4 contradicts a good deal of conventional logistics theory concerning the storage of goods. For one, capital tied up in goods increases when those goods are moved downstream (cf. Jonsson, 2008), which implies that from a capital holding cost perspective, goods should be stored upstream. Moreover, central theories about lean manufacturing argue for just-in-time deliveries with zero inventories (cf. Womack et al. (1990)), which this proposition contradicts. Proposition 4 furthermore counters current proposals for B2E storage; for example, Wihersaari (2005) recommends that forest fuel be used within one week following comminution, which is a process typically performed on roadsides to improve transport efficiency, yet which also increases perishability (A1). In response, a way to minimise losses is to acknowledge the different assortments of forest fuel and differences within those assortments. By keeping track of and using assortments that suffer the greatest losses in quality along a short time horizon, the economic consequences of perishability can be minimised.

Logistics literature also contains theories that advocate keeping inventory, which can activate benefits in terms of reduced costs in the supply chain and increased customer service. In the division between postponement and speculation, the latter advocates that holding goods can lower logistics costs and create advantages for customer service (e.g., Pagh and Cooper (1998)). Moreover, and to reiterate a point in the above discussion, keeping inventory at powerplants can be beneficial from a B2E supply chain perspective, for it can reduce the number of handling steps. Such a configuration also aligns with suggestions in the literature; for instance, Hall et al. (2001) have argued that the number of handling steps in supply chains should be reduced because they typically pose additional costs.

In short, moving storage downstream both confirms and contradicts logistics theory. Keeping inventory at powerplants does not per se benefit the energy producer, since it imposes extra capital holding costs. However, from a supply chain perspective, there is support for moving storage downstream in both the above discussion and related literature. A supply chain perspective—that competitors are not individual companies but instead entire supply chains—is a key foundation of supply chain management (Christopher and Towill, 2000). In that light, suppliers, hauliers, and energy producers should collaborate to develop thorough models for calculating both total cost, which comprises cost of all transport and handling activities, and inventory carrying cost, to determine the exact levels of inventory that should be kept at powerplants. Finally, coordination mechanisms (e.g., contracts, cf. Arshinder et al. (2008)) should also be identified that can distribute the gains and costs of moving storage downstream.

6.5 Proposition 5: Actors in the supply chain can benefit from long-term relationships

Proposition 5 suggests that actors (i.e., forest fuel suppliers, hauliers, and energy producers) in the physical flow of B2E can benefit from long-term relationships. Interorganisational relationships (A9) constitute an attribute of B2E supply chains that by definition can be altered, for example, because business relationships can be extended, either by continuously renewing contracts or preferably by longer contract periods.

6.5.1 Justification and significance for actors

For energy producers: Energy security and reduced cost of biomass

In general, long-term strategic alliances are developed among small groups of core suppliers (Lambert and Cooper, 2000). Given biomass's geographical spread (A3), nearly all suppliers in a given area may become core suppliers, in particular when there are small amounts of biomass in relation to the number of energy producers. For these, long-term relationships is a means in order to secure supply.

At the same time, and as several energy producers in Paper 4 expressed, concerns about ensuring future supply exist for producers, who in response can take different measures to be perceived as good customers by hauliers and suppliers. For example, one energy producer advocated paying slightly more than required in order to minimise the risk of losing suppliers in the future. Another energy producer proposed keeping generous open hours at receiving stations in order to be perceived as a good customer as means to ensure future supply. Alternatively or additionally to these measures, long-term relations can be formalised by way of contracts in order to secure future supply. Losing nearby suppliers poses the risk of having to procure distant biomass, which can be unprofitable. This claim takes support from findings in Paper 3 showing that the amount of biomass available regionally greatly affects supply chain performance in terms of cost of supply, which in turn shapes the price that a customers have to pay for biomass. Accordingly, two major incentives for energy producers to engage in long-term relationships are the possibility of thereby securing future supply and of avoiding long-distance procurement, which is costly due to the shape of the goods (A2).

For hauliers: Increased transport efficiency

Three findings jointly justify the importance of long-term relationships between hauliers and transport buying companies (i.e., energy producers or suppliers). Paper 4 has revealed concerns regarding the short-sightedness of energy producers, for as one haulier argued, in his local market, characterised by a state of uncertainty in demand of transport, hauliers do not dare invest in more efficient trucks. Later, in Paper 5, it was argued that long-term relationships enable hauliers to invest in new trucks with larger capacities and better engines. In another sense, long-term relationships are also important since truck drivers need to learn local conditions in order to better avoid pick-up failures (Paper 5). Altogether, long-term relationships to reduce uncertainty can enable hauliers to invest in proper vehicles and maintain skilled drivers, both toward improving transport efficiency.

6.5.2 Relation to the literature

The recommendation of sustaining long-term relationships aligns with central theories in literature concerning supply chain management (e.g., (Lambert and Cooper, 2000, Chen and Paulraj, 2004, Prajogo and Olhager, 2012, Shin et al., 2000). One pre-requisite of such relationships is the win-win for both parties (Lambert and Cooper, 2000), meaning that energy producers and upstream actors should benefit from long-term relationships, as shown to be the case for both energy producers and hauliers. Accordingly, Proposition 5 confirms that findings in literature addressing other types of goods hold true for B2E contexts as well.

As earlier argued, the business relationship can be extended with renewed or longer contracts. On that point, the length of contract terms is a widely discussed subject, for there are both advantages and drawbacks to extended contracts. In a related energy industry—the natural gas industry—the maturity of the industry has diminished the need to support inaugural large-scale investments, and when asset-specific investments are at stake, the average contract term is long in order to support the investments (von Hirschhausen and Neumann, 2008). Since the forest fuel market is relatively new and liable to change rapidly (Flisberg et al. (2015), long-term contracts might be preferable in B2E supply chains, primarily due to large investments in specialised vehicles for hauliers.

Summary

The purpose of this thesis has been to investigate how pre-treatment technology and coordination can improve the physical flow in B2E supply chains. Five propositions, based on findings in this thesis, have provided distinct paths for achieving that purpose. As shown in the above discussion, actors who perform activities in the physical flow can benefit from these propositions that, in turn, also improve the physical flow. As summarised below, these benefits are diverse and concern both effectiveness (e.g., in terms of using the right resources for an activity) and efficiency (e.g., in terms of using resources to perform activities in the right way).

Hauliers perform the core activity of the flow—that is, the movement of goods, which in this case is B2E. Transport efficiency involves not only efficient logistics resources, but also using the right resources for that transport. In particular, using the right trucks, with large capacities and better engines (i.e., Proposition 5) to create utilities according to customer needs (i.e., Proposition 1), and using those

trucks effectively and efficiently, to achieve high utilisation rates on long time horizons (i.e., Propositions 2, 4) are benefits for hauliers that improve the physical flow.

Suppliers and terminal operators manage activities necessary to support the movement of goods—namely, storage, transshipment, and comminution. Among benefits that they can reap are reduced storage volumes (i.e., Proposition 4), while performing the right activity at the right place (i.e., Proposition 2)—or similarly, creating the right utility at the right place, as proposed for energy producers and hauliers in Proposition 1—can make the physical flow cost-effective.

Torrefaction plant operators manage the activity of torrefaction—that is, the transformation of goods to improve product properties—which enables more efficient transportation. These actors' making their plants economically viable in the long run is essential for the physical flow and can be achieved by understanding location criteria, by adapting the size of plants to local circumstances in terms of biomass availability, and by managing the production strategy according to customers (i.e., Proposition 3).

Energy producers traditionally perceive themselves to be production units that manage the transformation of goods—that is, the conversion of energy carriers into usable forms of energy. However, energy producers can also influence the upstream physical flow by coordinating activities. As exemplified in Propositions 4 and 5, coordination of activities lowers costs in the supply chain, which with coordination mechanisms such as contracts can entail benefits, including reduced biomass costs for energy producers. Moreover, understanding that energy producers can create several utilities in the supply chain—in particular, the utility of time—can illuminate ways for expanding producers' operations, which can ultimately improve the production economy (i.e., Proposition 1).

7 Conclusions, Contributions, Directions for Future Research, and Reflections

This chapter presents the conclusions and contributions of the thesis, followed by recommended directions for future research and a few personal reflections.

7.1 Conclusions

To investigate how the physical flow in B2E supply chains can be improved, this thesis has been developed upon three cornerstones—namely, B2E supply chain attributes, pre-treatment technology, and coordination—each with a corresponding research question.

7.1.1 B2E supply chain attributes

Nine distinct attributes have been identified, all of which are key features that capture the essence of B2E supply chains, as well as determine their configuration and the physical flow therein. Diverse in nature, the attributes are related to the goods involved (A1–A2), the environment of the supply chain (A3–A4), the energy producer (A5–A6), or other actors (A7–A9). The nine attributes bear different types of interplays with configuration of the supply chain and the physical flow. They have been labelled as follows:

A1: Perishability

A2: Shape of goods

A3: Geographical spread

A4: Weather and climate

A5: Customer diversity

A6: Fluctuations in demand

A7: Time gaps between supply and demand

A8: System openness

A9: Interorganisational relationships

Different improvement efforts—for example, technological and managerial—can improve the flow in two ways. First, some attributes can be altered; for instance, the shape of goods (A2) can be altered by processing, as with torrefaction or comminution. Second, the relative importance that the attributes have in the physical flow can be reduced; for example, by improved receiving capacity at powerplants, suppliers can more easily direct flows toward the closest powerplants, thereby improving their efficiency and reducing the impacts of geographical spread (A3) upon the physical flow. From the opposite direction, attributes can shape or influence configuration; weather and climate (A4) shapes how flows are routed, for example, by dictating terms for storage levels and the location of terminals.

The thesis has suggested two propositions for efficient supply chain configuration. First, actors along energy supply chains should be reconceptualised as energy service providers, which implies a shift in focus from the goal of minimising costs for operations to the utilities or service that can be provided by their operations. By identifying which kind of utilities actors can provide, paths for expanding their operations become illuminated, which can in turn increase the cost-efficiency of

the physical flow. Second, three structural elements of the physical flow have been presented, all of which are essential to understand in order to achieve effective, efficient supply chain configurations and physical flows:

- The transport network has first-mile characteristics, and key decisions for suppliers include the location of nodes (e.g., terminals) and the routing of flows;
- Nodes can and should serve different functions in supply chains in terms of overcoming gaps in frequency, capacity, time, infrastructure, and product properties, all according to local circumstances and the customer diversity (A5); and
- B2E supply chains are characterised by system openness (A8), and to achieve cost-efficiency, connections to other supply chains need to be managed by terminal operators (e.g. by sharing fixed costs) and by having hauliers transport other types of goods when biomass transport is not in demand.

7.1.2 Pre-treatment technology

The first approach to improve the physical flow in B2E supply chains involves using pre-treatment technology, which in this thesis is represented by torrefaction technology. To investigate how torrefaction can improve the physical flow, three types of interplays between B2E supply chain attributes and torrefaction has been analysed.

First, torrefaction has the potential to improve the physical flow within B2E supply chains, primarily by altering supply chain attributes. In particular, torrefaction not only alters the perishability (A1) of the product (B2E), which in enhancing the physical flow by reducing losses in substance during storage benefits both suppliers and energy producers. Moreover, torrefaction alters the shape of goods (A2), thereby improving transport efficiency for hauliers and enabling transport across longer distances. As a result, B2E supply chains can become more cost-competitive, and energy producers can begin to take advantage of the untapped potential of biomass. At the same time, torrefaction alters the customer diversity (A5), since it makes biomass usable for several new types of end users (e.g., coal-fired powerplants and potential producers of vehicle fuel and green chemicals), who can also exploit biomass's untapped potential. However, the production strategies of torrefaction plants consequently need to accommodate different end users and distribution systems—for example, by producing pellets with greater energy density when distribution distances to customers are long.

Second, torrefaction can improve the physical flow by reducing the relative importance of attributes in B2E supply chains, e.g. in terms of fluctuations in demand (A6), by enabling a levelled demand for both biomass and its transport upstream in the supply chain. This effect is important for hauliers, who can thereby increase transport efficiency by enhancing the utilisation rate of dedicated trucks and personnel, as well as for suppliers, who can reduce storage volumes.

Third, from the opposite direction, B2E supply chain attributes influence the configuration of the torrefaction supply chain, particularly the availability of biomass, which varies with the geographical spread (A3) of forests and shapes the

optimal size of a torrefaction plant. In Sweden, for example, an optimally sized torrefaction plant produces 150,000–200,000 tonnes of TDB per year. Furthermore, due to system openness (A8), connections to other supply chains shape the location of torrefaction plants, since integration can lower torrefaction costs, whereas transport costs can be reduced by sharing infrastructure with other types of goods.

In sum, torrefaction plants are not only production units in B2E supply chains that can improve product properties and accommodate new end users, but more broadly an important component for improving the physical flow therein, either by altering the attributes or reducing their relative importance. However, the context—in this thesis, the B2E supply chain—dictates the terms of using the technology (i.e., torrefaction).

7.1.3 Coordination

The second approach to improve the physical flow in B2E supply chains investigated in this thesis is the coordination of activities. To clarify how activities can be coordinated, the interplay between B2E supply chain attributes and coordination of activities have been analysed. Compared to torrefaction, which in several cases can alter attributes, the coordination of activities can primarily reduce the relative importance of B2E supply chain attributes, especially of the shape of goods (A2). The relative importance of this attribute can be reduced e.g. when energy producers make use of means of coordination in terms of extending their open hours, improving comminution, lessening their demands upon delivery flexibility, and prolonging the season during which biomass can be supplied. All of these means of coordination can in turn increase hauliers' transport efficiency; by enabling them to avoid detours and also improve the utilisation rates of trucks and personnel on both short and long time horizons, their transport costs drop. Similarly, the relative importance of fluctuations in demand (A6) and perishability (A1) can be reduced by relocating storage downstream to powerplants, or by having energy producers invest in a supplementary business (e.g., pellet production during the summer) and thereby become bioenergy combines. However, the latter should be classified as an unintentional means of coordination, taken primarily for internal reasons at powerplants—for example, improved production economy—yet one that, even if inadvertently, benefits actors upstream in the supply chain as well. Both means are important for suppliers, who as a result can reduce storage volumes and, in turn, make biomass suffer less from perishability (A1). Plus, since transport demand is levelled throughout the year in such cases, the effects of fluctuations in demand (A6) are reduced, which increases the utilisation rates of trucks and personnel on long time horizons, transport cost for hauliers can be reduced.

The only attribute observed that can be altered by means of coordination is interorganisational relations (A9), insofar as they can be extended, for example, with longer contracts. Doing so enables hauliers to invest in newer trucks with better engines and larger capacities, which ultimately increases their transport efficiency.

Lastly, the context of B2E supply chains imposes conditions for the coordination of activities. There is a diversity of customers (A5) with different attitudes toward coordination; some of whom embrace coordination, in order to be perceived as good customers, chiefly as a means to ensure future supply, whereas others care little about what happens outside their gates, which can prevent from using means of coordination to improve the physical flow. At the same time, B2E supply is characterised by system openness (A8), in which network connections to other energy producers enable the trade of electricity and heat, which can pose a barrier toward or enable the use of means of coordination. Thus, the physical flow can be improved by coordinating activities, though the context—here, B2E supply chains—shape how activities can be coordinated. Compared to torrefaction, coordination exerts less impact on the supply chain and the physical flow, but its implementation also requires less effort and fewer actors.

7.2 Contributions

The thesis makes contributions in the domains of its three cornerstones—B2E supply chains, pre-treatment technology, and coordination—all of which are of interest to three groups: the logistics research community, the bioenergy research community, and in terms of managerial implications, the bioenergy industry. They are as follows:

B2E supply attributes:

- B2E supply chain attributes contribute to the logistics research community by providing a description of the context of B2E supply chains, which is essential for logistics researchers to gain an understanding of what distinguishes biomass from other types of goods. Subsequently, B2E supply chain attributes serve as a platform for the logistics and bioenergy research community's efforts toward choosing among and analysing technological or managerial approaches in order to improve the physical flow.
- The three structural elements of the physical flow in B2E supply chains—that is, first-mile characteristics, diversified nodes, and interacting product flows—pose managerial implications by being essential to achieving effective, efficient supply chain configurations and physical flows therein.
- Reconceptualising actors along the B2E supply chain as energy logistics service providers poses a managerial implication by providing a new perspective for understanding how operations can be expanded or adapted. In particular, energy producers can expand their operations by providing the utility of time—for example, by making use of excess heat to produce pellets during summertime and distributing them during wintertime, which induces a better production economy and makes the overall supply chain more cost-effective. This reconceptualisation also contributes to the logistics research community by highlighting logistics concepts such as utilities and thus illuminates logistic challenges for a unique type of good (i.e., biomass) with major monetary value and the potential to contribute to reducing environmental impacts associated with energy use. Such a reconceptualisation should therefore attract the logistics research community to conduct research on B2E supply chains to a larger extent.

Torrefaction:

- By showing that torrefaction plants are not only production units in B2E supply chains that can improve product properties (i.e., make biomass suitable for several end users), but also an important element in improving the physical flow (e.g., by improving transport and handling properties), this thesis contributes to the bioenergy research community, which mostly studies torrefaction from a technical perspective. The suggested interplay between torrefaction and B2E supply chain attributes serves as a framework for analysing how technological changes influence the physical flow.
- By taking a systems approach, this thesis has quantified the optimal size of torrefaction plants, as well as identified important parameters shaping the cost of delivering TDB to end users and thus serving as managerial implications for operators of torrefaction plants.
- As a managerial implication, there are three suggestions for the economic viability of torrefaction plants:
 - Torrefaction plants should be located according to multiple criteria at international (e.g., cost of feedstock), national (e.g., availability of biomass), and regional levels (e.g., possibilities for integration);
 - Assessing torrefaction plant size from a systems perspective minimises the total cost of supplying biomass to end users; and
 - Adapting production strategies to end users and distribution systems is essential for the competitiveness of torrefaction plants.
- This thesis has made a contribution to the logistics research community by showing that management of process technology to enable new end users of biomass is not only a technical problem but also a logistical one. In particular, Paper 2 shows how to use of profile analysis to address logistics aspect of managing technology, which forms an approach that can be used for other technologies in other contexts as well.
- Over the last two decades, most logistics research on technology has regarded information technology as a means to improve supply chains. This thesis has another technological focus: that of process technology that can manage product properties in order to improve supply chains. Accordingly, this thesis serves as a contribution to the logistics research community by highlighting and describing additional technologies beyond information technology that can improve the physical flow. On the whole, the thesis provides a platform for how technology can be used in other supply chains and for other types of goods.

Coordination:

- By using data from two stages in the supply chain, this thesis affords a managerial contribution: namely, the identification and analysis of how means of coordination at the hands of energy producers shape transport efficiency for hauliers (i.e., reducing transport costs). This finding should

serve as a managerial implication in terms of how actors jointly can reduce transports costs, which should justify a lower price of transports for transport buyers, thereby making B2E supply chains more cost-competitive.

- This thesis makes a contribution to the bioenergy research community by introducing coordination into a previously unexplored context and thereby highlighting a new approach for improving the physical flow. At the same time, as a means of coordination, moving storage downstream contradicts conventional logistics theory and should thus be of interest to logistics researchers seeking to explore its application for other types of goods.
- A layered approach for relating improvement efforts to transport efficiency was developed in Paper 4. Although its content was based on a B2E context, the structure of the framework was based on a systems approach and logistics theories. The framework could hence serve as a contribution to the logistics research community, as it should be further explored and refined for other types of goods.
- A managerial implication is that showing how long-term relationships are important for actors along the B2E supply chain enables hauliers to invest in trucks with better capacities and engines, all toward minimising the cost of supply for hauliers and for energy producers in order to ensure future supply.

7.3 Directions for future research

Mostly descriptive and exploratory in nature, this thesis and its findings should be further explored with other methods, including those of quantitative studies. Below follow suggestions regarding directions for future research.

Regarding torrefaction, empirical tests to assess handling and transportation properties need to be performed, as does an assessment of different customer requirements concerning product quality and service level. Once these aspects have been assessed, it will become possible to further develop and refine strategies for configuration of torrefaction and its supply chain. For example, assessing the cost of producing TDB with excellent storage properties (e.g., high hydrophobicity) is essential for realising shipping strategies that can exploit fluctuating oceanic shipping rates.

This thesis has addressed the economics of torrefaction supply chains from a national perspective, and follow-up studies could take two different routes. First, given that one simplification in Paper 3 was its one-to-one perspective—that is, without competition or any overlap in procurement areas among powerplants—future research could use geographical information systems and optimisation models to evaluate the findings. Second, from an international perspective, the untapped potential of biomass in Sweden is lower than in, for example, Brazil, Canada, and Russia. Future research should therefore address the configuration of these supply chains, particularly in respect to the size and location of torrefaction plants. In that sense, the research on torrefaction in this thesis should be

complemented by studies using other methods (e.g., optimisation methods) in order to determine the optimal location of torrefaction plants.

Although numerous means of coordination have been identified in this thesis, additional research should identify how these means can be put into practice. The concepts of coordination mechanisms can offer clear paths to ensure that means of coordination are implemented, as well as that the costs and benefits of improved coordination are distributed among actors in supply chains.

As this thesis has stressed, the utilisation rates of trucks and personnel are important for hauliers. By extension, industry-spanning efforts in investigating how different types of goods can complement each other are essential to improving transport efficiency. For instance, the logistics research community should develop models for combining different types of goods with seasonal cycles in demand for transport.

The five propositions suggested in the discussion of this thesis also require further examination in order to be implemented. For example, bioenergy combines remain uncommon, meaning that research should contribute to developing business models for using them in different circumstances. Logistics studies are also needed to develop models for responding to fluctuations in demand and uncertainty. From another angle, as Proposition 2 suggested, B2E supply chains can be conceived to pose first-mile problems, which further suggests that research on B2E supply chains should be able to learn from last-mile logistics—for example, regarding how to use standardisation and information toward reducing pick-up failures. At the same time, as Proposition 5 argued, if storage is necessary in B2E supply chains, it should be located at powerplants. To facilitate moving storage downstream and determine preferable levels of inventory, thorough models for calculating total costs also need to be developed.

Lastly, there is not always a business relationship between hauliers and energy producers. Instead, it is more often the suppliers who are responsible for purchasing transport. In such cases, future research needs to assist in multitier coordination in order to improve the physical flow.

7.4 Reflections

The final remarks of this thesis consist of a few personal reflections on supply chain attributes and on introducing torrefaction (and other pre-treatment technologies) and coordination into B2E supply chains. These reflections relate to one of two broad concerns: first, whether the most relevant supply chain attributes have been addressed and which are most important, and second, what the future holds for torrefaction and for coordination of activities in B2E supply chains.

Have the most relevant attributes been addressed?

A vital question that naturally arises after deriving attributes of any system is whether perhaps important attributes have been neglected. On that topic, Pagh and Cooper (1998) have suggested that in determining supply chain strategies, determinants should be selected according to their relevance to the scope of the study and not be overly numerous, which would risk blurring the importance of

essential ones. From that perspective, the attributes derived in this thesis are the most relevant for capturing the essence of B2E supply chains and the physical flow therein. Nevertheless, in addressing other levels of B2E supply chains, McCormick and Kåberger (2007) have argued that key barriers for B2E also include institutional capacity and know-how. Though arguably attributes of B2E supply chains, these two determinants are beyond the domain of physical flow. Furthermore, at a certain point, more or less everything influences the physical flow—for example, drivers' health, which influences the operational efficiency of trucks. Yet, stating every possible attribute would surely compromise the importance of the most essential ones—that is, those that particularly distinguish B2E and its supply chains from other types of goods and their supply chains. In that sense, the entire research process, which has consisted of more than five years of literature review, data collection, and analysis across several studies, has, from the perspective of the author of this thesis, rendered the identification of the most relevant attributes for describing B2E supply chains.

What is the relative importance of the attributes?

Concerning the relative importance of the nine identified attributes, from a subjective standpoint, the two most distinctly important are first the shape of goods (A2), a vital component that raises transport costs, which Lauri et al. (2014) have argued pose a major barrier to expanding the use of B2E. Second, fluctuations in demand bear great consequences for all actors upstream in B2E supply chains by causing both storage problems (e.g., excess inventory and substance losses) and poor utilisation rates of personnel and logistics resources. The importance of fluctuations in demand (A6) for energy producers was also argued by an interviewee in the study in Paper 4, who stated that his organisation's 'job is about managing fluctuations'. Altogether, the shape of goods (A2) and fluctuations in demand (A6) are both highly distinct in B2E supply chains and omnipresent in all supply chain configurations.

The industrial use of torrefaction

When this thesis was initially undertaken, very few papers addressing torrefaction had been published, despite significant interest from the industry and the possible construction of several potential torrefaction plants. In the years that followed, however, research on the topic has increased significantly, while industrial interest has somewhat declined and torrefaction plants are yet to be constructed. Though analysing the reasons for this shift is beyond the scope of this thesis, from a subjective standpoint the lack of political incentives, technical problems with torrefaction, and declining prices in energy are likely barriers to the expansion of torrefaction. To a large extent, developments in hydraulic fracturing, also known as fracking, have resulted in significant increases in the availability of fossil fuels, which have brought about the declining interest of energy producers in replacing fossil fuels with biomass. In fact, discovered in the research in Paper 3, two of eight pellet plants visited were preparing to close due to market conditions, particularly the price of pellets. Furthermore, planning and realising a torrefaction plant involves multiple actors, not only the potential operator, for supply has to be secured with respect to a long-term perspective by forging relationships with multiple actors and demand with potential end users, all of which need to be in place. Taking all of these factors into account, it is unsurprising that torrefaction

has not yet achieved full commercialisation. Partly in response, this thesis has provided a foundation for understanding how torrefaction can be used to improve the physical flow in B2E supply chains, though clearly political incentives, market conditions, and other factors determine when and where the results of this thesis will be used.

The industrial use of means of coordination

Compared to torrefaction, means of coordination are far easier to implement into B2E supply chains, for they require fewer actors and can be realised on shorter time horizons. Although some are indeed implemented today, many more could be implemented to a larger extent, at least after a few different obstacles are overcome. First, the forest fuel supply chain involves many conservative actors, perhaps as a result of energy producers' being municipal and caring little about what happens outside their gates. Second, as an interviewee expressed in Paper 4, even small changes require top management's involvement due to the organisational structure in municipal companies. Third, business relations are not always between hauliers and energy producers, but instead between energy producers and suppliers, which in turn contract hauliers. These obstacles clearly need to be overcome in order to use means of coordination and reap the potential benefits identified in this thesis. To that end, additional research is also needed, particularly regarding management culture and relationship management from a supply chain perspective.

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