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Socio-Economic Assessment of Implementing Mobile Biorefineries

A pre-study with a focus on the European Union

Master's thesis within the master degree program
Industrial Ecology – for a sustainable future

Edvard Höcke and Anton Jacobson

Department of Energy and Environment
Division of Environmental System Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
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Edvard Höcke
Anton Jacobson

Tutors: Rickard Arvidsson and Gustav Sandin Albertsson

Examiner: Rickard Arvidsson

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Department of Energy and Environment
Division of Environmental System Analysis
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

Cover:
Conceptual image of a mobile biorefinery in the forest.

Chalmers Reproservice
Göteborg, Sweden 2015

Abstract

Fossil resources will likely face future resource problems, and the use of such resources is one of the main drivers for global warming. Biological feedstock has been suggested as a potential alternative to fossil resources. Such feedstock can be used in biorefineries to produce fuels and materials. A desire to make biorefineries more flexible by making them mobile has been expressed by the European Union's Commission of Research, which has initiated a research project called Mobile FLIP to develop mobile biorefinery concepts. A socio-economic assessment of implementing these mobile biorefineries is to be carried out within this project, and that is where this study aims at contributing.

To identify socio-economic factors related to implementing mobile biorefineries, the method of content analysis was applied by analysing 25 reports and articles from both journals and newspapers. The texts were culled for arguments that associate or dissociate socio-economic factors to mobile biorefineries. A total of 104 arguments where identified and categorised into four primary arguments: (1) cost, (2) feedstock availability, (3) rural development and (4) forest fire. The identified arguments were both compared to two established frameworks for social assessment of products, and analysed by reviewing the existing literature and performing some screening calculations.

Most of the identified factors could not be identified in the established frameworks for social assessment of products. This is likely due to in the context in which these were developed. Current product social assessment frameworks were developed in a developing country context, while mobile biorefineries are mainly discussed in a developed country context.

All socio-economic factors identified in this study should be evaluated further to confirm their importance and impact. Some specific suggestions of relevant methods for further analysis are suggested. Life cycle costing (LCC) could be used for assessing the primary argument cost. A risk assessment should be performed to assess the potential risk of forest fires. A societal life cycle assessment using working hours as indicator may be used to assess rural development in general and rural jobs in particular.

Keywords: Biorefinery, bioeconomy, content analysis, flexibile, rural development, social life cycle assessment.

Acknowledgements

First of all we would like to thank our two supervisors which have been a great support throughout the project. Gustav Sandin Albertsson has been a big help and has come with many good ideas and suggestions to improve the results of this project. Rickard Arvidsson at Chalmers University of Technology has been a great help with valuable and interesting discussions which have supported us with choosing the right path for moving forwards with the project, and has come with many good recommendations along the way.

We would also take the opportunity to thank SP Technical Research Institute of Sweden and Johanna Berlin for giving us the opportunity to realize this thesis work. It has been a very good experience for us and we have learnt many things along the way!

And last but not least, we would like to say thank you to Chalmers University of Technology for five (six) great years!

List of Abbreviations

CA	Content Analysis
CDF	Cumulative Distribution Function
E-LCA	Environmental Life Cycle Assessment
GIS	Geographic Information System
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
MB	Mobile Biorefinery
NPV	Net Present Value
PSIA	Product Social Impact Assessment
R&D	Research and Development
SB	Stationary Biorefinery
SCB	Statistics Sweden
S-LCA	Social Life Cycle Assessment
SP	SP Technical Research Institute of Sweden
TIS	Technical Innovation System

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1 Introduction

The world's resources are limited and the needs of the growing human population are constantly increasing. Fossil fuels have been used as the main energy source in industries since the beginning of the industrial revolution and are used as the primary energy source within the transport sector (Stuiver, et al., 2012). The use of fossil fuels is one of the drivers of global warming and many other environmental issues. Consequently, many industries are trying to phase out fossil-based raw materials, which in turn increase the pressure of finding new sources of energy and materials (SP, 2013a).

Biological feedstock is expected to be a part of the phase-out of fossil-based raw materials in order to create less carbon emission-intensive products (Reddy, et al., 2012). The European Union and industry leaders have launched a European joint undertaking on a bio-based economy to facilitate the bio-based industry to be more competitive on the market (European Commission, 2011a). The bio-based economy is expected to create thousands of jobs, mostly in rural areas, and to reduce emissions of green-house-gases with 50% compared to continuing using fossil fuels (European Commission, 2011a).

1.1 Background

To develop new technologies for the future, many factors need to be taken into consideration. Conventionally, economic and technical factors are considered, but in recent years, sustainable development factors have become increasingly important (Lydenberg, 2012). Sustainable development is often described in terms of the three pillars of people, planet and prosperity ('the 3 Ps'), and its ultimate goal is to achieve human well-being (Benoit, et al., 2009). To assess the environmental impacts associated with a certain technology or product, environmental life cycle assessment (E-LCA) has been advanced as an important and comprehensive method (Baumann & Tillman, 2004).

E-LCA focuses only on the environmental information and impacts from the technical processes of the product life cycle and does not take any social or economic factors into account (Baumann, 2012). To broaden the focus from environmental factors, other methods to advice decision-making and to assess socio-economic factors are being developed, such as the social LCA guidelines (S-LCA guidelines) and the handbook for product social impact assessment (handbook for PSIA) (Benoit, et al., 2009; Fontes, 2014). The S-LCA guidelines and the handbook for PSIA consider social and socio-economic impacts and are still under development and in need of additional research. Socio-economy is a scientific field that examines social and economic factors in combination to gain an understanding how these two factors interlink and influence each other (Business Dictionary, 2015). The term includes factors on a scale from pure economic factors to pure social factors.

SP Technical Research Institute of Sweden (SP) will participate in a four year long international research project called Mobile FLIP. The project was established by European Union's Commission of Research and Innovation by communicating a desire to make biorefineries more flexible by making them mobile (European Commission, 2013). This potentially involves a considerable re-organising of existing product chains for biomass. The project involves assessments of economic, environmental and social implications that the transition from stationary to mobile biorefineries may cause. SP is involved in all three assessments, but is mainly responsible for the social and socio-economic assessment. This study is a pre-study to that assessment, focussing primarily on socio-economic factors.

1.2 Problem statement

Implementation of mobile units for biorefineries may be an interesting alternative to conventional stationary biorefineries in Europe. When transitioning to new technologies, there are many factors that need to be taken into consideration to ensure that the change leads to sustainability improvements. Socio-economic factors are among the factors that are expected to improve due to the introduction of mobile biorefineries. How these factors will be affected needs to be assessed in order to give an idea of what can be expected from this transition. Currently, no study of socio-economic impacts from mobile biorefineries has been conducted.

1.3 Aim

The aim of this study is to investigate which socio-economic factors that are expected to be affected by implementing mobile biorefineries instead of conventional stationary plants. These identified factors will then be assessed and analysed in order to investigate what is reasonable to expect from such a transition. This involves to:

1. Identify important socio-economic factors related to making biorefineries mobile,
2. Compare the socio-economic factors with established scientific methods for social assessments,
3. Assess the identified socio-economic factors,
4. Recommend further research

1.4 Scope and delimitations

This study will not take any environmental impacts related to implementing mobile biorefineries into consideration. Environmental aspects are part of the scope for another project within Mobile FLIP, which is why it is excluded from this study.

This study will not assess specific technological options available for mobile biorefineries. This is because such detailed technical information is believed not to have high relevance in relation to assessing socio-economic impacts.

This study will only regard the impacts the implementation of mobile biorefineries would have within the geographical region of the member states of the European Union. This delimitation is defined by the scope for the project Mobile FLIP, which is why it is applied in this study as well.

2 Theoretical background

This chapter will cover the basic theoretical concepts that are required to understand the content of this study. It will explain the concept of biorefining and two different variants of biorefineries: traditional, stationary units and more recently developed mobile units.

2.1 Biorefineries

A biorefinery is a type of processing plant that converts and enhances biomass feedstock into different bioproducts (European Commission, 2008). Biorefineries are researched as an economically and environmentally feasible substitute to fossil resources in the transition to a global, sustainable economy (Kamm, et al., 2012). The technology is intended to optimise the use of resources and to limit waste in an attempt to maximise the benefits and profitability of biomass, so that bio-based products can replace non-bio-based products (King, 2010). Similar to petroleum, biomass has a complex composition and can be separated into main groups of components to be refined to valuable products (Kamm, et al., 2012). Depending on which refining technology that is implemented, different feedstock will generate different outputs (European Commission, 2008) (Figure 2.1). The main outputs can be categorised into fuels, chemicals, and bulk materials (e.g. polymers) (Kamm, et al., 2012). There are many conversion processes implemented in biorefineries to achieve different outputs (King, 2010) (Figure 2.1). There are a few production processes that have been implemented on industrial scale, but most are still under development.

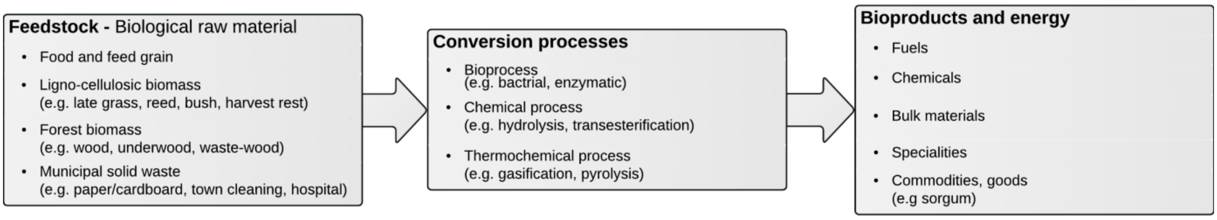

Figure 2.1: Basic principle of a biorefinery, developed from Kamm, et al. (2012).

There are three main types of conversion processes: bioprocesses, chemical processes and thermochemical processes (Hellsmark, et al., 2014):

- **Bioprocesses**
  In biotechnical conversion, cellulose is transformed to different fuels and chemical (Hellsmark, et al., 2014). The interest in the development of these processes increased during 1980 because of the increased interest in bioethanol for cars. For example, in Sweden, one demonstration plant using bioprocessing has been developed in Örnsköldsvik (Jönsson, 2013). In this plant, mainly lignocellulose from forest products is used to produce bio-ethanol (SP, 2013b).

- **Chemical processes**
  Chemical processes contain a wide range of chemical reactions to change the chemical compounds of the feedstock (Hackl & Harvey, 2010). There are two main chemical processes implemented: separation of lignin from black liquor and refinement of tall oil (Hellsmark, et al., 2014). For example, in Sweden there is a company called Sunpine which is located in Piteå. Sunpine refines pine oil through chemical processing (Carlsson & Antonsson, 2011).

- **Thermochemical processes**

  There are four main types of thermochemical processes (Hellsmark, et al., 2014). One of the main types is gasification of solid fuel to produce bio-methane. Gasification of biomass is performed in an oxygen deprived environment and high temperatures (>700°C) (Hackl & Harvey, 2010). The main output is syngas (primary H_2 and CO), which can be used to produce fuel for heat and electricity production, but also be further processed to bio-oil (Garzia-Perez, et al., 2009). Another common type of thermochemical processes is pyrolysis and it operates, like gasification, in an oxygen-deprived environment but at lower temperatures (300-600°C) (Hackl & Harvey, 2010). Pyrolysis produces syngas, pyrolysis oil and biochar. Biochar is a material similar to coal which can be applied as a soil amendment to improve soil fertility and sequestrate carbon and it can also be used as an energy source by combustion. The pyrolysis oil can be filtered to bio-oil and be used as a fuel for cars (Libra, et al., 2011; Hackl & Harvey, 2010).

2.1.1 GoBiGas – an example of a stationary biorefinery

GoBiGas is a biorefinery demonstration plant located in Gothenburg, Sweden, which came into operation in early 2014 (Söderberg, et al., 2012). The plant produces biogas from forest residues by a thermochemical process called thermal gasification. It is the first plant in the world on this scale for this specific technology. The GoBiGas-project is divided into two phases. It is currently in its first phase where the demonstration plant will test the feasibility of the technology. In phase two, the plant is supposed to expand into a commercial-sized plant (Gunnarsson, 2015).

The feedstock that is used in GoBiGas is forest residues, more specifically branches and tops. This feedstock is a secondary product from the forest industry. Thus, another actor will buy the main forest biomass (e.g. timber and pulpwood, for production of construction materials and paper, respectively), and GoBiGas will use the forest residues. Thermal gasification, which is used by GoBiGas, consists of four main steps (Söderberg, et al., 2012):

- Fuel drying
- Gasification
- Methanisation and gas purification
- Distribution to existing gas and district heating distribution system

The primary output from the plant is biogas, which is primary sold to vehicles, but the plant also produces waste heat that is used for district heating (Göteborg Energi, 2015). GoBiGas has a close cooperation with Volvo Trucks that buy most of the gas produced in GoBiGas phase one. This is an important niche market for GoBiGas, which ensures the sales of gas during the start-up. When phase two is realised, the gas will be sold to a broader clientele.

In order to develop a general process model of stationary biorefineries, the GoBiGas plant has been analysed through interviews and information from the GoBiGas website. The model is based on the second phase of GoBiGas (Figure 2.2). This concept model is used as a basis in the comparison between stationary and mobile biorefineries in this study.

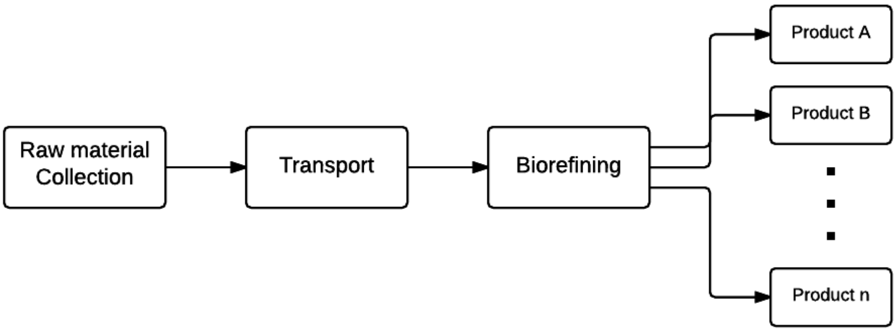

Figure 2.2: General model of a stationary biorefinery.

2.1.2 Mobile pyrolysis unit from Washington state university – an example of a mobile biorefinery

A considerable amount of research targets the development of new technologies for biorefining. One concept that has gained attention is a mobile concept where parts of, or the whole, biorefinery is made mobile to help improve logistic, economic and environmental parameters (Ha, 2012). This to make biorefineries more flexible and cut transport costs by transporting more energy intense, pre-processed material instead of raw biomass.

Washington State University in the US has developed a mobile biorefinery concept using pyrolysis (a thermo-chemical biorefining process) (Garzia-Perez, et al., 2009). This concept takes advantage of forest thinnings, agricultural waste, and other sparsely distributed wastes that are conventionally burnt on site today. As feedstock, the pyrolysis unit uses softwood bark gathered from the state of Washington. The main outputs from fast pyrolysis are:

- Syngas – often used for combustion to generate electricity on site,
- Bio-oil – in slow pyrolysis, the bio-oil is mainly used for combustion to generate electricity,
- Biochar – used as soil amendment and barbecue coal.

The main products from the mobile unit in Washington are bio-oil and syngas. It also produces biochar, which will mainly be used as fuel for the refinery.

The bio-oil will be transported to a larger facility to become further refined into transportation fuels. This example is used to develop a general process model for mobile biorefineries in this study (Figure 2.3), which is used as a basis in the comparison with stationary biorefineries.

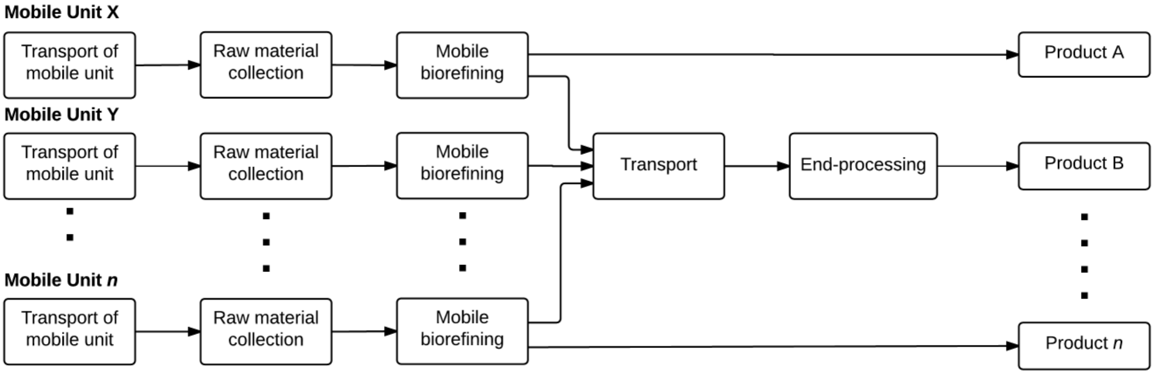

Figure 2.3: General model of a mobile biorefinery.

3 Method

In this study, a three-fold method approach has been adopted:

1. Empirical identification of socio-economic factors for subsequent assessment, using content analysis.
2. Comparison of socio-economic factors to two existing socio-economic assessment frameworks: the S-LCA guidelines and the handbook for PSIA (Benoit Norris, et al., 2011; Fontes, 2014).
3. Screening assessments of the identified socio-economic factors and suggesting future efforts for more detailed assessments.

The method content analysis (CA) will be introduced in section 3.1. The subsequent sections describe four different applications of this method implemented in this study (sections 3.1.1, 3.1.2, 3.1.3 and 3.1.4). Each application is first described and then followed by a description of how it was implemented.

To gain an understanding for how socio-economic factors are assessed in current scientific literature, the two assessment frameworks described in the guidelines for S-LCA and the handbook for PSIA are described in section 3.3 (Benoit Norris, et al., 2011; Fontes, 2014). These two publications will hereafter be referred to as the guidelines and the handbook, respectively. These frameworks provide different indicators by which they assess socio-economic impacts. These indicators will be used as a basis for comparison to the factors identified in the CA in order to assess the applicability of these two assessment frameworks to the case of mobile biorefineries.

3.1 Content analysis

CA is a method which examines "artefacts of social communication", such as written documents or transcripts of verbal information (Berg, 2007). It is a procedure to objectively collect and organise information to help analyse the characteristics and meaning of information (GAO, 1989) (Figure 3.1). When a source communicates a message, there might be a hidden agenda in the information. CA tries to investigate the communication from the source to give an objective description of the content in the message (Prasad, 2014).

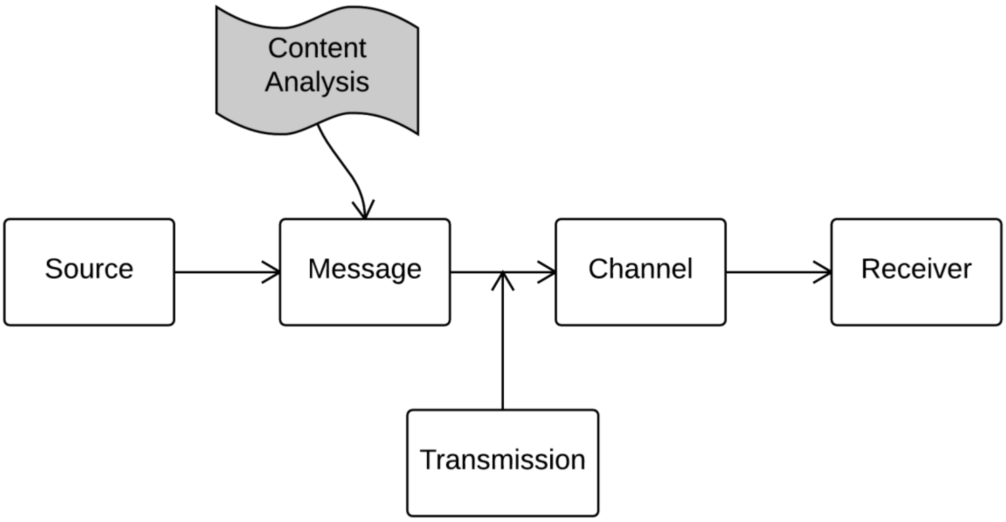

Figure 3.1: Overview of how content analysis is implemented in the communication process, developed from Prasad, (2014).

The purpose of the CA in this study is to screen relevant literature that relates to mobile biorefineries in order to obtain information about which socio-economic factors that are considered important. The collected data is called *corpus*, which comes from Latin and means body. The method will provide ideas for relevant socio-economic factors to assess in subsequent socio-economic assessments in the Mobile FLIP project.

3.1.1 Quantitative and qualitative content analysis

CA can be quantitative, qualitative, or both, depending on what is most appropriate for the context of the study (Berg, 2007). A quantitative analysis examines a text by counting message elements and/or keywords that are central to find trends, themes, amount of emphasis on different topics and numerous other factors (Kondracki, et al., 2002). A qualitative analysis, on the other hand, examines the latent content in a text to find the "true and deeper meaning" of message elements and identifies contradictions, theories, intents etc. that can be used to draw conclusions from the information (Kondracki, et al., 2002). Often, the two types of analyses can be combined. This can be achieved by e.g. qualitatively assessing the content by categorising different phrases and words. The categories can then be incorporated into a quantitative approach by analysing frequency of the categories to identify trends in the content (Mayring, 2000). To cull a text, the use of keywords can be implemented. This is done to simplify the process to cull relevant information and to delimit the material.

To perform the CA in this study, keywords were implemented to sort the information in the *corpus* and to analyse which values authors attribute to them. Initially, the keywords "mobility" and "mobile" were used to cull the texts for attributed values. To fully incorporate all features that mobile biorefineries gain from being mobile, a need for more keywords was identified. Some of these features become apparent when reading the texts in the *corpus*. Firstly, a distinction needed to be made between being flexible and being mobile. Some literature on mobile biorefineries interconnects "being mobile" with "being flexible" and associates the words with each other. For example, Ha, (2012) wrote that *"mobile pyrolysis units are more flexible than centralized pyrolysis units"*. Elsewhere, mobility has been defined as *"the ability to move or be moved freely and easily"* (Oxford University, 2015a), and the definition of flexible is being *"able to be modified to respond to altered circumstances"* (Oxford University, 2015b).

In this study, being "mobile" is considered equivalent to being "flexible in space" but also as a subset to being "flexible". For example, about the economic feasibility of mobile biorefineries, the following was written: *"A major strength of the mobile pyrolysis unit is its flexibility to move directly to the production areas avoiding constraints"* (Ha, 2012). This is an example of a situation where flexibility is used as a synonym to being mobile which occurs frequently in the literature written about mobile biorefineries. Therefore, in the CA, the word flexible will be used as a keyword when it is used in the context of being flexible in space.

Two other consequences from making a biorefinery mobile are that the refining process gets decentralised and built on a small-scale. Decentralisation has been defined as *"to move the control of an organization or government from a single place to several small ones"* (Cambridge University, 2015). In the context of making a biorefinery mobile, the unit acquires mobility but also becomes decentralised in terms of not being part of a big centralised biorefinery. This entails that advantages and disadvantages related to "to being decentralised" also are important to consider when analysing the literature on mobile biorefinery units.

Conventional biorefineries are big, stationary complexes and their size may be a limiting factor if they were to be made mobile. Therefore, mobile units would need to be built on a smaller scale, which is also an important feature to analyse in the CA to capture all possible angels of the mobility.

Therefore, both decentralised and small scale will also be considered to relate to mobility in this study, and thus be included as keywords in the CA.

3.1.2 Inductive and deductive approach of content analysis

Depending on the intent or purpose of the CA, an analyst faces a choice of approach for the CA (Kondracki, et al., 2002). These are inductive and deductive approaches, where the inductive approach is generally used for qualitative studies and the deductive approach is often used for quantitative studies (Mayring, 2000). The two approaches are used to categorise the arguments from the CA. The categorisation sorts the different arguments to get an overview of the *corpus*. With a deductive approach, the categories are predetermined and the arguments are sorted into the different categories during the analysis of the texts. Contrary, when implementing the inductive approach, the analyst examines the communicated message objectively without preconceived notions or predetermined categories and the categories are defined during and after the process of finding arguments.

An inductive approach for the CA was applied in this study. All text in the *corpus* was thoroughly culled for arguments that related to being mobile and how that relates to socio-economic factors. The arguments of relevance where gathered in a list and categorised according to what socio-economic factors the argument relate to (Appendix A).

3.1.3 Association and dissociation in content analysis

To motivate an argument in relation to an object, authors often provide arguments for why e.g. mobility is beneficial or not beneficial. In a paper from Boholm and Corvellec, (2008), two general categories were identified for argumentative techniques based on the theory of the New Rhetoric developed by Perelman and Olbrechts-Tyteca, (1958): association and dissociation. This means that when one is arguing for something, one can associate a value with the object of argumentation by connecting a value to the object, e.g. by the statement "mobility increases feedstock supply". The object of argumentation is here mobility (referring indirectly to mobile biorefineries), and the value is feedstock supply. One can also dissociate a value with the object by disconnecting a value from the object, e.g. by the statement "mobility does not increase feedstock supply". In the two examples above, mobility is associated or dissociated with a positive value (feedstock supply). When the positive value is dissociated, it implies that the argument is negative to mobility. There can also be a negative value association and dissociation to the object.

In Table 3.1, the combinations of association-dissociation and negative value-positive value are illustrated.

Table 3.1: Combinations of the dichotomies of association-dissociation and negative-positive value. Based on Arvidsson and Boholm, (2014).

	Positive value	Negative value
Association	Mobility is associated with a positive value, i.e. a positive evaluation by association (e.g. "mobility increases feedstock supply")	Mobility is associated with negative value, i.e. a negative evaluation by association (e.g. "Mobility is costly")
Dissociation	Mobility is separated from positive value, i.e. a negative evaluation by dissociation (e.g. "Mobility does not increase feedstock supply")	Mobility is separated from negative value, i.e. positive evaluation by dissociation (e.g. "Mobility is not costly")

The CA was performed by culling the *corpus* for associations and disassociations to the keywords mobile, flexible, small scale and decentralized. This concept was implemented to find arguments related to mobile biorefining, and subsequentently identify socio-economic factors used in those arguments. All arguments were initially categorised according to the dichotomies of associations and disassociations.

3.1.4 Coding in the content analysis

In a paper by Boholm and Arvidsson, (2013), a CA was conducted by classifying verbal acts as standpoints, primary arguments or secondary arguments. Secondary arguments are defined as the arguments that support primary arguments, which in turn are defined as arguments that support standpoints. The arguments can then be either negative (contra) or positive (pro) to the standpoints.

When conducting the CA in this study, different arguments were identified and then classified as primary or secondary arguments. The two standpoints that were considered were "mobile biorefineries are beneficial" and "mobile biorefineries are not beneficial" and the following coding categories were used:

- Primary argument *pro* mobility: Arguments that support the standpoint that mobile biorefineries are beneficial.
- Primary argument *contra* mobility: Arguments that support the standpoint that mobile biorefineries are not beneficial.
- Secondary argument *pro* mobility: Arguments provided to support the primary argument for the standpoint that mobile biorefineries are beneficial.
- Secondary argument c*ontra* mobility: Arguments provided to support the primary argument for the standpoint that mobile biorefineries are not beneficial

3.1.5 Content analysis corpus

To gain an objective view of what has been written about mobile biorefineries, texts from different sources were gathered and analysed. Together, these texts constitute the *corpus* of the study. The *corpus* consists of articles from newspapers, scientific papers, company reports, reports from NGOs and the European Union that was found in databases and on the internet. The *corpus* consists of 25 different sources: 9 reports, 5 journal articles and 11 articles from newspapers (Table 3.2). The *corpus* was used to find arguments that are pro or contra mobile biorefineries and link to socio-economic factors.

Table 3.2: The corpus for the CA.

Type of media	Title	Year	Source
European union reports	Biomass Action Plan	2005	Commission of the European Communities, (2005)
	Innovating for Sustainable Growth: A Bio economy for Europe	2012	European Commission, (2012)
Other reports	New Bio-refinery concept to convert softwood bark to transportation fuels	2009	Garcia-Perez, et al. (2009)
	Solar Energy to Biofuels	2010	Agrawal & Singh, (2010)
	GIS Program to Optimize Feedstock Utilization for Mobile Pyrolysis Units	2011	Ha, et al. (2011)
	Optimization of Preprocessing and Densification of Sorghum Stover at Full-scale Operation	2011	Yancey, et al. (2011)
	Optimizing Feedstock Logistics and Assessment of Hydrologic Impacts for Sustainable Bio-energy Production	2012	Ha, (2012)
	Optimized Feedstock Logistics for Mobile Pyrolysis Units in the North Central Region of the U.S	2014	Ha, et al. (2014b)

	A Geographic Information Systems Program to Optimize Feedstock Logistics for Bioenergy Production for Mobile Pyrolysis Units	2014	Ha, et al. (2014a)
Journals articles	Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential	2010	Roberts, et al. (2010)
	New Biofuels Processing Method for Mobile Facilities	2010	Venere, (2010)
	Economic Feasibility of a Mobile Fast Pyrolysis System for Sustainable Bio-crude Oil Production	2011	Palma, et al. (2011)
	Turning Agriculture into Oil, Bio Oil, That is	2013	United States Department of Agriculture, (2013)
	New Versatile Process Efficiently Converts Biomass to Liquid Fuel	2014	Venere, (2014)
Articles from newspapers	Mobile Biorefinery Concept Tackles Leftover Biomass	2010	Defreitas, (2010)
	Company Takes Biodiesel From Field to Fryer to Fuel	2011	Baragona, (2011)
	ND Research Center Demos Methanol from Wood for off-grid Power	2012	The Energy & Environmental Research Center, (2012)
	UK Project Looks at Creating Biofuel on the Farm	2012	Thornberry, (2012)
	Battelle Develops Mobile Technology to Produce Bio-Oil	2013	Battelle, (2013)
	Feds Launch CSU-run Research into Tapping Forests for Liquid Fuel	2013	Finley, (2013)
	Seaweed-based Ethanol Technology gets Boost in Vietnam	2013	Lane, (2013a)
	Biorefinery 2015 – The Shape of Advanced Biofuels to come – Part II	2013	Lane, (2013b)
	Nation Eyes Bounty from Bio-fuels Push	2013	Viêt Nam News, (2013)
	XTRM Announces Mobile Cannabis/Hemp To Biodiesel Unit	2014	Baystreet, (2015)
	The Pine Beetle Problem: Making Renewable Energy Lemonade from Biomass Lemons	2015	Dorminey, (2012)

3.2 Assessing socio-economic impacts

There are methods available to assess environmental impacts, such as LCA, material flow analysis (MFA) and environmental impact assessment (EIA) (Finnveden & Moberg, 2005). Recently, social impacts have been gaining increasing attention in society and the LCA community, where the method S-LCA is being developed (Arvidsson, et al., 2015).

There have been some attempts to develop frameworks for S-LCA. Among the earlier publications, the articles by O'Brien, et al. (1996) and Dreyer, et al. (2006) can be found. Developing frameworks to assess social impacts is, however, difficult because there are many implications related to measuring social issues. For example, according to Baumann et al. (2013), some social factors and indicators used in S-LCA can be interpreted differently depending on cultural background and on political, ethical and ideological views. Arvidsson et al. (2015) also discussed the difficulty of assessing social impacts, focusing on working hours, child labour and property rights. These social factors were described as hard to assess because of their ambiguous nature. It is, for example, difficult to determine what a "decent" number of working hours are. Too many working hours correlates with stress syndromes and other health issues. At the same time, too little work may lead to lack of social interaction, low income and poverty. This implicates a delicate balance between working too much and too little. In addition, related to child labour, if a child has to work instead of going to school, that might be considered a negative consequence. However, if the alternative to working is prostitution or enforced military, child labour could be considered positive. Prohibiting child labour may also imply a negative impact economically for the child in a developing country where poverty is prominent.

Jørgensson, et al. (2009) discussed the importance of having well-founded impact pathways in S-LCA. This is something that is accepted in E-LCA but has until recently not been addressed to any greater extent in S-LCA. They emphasised the importance of analysing impact pathways to ensure that indicators in S-LCA actually represent benefits or damage to the areas of protection (the social topics or categories being assessed). Similarly to Arvidsson et al. (2005), Jørgensson, et al. (2009) discussed the difficulty in defining to what extent child labour is harmful, and also difficulties related to defining indicators that can assess human well-being. They concluded that current indicators for child labour and well-being used in S-LCA frameworks lack validity.

This implies difficulties in the assessment of social impacts because of their subjective nature. Regardless of that, different frameworks and methods are being developed for assessing social impacts. Two frameworks that have gained some attention are the guidelines for S-LCA of products and the handbook for PSIA (Benoit, et al., 2009; Fontes, 2014). These two methods will be implemented in the comparison between the socio-economic factors identified in the CA and the more established scientific frameworks for social impacts in this study.

3.2.1 Guidelines for social LCA of products

The guidelines for S-LCA is a framework that assesses social and socio-economic factors and their negative and positive impacts for a specific product (Benoit, et al., 2009). It is used to analyse all life cycle stages, from cradle to grave of a product, just like conventional E-LCA. It can be applied on its own or together with E-LCA. It is intended to provide social and socio-economic information to advice in decision-making, assess the social and socio-economic impacts of production and consumption, as well as advice when improving socio-economic performance of organisations.

The framework is similar to E-LCA, with the most obvious difference being its main focus: assessing social and socio-economic impacts instead of environmental impacts (Benoit, et al., 2009). To achieve this, the conventional E-LCA hierarchy of impact categories and inventory data has been developed and modified into a slightly different structure (Table 3.3). A more detailed definition of subcategories, inventory indicators and inventory data can be found in the "The Methodological Sheets for Subcategories in Social Life Cycle Assessment", which is a follow-up publication to the S-LCA guidelines (Benoit Norris, et al., 2011).

There are five stakeholder categories identified in the guidelines: workers, consumers, local community, society, and value chain actors (Table 3.3 and Figure 3.2). Each stakeholder category has a number of subcategories. These are used to specify which type of impacts that can occur to each stakeholder. For example, workers have the subcategories child labour and forced labour. Each subcategory also has numerous specified social indicators that an analyst can use to assess social impact for a specific subcategory. For example, child labour has one social indicator which is "percentage of children working by country and sector", which has a unit of measurement that can be either quantitatively, semi-qualitatively or qualitatively assessed with suggested data sources. In this specific subcategory, the suggested source for general data is the report "Understanding Children Work" (by the ILO, World Bank, and UNICEF) (Benoit Norris, et al., 2011).

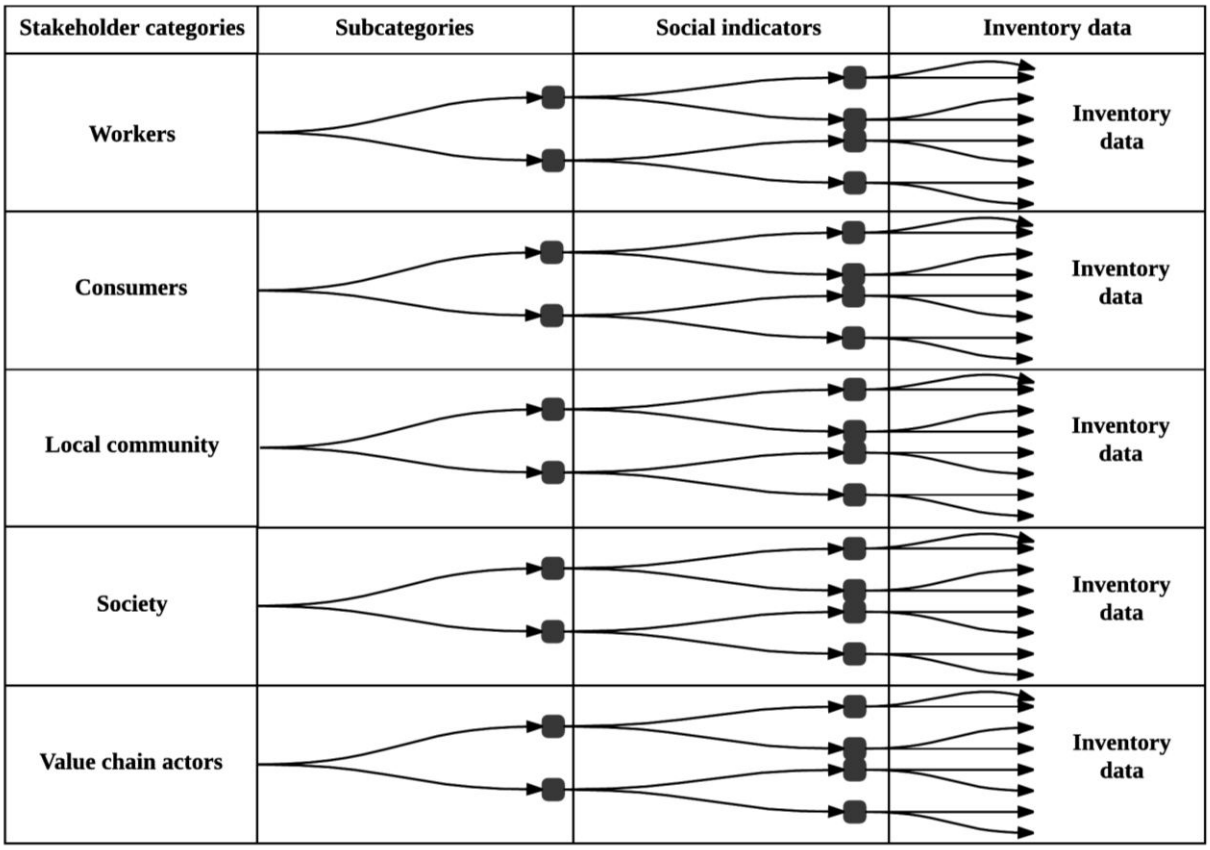

Figure 3.2: Overview of the guidelines assessment system structure, developed from Benoit, et al. (2009).

Table 3.4: Presentation of subcategories in the guidelines, developed from Benoit Norris, et al. (2011).

Stakeholder categories	Subcategories
Workers	Freedom of association and collective bargaining
	Child labour
	Fair salary
	Working hours
	Forced labour
	Equal opportunities/discrimination
	Health and safety
	Social benefits/social security
Consumers	Health & safety
	Feedback mechanism
	Consumer privacy
	Transparency
	End of life responsibility
Local community	Access to material resources
	Access to immaterial resources
	Delocalization and migration
	Cultural heritage
	Safe & healthy living conditions
	Respect of indigenous rights
	Community engagement
	Local employment
	Secure living conditions
Society	Public commitments to sustainability issues
	Contribution to economic development
	Prevention & mitigation of armed conflicts
	Technology development
	Corruption
Value chain actors	Fair competition
	Promoting social responsibility
	Supplier relationships
	Respect of intellectual property rights

3.2.2 Handbook on product social impact assessment

The handbook is a framework to evaluate potential social impacts of a product or a service throughout its life cycle, from cradle to grave (Fontes, et al., 2014). The terminology in the handbook and the guidelines differ. For example, in the handbook, stakeholder categories are referred to as stakeholder groups. Three stakeholder groups are taken into consideration in the handbook: workers, consumers and communities. The handbook is designed to achieve the following three main objectives:

1. Make positive and negative impacts of products visible and measurable
2. Support decision-making and communication at product level
3. Contribute to overall sustainability assessment

The handbook's assessment method is carried out in eight steps as illustrated in Figure 3.2 and further described below.

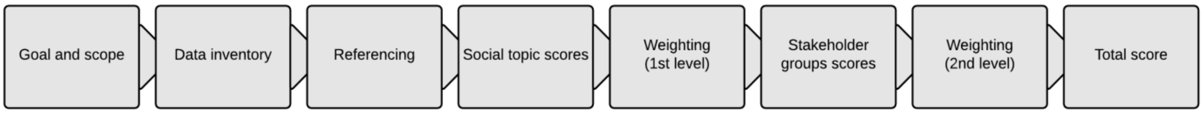

Figure 3.3: The method structure in the handbook, developed from Fontes, (2014).

1. Much like conventional E-LCA, a clear goal and a geographical scope needs to be defined. The analyst should also define which stakeholders within the stakeholder groups that should be investigated. For example, which workers should be included, e.g. only direct employees or also contractors, and also the number of social topics that should be investigated (Fontes, et al., 2014).
2. In the handbook, there are two types of approaches to data collection. The first one is a scale-based approach, where both quantitative and qualitative data is needed. This type of data can be collected with e.g. questionnaires and interviews, and should then be aligned with a specific scale defined in the handbook. The scale goes from -2 to +2, where 0 is the reference value, which preferably is an international standard. The second approach is the quantitative approach, where only quantitative data are collected and should preferably be collected by working hour, by mass or by economic value generated (Fontes, et al., 2014).
3. To analyse the collected qualitative data, it is interpreted in relation to the handbook's scale mentioned in step 2.
4. The social topic scores aggregate the data to a dimensionless number which represents the impact on a social topic (corresponding to environmental impact categories in E-LCA). This is done to make the results easier to communicate with non-handbook executors (Fontes, et al., 2014).
5. The social topic scores can be weighted with factors based on e.g. public or expert opinions or objective assessments by experts (Fontes, et al., 2014).

6. The stakeholder group score is an aggregation of the social topic scores allocated to a specific stakeholder group (Fontes, et al., 2014).
7. The analyst can choose to weight the stakeholder group scores as well but it is not suggested, and if it is being applied, it should be transparent (Fontes, et al., 2014).
8. The final step is to allocate all the social topic scores into one aggregated, dimensionless number that represents the total social impact (Fontes, et al., 2014).

Table 3.5: Presentation of stakeholder groups and social topics in the handbook, developed from Fontes, (2014)

Stakeholder groups	Social topics
Workers	Health and safety
	Wages
	Social benefits
	Working hours
	Child labour
	Forced labour
	Discrimination
	Freedom of association and collective bargaining
	Employment relationship
	Training and education
	Work-life balance
	Job satisfaction and engagement
Consumers	Health and safety
	Experienced well-being
Local communities	Health and safety
	Access to tangible resources
	Local capacity building
	Community engagement
	Employment

4 Results from the content analysis

The CA identified 104 occasions in the *corpus* that argued for or against mobile biorefineries. The arguments were categorised into four primary arguments and seven secondary arguments:

- **Primary argument:** Cost

  Secondary arguments:
    - Storage cost
    - Development cost
    - Production cost
    - Transport cost
- **Primary argument:** Feedstock availability

  Secondary arguments:
    - Production problems
    - Weather
- **Primary argument:** Rural development

  Secondary arguments:
    - Rural jobs
- **Primary argument:** Forest fires

Table 4.1 and Figure 4.1 show an overview of how the arguments are interlinked and how they relate to the standpoints. In sections 4.1, 4.2, 4.3 and 4.4 below, all the arguments are explained in more detail by exemplifying with some arguments from the *corpus* and by elaborating on their context.

Table 4.1: Content analysis result table.

Primary argument	**Uses**		**Secondary argument**	**Uses**	
Costs	Pro	5	Transport costs	Pro	44
				Contra	1
			Production costs	Pro	1
				Contra	2
	Contra	14	Development costs	Pro	0
				Contra	1
			Storage costs	Pro	2
				Contra	0
Feedstock availability	Pro	11	Weather constraints	Pro	11
				Contra	0
	Contra	0	Production problems	Pro	7
				Contra	0
Rural development	Pro	1	Rural jobs	Pro	2
	Contra	0		Contra	0
Forest fire	Pro	2			
	Contra	0			

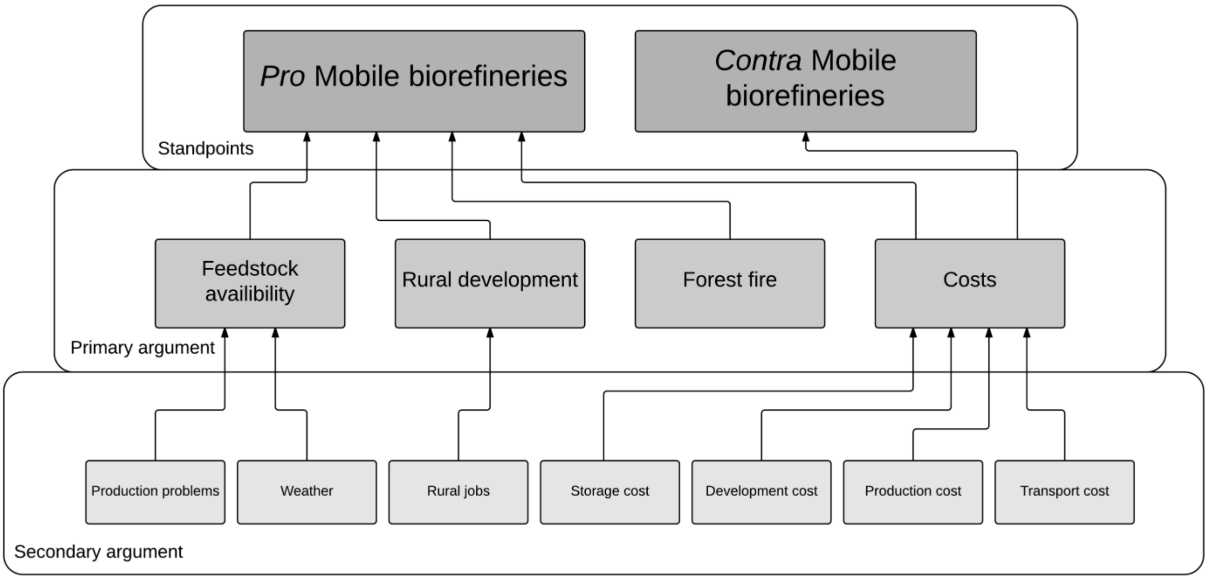

Figure 4.1: Content analysis result, overview of how arguments relate to standpoints.

4.1 Cost

The primary argument cost was the most frequently used primary argument in the analysis (Table 4.1). It is mentioned a total of 70 times in 17 different texts in the *corpus*. Mostly, the arguments were positive to the mobile solution for the biorefineries. However, 18 of the 70 arguments were negative. The negative arguments were mainly focusing directly on the primary argument, while most of the positive arguments were related to a secondary argument: transport costs.

4.1.1 Primary argument: cost

Five arguments in three different texts were positive to cost as a primary argument. An argument from Ha, (2012) said *"A network of small mobile pyrolysis units may be the most cost effective system to convert biomass from agricultural feedstock's to bio-crude oil"*. There were also statements that mobile units are better than stationary, but that they should not relocate often*: "In the case of corn stover from Texas and energy sorghum from Nebraska, the probabilities of success increased as the moving schedule is less frequent, except for a stationary unit"* (Palma, et al., 2011). These are two representative arguments for the primary argument cost.

More than half of the negative arguments on cost focus directly on the primary argument. In Palma, et al. (2011), a detailed economic analysis was made. They used 15 different scenarios where the geographical boundaries and number of relocations changes. The report said that: *"In general, the NPV (Net Present Value) was highest with a stationary scenario and it decreased with additional moving times"* and *"For corn stover in Illinois, the mean NPVs go from -\$2.2 million with a monthly moving schedule to -\$1.4 million with a stationary pyrolysis unit"*. The report had detailed calculations on the economic feasibility of the 15 different scenarios. In Ha, (2012), it was written *"The highest probability of success was a stationary model (the mobile pyrolysis unit stayed one location for 12 months)"*.

4.1.2 Secondary argument: transport cost

The secondary argument transport cost is the most frequent argument in the *corpus*. It is mentioned 44 times in the texts in a positive context (Table 4.1). In Venere, (2010), it was written that: *"Transporting of biomass is expensive because of its bulk volume, whereas liquid fuel from biomass is far more economical to transport"*. Similarly, in Lane, (2013), it was explained that *"Transport of biomass is expensive, so we had to prove that a self-contained, small batch design could operate close to the farmers"*. In Ha, (2012), it was written: *"The concept is to use mobile pyrolysis units to convert low density biomass to high density bio-oil to minimize feedstock transportation cost"*. This is the most representative opinion in the *corpus*. It is also representative of the pro mobile biorefineries arguments in the *corpus*. The authors argue that by refining the product more closely to the feedstock, the energy density in the transported material will increase and the cost for transport per unit energy will decrease.

One out of the 45 arguments on transport cost relate to the negative standpoint for mobile biorefineries. In Palma et al. (2011), it was argued that *"However, their size presents potential feedstock transportation issues, so the logistics must considered* [sic]*"*. It was not defined which transport issue that was referred to, nor which part of the logistics it affected.

4.1.3 Secondary argument: production cost

Two texts in the *corpus* mention the production cost as a positive argument for the mobile refinery. In Garzia Perez et al. (2009), it was written: *"Obtaining an easily transportable stable product that can be converted to transportation fuel in a large centralized facility result in lower cost"*. This argument concerned a decentralised medium size biorefinery which was too big to be mobile, but the concept can be applied also for smaller mobile units.

The contra argument for the secondary argument production cost is mentioned in two texts where production cost was coupled to a negative impact of the mobile biorefineries. In Palma et al. (2011), it was explained that *"For a stationary unit located in Texas and Nebraska, the CDF's (Cumulative distribution function's) are steeper exhibiting a smaller range in return because a stationary unit has higher and more constant production with more working days per year, compared to mobile scenarios, hence, reducing downside risk and increasing net returns"*. The argumentation concern the time period before, during and after the movement when the production is lower than maximum.

4.1.4 Secondary argument: development cost

As shown in Table 4.1, there is one argument in the *corpus* which argues that the development cost will increase when using a mobile solution*: "Technical breakthroughs will be needed to build self-contained as well as augmented biomass conversion processes on a small, distributed scale to avoid transportation of low energy density SA* [sustainably available] *biomass over long distances"* (Agrawal & Singh 2010).

4.1.5 Secondary argument: storage cost

In the *corpus*, storage cost is mentioned two times, both times in a positive context for mobile biorefineries. For example, in Ha et.al. (2014b), it was argued that with mobile refineries, the need of storage was less important than for a stationary solution: *"Large centralized biomass processing plants can process up 23,000 tons (20,865 metric tons) of biomass per day but must contend with high expenses associated with the transportation infrastructure and biomass storage and handling problems"*. This argument was written in a context where it was compared with a mobile solution, which does not have these constraints.

4.2 Feedstock availability

Feedstock availability is the second most frequently mentioned argument in the CA *corpus*. It is mentioned 29 times, which represents roughly 30% of the total amount of arguments (Table 4.1). All the identified arguments for feedstock availability are pro mobile biorefineries. 55%

are related directly to the primary arguments, and 35% to the secondary argument weather constraints. The remaining 10% relate to the argument production problems.

4.2.1 Primary argument: feedstock availability

The primary arguments for feedstock availability that are pro mobile biorefineries mainly refer to the constraints in local feedstock availability or supply that a unit could avoid due to its mobile properties. In Ha et al. (2014), it was written that "*Mobile pyrolysis units can be repositioned in the event of a crop failure and can take advantage of seasonal feedstock supplies*". Ha et al. (2014) emphasized how the mobility makes the unit less constrained by factors it cannot influence, such as crop failure and seasonal feedstock supply. Many articles compared mobile biorefineries with stationary refineries to present the constraints that a stationary solution had, which the mobile solution does not. For example, Palma et al. (2011) compared centralized biofuel production with mobile units: "*Mobile pyrolysis units, by definition, are portable and more versatile than conventional centralized biofuel production facilities. Their small size enables them to be transported quickly and easily on a tractor trailer to take advantage of seasonal feedstock availability at multiple locations*". These two arguments represent the opinion of most authors on feedstock availability for mobile biorefineries.

4.2.2 Secondary argument: weather constraints

The secondary argument weather constraints is based on the advantages which mobile units obtains when they can move from place to place if the weather limits its ability to gather feedstock locally. "*Due to the many constraints that affect the production of bio-oil by a centralized plant using agricultural feedstocks, such as weather, that affects feedstock production and feedstock hauling costs, mobile pyrolysis units have many advantages. Mobile pyrolysis units are more flexible than centralized pyrolysis units and the therefore better able to overcome these constrains*" (Ha, 2012). The author claimed that the mobile feature would make the unit more flexible in terms of taking advantage of feedstock that was locally available and currently not hard to harvest because of weather conditions. This argument is representative for what is expressed in the *corpus* on weather constraints, since all of the authors referred to the advantage of having increased flexibility as a mobile unit when dealing with weather constraints.

4.2.3 Secondary argument: production problems

The production problems argument is mentioned two times in the *corpus* and constitutes 10% of the total amount of arguments for feedstock availability (Table 4.1). It refers to the fact that if there would be a failure in producing the raw material, e.g. crop failure or late harvest, the mobile unit could take advantage of its mobility and gather feedstock where there are crops available for harvesting. The argument is similar to the one of weather constraints with the distinction that it refers to the crop failing due to other reasons than weather conditions. Ha et al. (2014) wrote: *"If one region is having difficulty supplying feedstock due to weather conditions or crop production problems (i.e. late harvest or failed crop), mobile pyrolysis units can be moved to more productive feedstock areas"*. This argument is representative for the arguments for using mobile units in case of local production problems, where the unit could move to more productive feedstock areas.

4.3 Rural development

The rural development argument is mentioned three times in the *corpus* and relates to the social benefits that can be gained by developing new industries in rural areas.

4.3.1 Primary argument: rural development

One argument was categorised as relating directly to the primary argument rural development. It was somewhat unspecified in terms of why the authors think that rural development will occur due to the implementation of mobile refinery units: *"Smaller decentralised plants burning solid biomass or biogas tend to cost more, but often have advantages for the environment and for rural development"* (Commission of the European Communities, 2005).

4.3.2 Secondary argument: rural jobs

The only identified secondary argument for the development of rural areas is that new jobs will be created locally as a result of developing new industries in rural areas. The possibility of implementing mobile biorefineries to get rid of old trees in the forest that cause a risk of bush fires was discussed in Finley, (2013): *"We're interested in determining ways we can* […] *create jobs in rural areas"*. It seems that the authors believed that by introducing these mobile units to get rid of the dried old trees, it may help creating new jobs rurally. In Baragona, (2011), a local farmer was interviewed about mobile biorefineries. He believed in the technology and said: *"It's going to save us money, save them money, and help the environment as well. All that, and help local farmers"*. This is said in a context regarding mobile biorefineries as a solution to meet the increasing demand of bio-fuels.

4.4 Forest fire

The forest fire argument is mentioned two times in the *corpus* (2% on the total number of arguments) (Table 4.1). It relates to the risk of starting bush fires due to old, dry, fallen trees that accumulate in forests over time. Biorefineries are considered a viable option to get rid of them efficiently and economically.

Finley, (2013) argued that there are advantages of using mobile biorefineries to reduce fire hazard risks: *"Getting diseased wood out of forests more rapidly is going to reduce the risks of severe fire"*. It was also written that *"We're interested in determining ways we can help* […] *reduce fire hazards* […]*"*. This was written in the context of using mobile units to extract more diseased wood from the forest, and that fire hazards thereby could be reduced.

5 Comparison of identified arguments to the guidelines and the handbook

The arguments that were identified in the CA related to four main socio-economic factors that are linked to the implementation of mobile biorefinery units. There currently exist established scientific frameworks by which social impacts of products can be assessed, as mentioned in section 3.3. Two main frameworks are the guidelines and the handbook, which are considered in this study. A comparison between the results of the CA and the factors used to identify socio-economic aspects in the guidelines and the handbook will be performed in the following section. This was done to conclude how well these frameworks could be applied for assessing mobile biorefineries in the European Union.

5.1 The guidelines

The guidelines have a total of 31 subcategories (Table 3.4) and two of them are deemed to relate to the identified factors: Local employment and contribution to economic development. How these categories relate will be described further below.

5.1.1 Local employment

This subcategory relates to rural development, and specifically to rural jobs. It takes different factors into consideration, but there are two specific inventory indicators which relate directly to the category rural jobs: "percentage of workforce hired locally" and "percentage of spending on local suppliers" (Benoit Norris, et al., 2011). These two are relevant factors to investigate if one wants to assess to which extent an organisation or a product actually create rural jobs.

5.1.2 Contribution to economic development

This subcategory assesses an organisation's contribution to rural and national development, and when implemented specifically on rural areas it relates to the rural development argument identified in the CA (Benoit Norris, et al., 2011). The category includes three different inventory indicators:

- Economic situation of the country/region (GDP, economic growth, unemployment, wage level, etc.)
- Relevance of the considered sector for the (local) economy (share of GDP, number of employees in relation to size of working population, wage level, etc.)
- Contribution of the product/service/organization to economic progress (revenue, gain, paid wages, R&D costs in relation to revenue, etc.)

All three indicators seem relevant for assessing the rural development impact an organisation or product may have in a country or region. They are implemented in a logical sequence by first evaluating the economic situation of the region and then comparing it to how much impact the related activities have locally.

5.2 The handbook

Out of the handbook’s 19 social topics, one was deemed to relate to the identified factors in the CA (Fontes, et al., 2014). How this category relates to the identified factors will be explained further below:

5.2.1 Employment

The social topic employment also relates to the factor rural development and examines to which extent a company or facility create new jobs. In the handbook, it is assessed as the number of jobs created and lost during the reporting period. This topic relates to rural development, but in the handbook it is not explicitly expressed that it regards rural or local employment, only amount of new jobs in general. This means that these jobs could be created in other places as well, but it is an indicator which could potentially be adapted to consider specific jobs, such as rural jobs.

Table 5.1: Overview of how the factors correlate to the studied social impact assessment frameworks.

Identified social factors	Corresponding categories in the guidelines	Corresponding topics in the handbook
Cost	-	-
Feedstock availability	-	-
Rural development	Local employment	Employment
	Contribution to economic development	-
Forest fires	-	-

6 Assessment and analysis of identified socio-economic factors

In this chapter, the identified socio-economic factors from the CA will be assessed and analysed. This will be done by investigating each primary and secondary argument, respectively. The underlying reasons that support the primary and secondary arguments will be described, and assessed based on available knowledge. Some minor calculations will be performed to assess whether what the claims in the *corpus* seem reasonable. Some of the texts in the *corpus* focus on other geographical regions then the EU, but are still considered relevant for making general assessments of mobile biorefineries. Methods and approaches for further, more detailed assessments of the identified socio-economic factors are suggested.

6.1 Cost

Cost and its secondary arguments are the most frequently mentioned arguments, both for and against the implementation of mobile units for biorefineries. Out of 17 arguments directly related to the primary argument cost, 16 were found in three peer-reviewed research papers: Palma et al. (2011), Ha, (2012) and Garzia-Perez et al. (2009). The authors had a scientific approach with evaluation methods to support their arguments for and against the mobile units. The remaining argument said that the cost of making biodiesel is in their specific case the same as regular diesel, which increases its competitiveness on the fuel market (Baragona, 2011). No specific motivation for this claim was provided.

Palma et al. (2011) used a Monte Carlo analysis to assess the economic feasibility of a mobile pyrolysis unit. They included variables such as historical prices and yields, as well as machine, labour and fuel costs. They also estimated conversion ratios from feedstock inputs to bio-oil, biochar and syngas outputs. The output of their calculation was the net present value (NPV) over a timeframe of 10 years. The NPV was calculated as follows, assuming a discount rate (i) of 5%

$$NPV = -(BeginningNetWorth) + \sum_{j=1}^{10} \frac{Dividends_j}{(1+i)^j} + \frac{EndingNetWorth}{(1+i)^{10}}$$

Equation 6.1: Equation for calculating NPV.

In Equation 6.1, $BeginningNetWorth$ is the necessary investments that are needed to realise the project, such as producing the pyrolysis unit, purchasing trucks and truck trailers to transport it on, etc. The $Dividends$ are assets paid to investors and ending net worth is the net worth over the total time of the investment, and j stands for the time frame of the calculation in years. The NPV is the difference between present cash inflows and outflows and is used to analyse how profitable an investment is. If the NPV is greater than zero (NPV>0), an investment is considered economically feasible (Palma, et al., 2011).

Palma et al. (2011) modelled 15 different scenarios within three different geographical regions, using relevant local feedstock. Five scenarios were modelled for the feedstock corn stover in Illinois, five for corn stover in Texas, and five for energy sorghum in Nebraska. In each geographic location, there were scenarios where the unit moved 12 times (monthly), six times (bi-monthly), four times (quarterly), two times (bi-annually) and one stationary scenario.

In all 15 scenarios, the mean NPV was negative, although it improved (became less negative) when the number of movements were reduced. Palma et al. (2011) also calculated the probability of being economic feasible (positive NPV) for the different scenarios by calculating cumulative distribution functions (CDF) for NPV>0. According to Palma et al. (2011), 90% and higher probability of economic feasibility is generally considered as a good chance of economic feasibility when projects are evaluated by investors. They concluded a low percentage for all scenarios, with a range of 0-15% probability of economic feasibility. The probability increased with fewer movements, except for a stationary unit in Texas and Nebraska where the probability decreased slightly compared to a mobile unit.

To find out why the two mobile scenarios in Texas and Nebraska gained a higher NPV than the stationary scenarios one need to look at the numbers in Palma, et al. (2011). In the report, the mean values for the NPV was lower for the mobile than for the stationary unit, in all scenarios. However, the uncertainties in the mobile solution the standard deviation was higher than for the stationary plant. This made the normal distribution wider for the mobile solution, but also means that $NVP > 0$ for some cases at the upper end of the probability distribution, which made the probability of economic success > 0. This is exemplified in Figure 6.1 were one can see the normal distribution of one example from Palma et al. (2011). The high standard deviation was likely present for the mobile concept because it is a new concept which has not been implemented yet, thus the data was uncertain. The mobile concepts in Texas and Nebraska therefore had a higher probability of economic feasibility compared to the other scenarios because it was associated with a higher standard deviation, which likely depended on uncertainties in the concept.

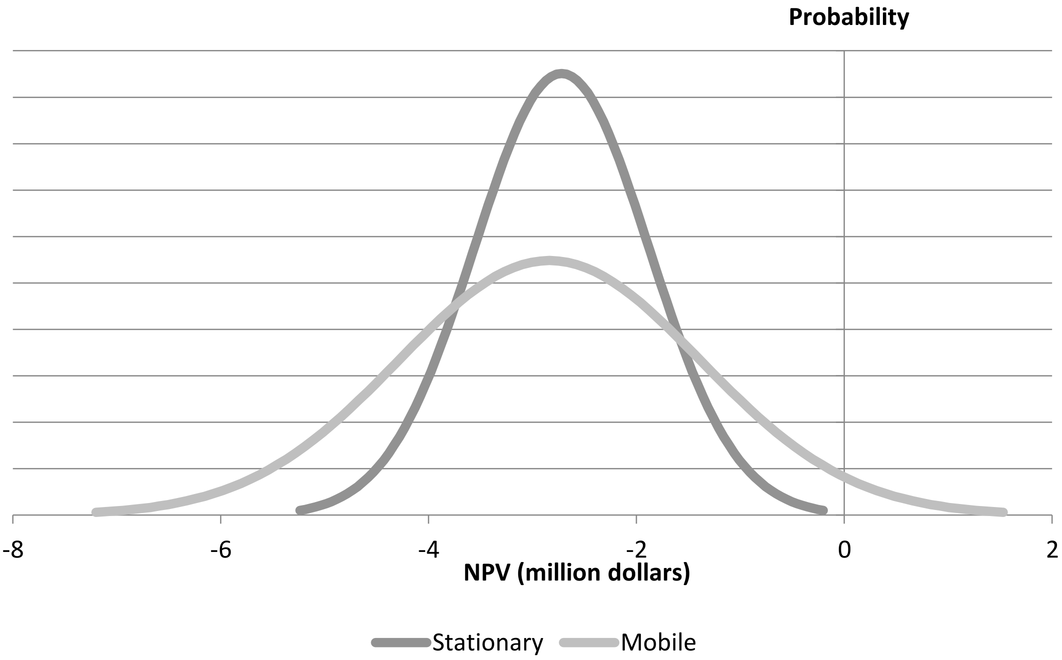

Figure 6.1: Probability of economic feasibility for stationary and mobile units using energy sorghum in Nebraska, developed from Palma, et al. (2011).

To verify and analyse their results, Palma et al. (2011) performed three sensitivity analyses by alternating the three parameters cost of feedstock, conversion efficiency and the crude oil price. These are presented and analysed below:

- If feedstock costs were reduced by 50%, the probability of a positive NPV would increase to 90% and higher for eight out of 15 scenarios. With a 75% reduction of feedstock price, all scenarios' probability of economic feasibility would be 90% or higher. The global market price for e.g. sorghum has increased from \$191 to \$196 /ton since 1960 and has been fluctuating over time (World Bank, 2015). The mean price for sorghum over the last 55 years was \$183/ton with a standard deviation of \$55/ton which is roughly 30% of the mean price. In other geographical regions other feedstock may be more convenient to use e.g. wood chipped forest residues in Sweden. The market price for wood chipped residues in Sweden has since 1993 to 2012 increased with about 70% with internal fluctuations (Energimyndigheten, 2013). Both the wood chipped forest residues and sorghum price has increased over time which indicates a trend in an increased feedstock price rather than a decrease. This also emphasises the importance of assessing each specific case based on geographic region and type of feedstock when assessing the economic feasibility of mobile biorefineries.
- If the feedstock-to-bio-oil conversion efficiency would increase from the current 150-225 liters/ton corn stover and 130-210 liters/ton energy sorghum to 265-340 liters bio-oil/ton feedstock (an increase in conversion efficiency from about 22% to 35%), the

probability of economic feasibility would increase to higher than 99 % for all of the scenarios. According to Capunitan & Capareda, (2010) on Corn Stover Pyrolysis conversion efficiensies, it is currently possible to gain up to 265-340 liters/ton feedstock in a pyrolyser that uses corn stover. So in the case of using pyrolysis with corn stover, these levels of conversion efficiency increase seem possible.

- The authors used an unspecified baseline for the changes in oil prices until 2020. To test the sensitivity in the system, they increased the baseline with different percentages. If the increase in price is 150% of the baselines price per year, the probability of economic feasibility increased to 59-100%. If the increase would be 75 % over baseline each year, all scenarios had more than 90% probability of economic feasibility. According to the World Bank, (2015), current forecasts say that crude oil prices will reach \$74.1 in 2020, which is lower than the price of \$115.3 that Palma et al. (2011) projected. Considering that the probability of NPV>0 in this case was quite sensitive to fluctuating oil prices, this may considerably influence the future economic competetiveness of the bio-oil produced by this mobile concept. Although crude oil is a non-renewable resource, and its continued use will ultimately lead to depletion and consequently high prices, recent variations in oil price are not as high as required to obtain a positive NPV for mobile biorefineries (Sorrel, et al., 2009).

Consequently, although the baseline scenario indicates a low probability of economic feasibility, the sensitivity analysis points towards possibilities to reach profitability. However, rather dramatic changes in current prices are required for this to happen.

Ha, (2012) presented a geographic information systems (GIS) model which was developed to optimize the routes and amount of movements for a mobile pyrolysis unit in the North Central region of the US. This analysis was based on current transportation networks, cropping patterns, feedstock production rates and oil refinery locations in the region. Ha, (2012) modelled GIS for seven scenarios where the unit was moved in 1, 2, 4, 6, 8, 10 and 12 months intervals, respectively. The feedstock included in the study were switch grass, corn stover and energy sorghum. An analysis of the road infrastructure was implemented to calculate the optimal route to move the unit from station to station and from station to oil-refinery.

Much like Palma et al. (2011), the study by Ha, (2012) employed a financial Monte Carlo simulation model to calculate the NPV for the mobile pyrolysis unit when using alternative feedstock, locations and different frequencies of movements. The data from the GIS results were coupled with the economic model and were used as the base for calculating the total revenue of the system. Ha, (2012) also calculated the probability of economic feasibility by using CDF calculations for NPV. Unlike Palma et al. (2011), Ha, (2012) was not very specific about the time frame for the study, although a 10 year period was mentioned.

Ha, (2012) concluded that the probability of economic feasibility increases as the amount of moving times decrease. The highest probability of economic feasibility was achieved for the semi-stationary scenario, where the unit would move once a year.

Both Palma et al. (2011) and Ha, (2012) used data based on current conditions for biorefining technologies. The technologies for mobile and stationary biorefineries are currently under of development and are therefore costly to produce and the processes are not very efficient. Although the results from Palma et al. (2011) and Ha, (2012) indicated that mobile biorefineries will have difficulties in reaching positive NVP, it is important to note that their economic models are based on a pyrolysis unit with a specific feedstock in US. There exist a wide range of technologies for biorefining, and different types of feedstock may be used in the future. Therefore, NPV calculations need to be implemented for each specific case depending on technology, geographical region, feedstock and demanded output. One suggestion could also be to perform life cycle costing (LCC) to map the total costs associated with the refineries during its whole life cycle as a complement to NPV calculations. In the following sections, specific costs will be discussed in more detail.

6.1.1 Transport cost

As presented in section 4.1, transport costs are often seen as an important issue when mobile biorefineries are discussed. We can also conclude that most of the arguments related to transport cost (44 out of 45) were positive in relation to mobile biorefineries. The texts in the *corpus* seemed convinced and agreed that the transport cost will decrease by implementing mobile units.

The negative arguments claimed that *"... their size presents **potential** feedstock transportation issues, so the logistics must be **considered**"* (bold font inserted). This is not a particularly strong argument and it only asks for awareness and that the logistics must be considered. There was no further argumentation behind it, and it did not say explicitly that the transport cost would increase.

The remaining arguments said that there are problems related to transporting biomass long distances which may constrain stationary concepts. Because of its low energy density, it quickly becomes economically unfeasible to transport them, which constraints the biorefinery in terms of having access to input material. According to a report from the World Bank on bioenergy development, the current feasible hauling distance for the average biomass feedstock is roughly 50 km (Cushion, et al., 2010). The authors from the *corpus* wrote that if a mobile unit pre-process the biomass into e.g. bio-oil before longer transports, either the transport costs should decrease or the possible transport distances increase. This would be achieved because the energy content in bio-oil is much higher than in the raw feedstock and could therefore be transported longer before it is uneconomic. A screening comparison below will focus on energy in the form of bio-oil being the valuable commodity to be transported, although other biorefinery products for other applications are also possible (e.g. bio-char as fertilizer).

Depending on the trailer, both the volume and the weight can be the limiting factor for how much potential load that can be transported with a trailer. If the weight [kg] is the limiting factor, the transportation cost will decrease with 32-46% if transporting bio-oil instead of wood chips. If the volume instead is assumed to be the limiting factor [m^3], the cost of the transport will decrease with 83-90%. These calculations are based on Equation 6.2 and the data from Table 6.1.

Table 6.1: Energy content of different feedstock and bio-oil.

Energy source	Moisture [%]	Energy content [MJ/m^3]	Energy content [MJ/kg]	Reference
Beech (wood chips)	15	4500	15	Francescato et al. (2008)
Beech (wood chips)	30	4000	12	Francescato et al. (2008)
Spruce (wood chips)	15	3000	16	Francescato et al. (2008)
Spruce (wood chips)	30	2800	12	Francescato et al. (2008)
Bio-oil	~0	27000	23	Garzia-Perez et al. (2009)

$$1-\left(\frac{Energy\ content\ wood\ chips}{Energy\ content\ bio-oil}\right)=Decrease\ in\ transport\ cost$$

Equation 6.2: Equation to calculate the decrease in transport cost.

The calculations above are based on that the trailer has the exact same volume or weight limits, which may not be the case in practice. Different trailers are used for transporting different products. Trailers transporting e.g. liquids are conventionally cylindrical to decrease the force and momentum created by the moving liquid and trailers for transporting e.g. timber are more cuboid (Kolaei, et al., 2014). One should also note that there will also occur shorter transports with feedstock to a mobile refinery, but they have been considered to be negligible in this study. This causes uncertainties in the calculations, especially when the volume is limiting. But it can still be concluded that the transport cost will likely decrease if mobile biorefineries are implemented.

There may also be cases where a stationary plant is not very constrained by transport distances. For example, the plant GoBiGas (as mentioned as the example plant in section 2.1.1) is not limited by the transport distances for feedstock because it is located in the harbour of Gothenburg (Gunnarsson, 2015). This enables the biorefinery to use sea transport, which then could notably increase the economically feasible transport distance. For cases where different modes of transport (e.g. by boat or train) are possible, the principal-level comparison in Table 6.1 is not sufficient, but more detailed economic evaluations are required.

6.1.2 Production and development costs

The production cost argument is mentioned three times in the *corpus*, two times as contra and one time as pro mobile units.

The pro argument is found in Garzia-Perez, et al. (2009) and was mentioned in a context when a mobile biorefinery pre-processes the feedstock before transport: "*Obtaining an easily transportable stable product that can be converted to transportation fuel in a large centralized facility should result in lower costs".* They did not elaborate any further on why it was believed that the costs should be lower in this context.

The two contra mobile biorefineries arguments wrote that the cost was strongly related to the produced output. Since the cost of the production was constant as long as the biorefinery is active, this potentially means an advantage to a stationary concept, since then production does not need to be interrupted due to movement (Palma, et al., 2011). This argumentation entails that there is a linear relationship between amount of output and production cost. The more output produced, the more the production cost per weight unit of output will decrease. The following analysis will therefore mainly handle the production capacities of the mobile and stationary biorefinery.

As presented in the contra arguments for mobile biorefineries in Palma et al. (2011), the output depends on the amount of working days. As a screening assessment, we have considered a case where the same amount of output is produced from one stationary and a number of mobile biorefineries, respectively. Assume that one stationary unit produces x m^3 bio-oil and n mobile biorefineries each produce x/n m^3 bio-oil. If all n mobile units are used, the output will be the same as for the stationary unit.

When a mobile biorefinery is moved, an average of three working days of production is lost (Palma, et al., 2011). This means that depending on how many times per year the biorefineries are moved, there will be losses in output and therefore increased production costs. This means that, as discussed in section 6.1, fewer movements are better than many movements. If n biorefineries are moved y times each year, $y * 3/365$ ($0.82\% * y$) of the annual production will be lost, potentially causing increases in production cost of similar magnitude. Note that it was assumed here that all refineries, both stationary and mobile, can operate all days of the year without need for maintenance or similar activities. However, since n mobile units are used, the production could be more or less constant, provided the units are not moved within the same time period. So to avoid that the production rate decreases, the units could be moved at different times. It is difficult to determine the actual impact on production capacity due to relocation of mobile biorefineries. Therefore, these factors need to be assessed further to confirm their actual impact.

The development cost argument states that there are high costs related to developing new technologies due to investments in R&D and that a small scale production, which would be achieved through a mobile unit, cannot take advantages of economies of scale.

In Agrawal and Singh, (2010) it was written that : *"Technical breakthroughs will be needed to build self-contained as well as augmented biomass conversion processes on a small, distributed scale* […] *Such plants may be mobile so they can be moved according to the availability of biomass at different locations at different times of the year"*. This argument stated that there is a need for technical breakthroughs to develop biorefining technologies and that it could be beneficial to make them mobile. This argument is based on the current situation where the technology is underdeveloped, costly and not diffused in society and therefore in need of investments in R&D. This is often the case when developing new technologies. If monetary assets are invested in developing the technology, it will likely become more efficient and potentially become competitive on the market (Bergek, et al., 2008). This could be achieved by e.g. political initiatives through subsidies for the specific technology to nurture its development.

6.1.3 Storage cost

Storage cost is mentioned two times in the *corpus* and regards that there are high expenses linked to storage of biomass for the stationary units. The stationary biorefineries have to have a constant input to maximize output. This could be achieved by storing feedstock in proximity as a buffer, which would ensure that the input can be kept constant, even with temporary external disturbances in raw material supply. In the case of mobile units that operate close to the raw material, the storage is not as important because of the proximity to the feedstock and therefore may not have to be implemented to any greater extent.

In Wright et al. (2008), the storage and total cost for a stationary fast pyrolysis unit was presented. The numbers showed that the storage cost contributed roughly 3% to the total costs for this specific case. It thus seems that storage cost is a small, although non-negligible, share of the total cost, which supports the arguments that mobile biorefineries are beneficial compared to stationary ones in this respect. Storage costs should therefore be considered in future economic comparisons between stationary and mobile biorefineries.

6.2 Feedstock availability

In the *corpus*, all 11 arguments related to feedstock availability as a primary argument are pro mobile biorefineries. The authors all claimed that the mobile units could help ensure feedstock availability through the possibility to move to new locations where the feedstock is currently available. As discussed in section 6.1.2, this will lead to stops in production and thus to increased production costs, but the feedstock is instead more accessible because of the mobility.

In section 6.1.1, it is concluded that the transport cost will decrease when the biomass is pre-treated before transport. When it comes to feedstock availability, there is a new positive aspect related to this. If the transport cost decreases, the transport distance can be increased. This means that the area for gathering feedstock can be expanded, still keeping the same cost per km as for transports to stationary biorefineries. This could increase the feedstock availability by expanding the area from which feedstock can be gathered. Note that this reasoning is limited to transport costs, and based on that reduced transport costs are not required to compensate for other costs in order to make mobile biorefineries having a positive NPV or being competitive compared to stationary biorefineries.

As a screening assessment based on the results from Equation 6.2 presented in section 6.1.1, the potential increase in feedstock gathering area was calculated (Appendix B). This was done by analysing two extreme cases: (1) Using the most energy dense feedstock in a trailer limited by weight, and (2) using the least energy dense feedstock in a trailer limited by volume

In the first case, the potential gathering area increases by approximately two times, and in case two, it increases by a hundred times. This calculation is based on the cost of transport only, and does not include e.g. infrastructural aspects.

These are the two generalised cases which makes it hard to tell exactly how much the potential expanded gathering area will increase since it depends on many factors such as the type of feedstock, types of trailers, road conditions and road infrastructure. We can still conclude that the gathering area will likely increase with the implementation of mobile biorefineries, again provided that reduced transport costs must not compensate for other costs rather than be used to increase the feedstock gathering area.

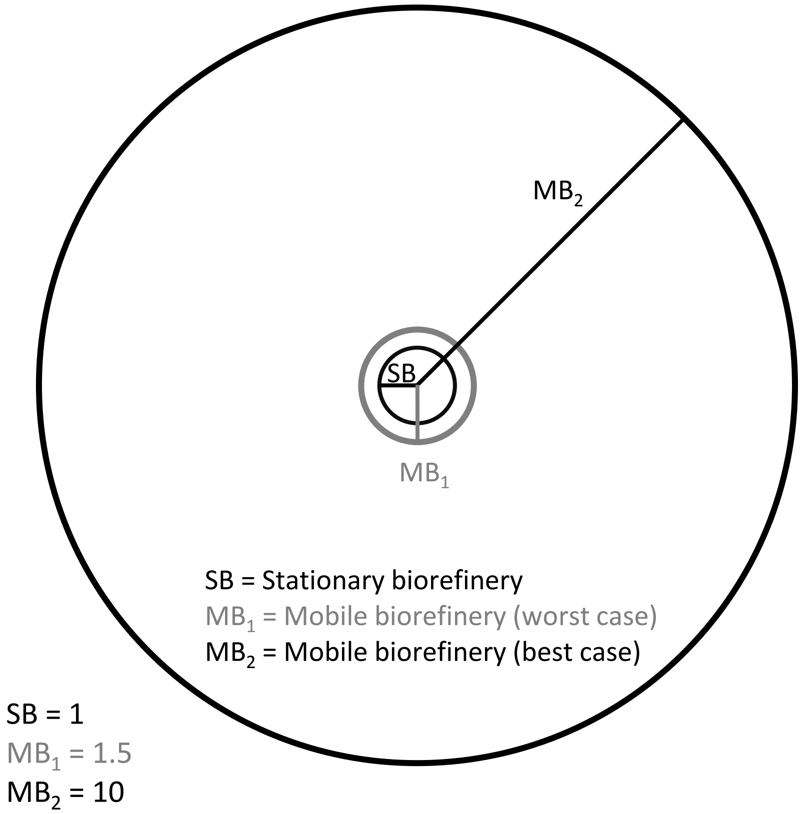

Figure 6.2: Conceptual presentation of the potential increase in gathering area.

Another factor that should be considered when assessing the feedstock availability argument is that the arguments in this CA for why feedstock availability is important were all based on the premise that the feedstock was gathered in the US. In the studies by Palma et al. (2011) and Ha, (2012), they used cultivated energy crops as input for refining. In the US, 18% of the land area is dedicated for cropland, and not all of that area is dedicated to energy crops specifically (Nickerson, et al., 2007). In other geographic regions, feedstock may be more abundant than in the case of sorghum in the US. For example, in Sweden, feedstock in the form of trees is densely available, since 69% of Sweden's total land area is covered by forests (SCB, 2010). A case like this potentially changes the prerequisites for complications related to being close to the feedstock. Therefore, in the case of e.g. using biorefining in Sweden, the availability of feedstock when using forest residues as input is high in most geographic locations. It may thus be less of a limiting factor in e.g. Sweden compared to the US, albeit, in specific regions, the density of raw material may be sufficient in the US and insufficient in Sweden. There is also already a stable market for forest residues in place in Sweden today, where the residues are currently used in smaller district heating facilities and larger facilities (Energimyndigheten, 2014).

As discussed in section 6.1.1, the cost of transporting feedstock is lower when using boats, which could potentially increase the economically feasible transport distance. The use of other, more efficient transport options may thus reduce the problem of local feedstock availability. Palma et al. (2011) and Ha, (2012) both analysed cases in the US, mostly in inland states (except for Texas), which may be why feedstock availability was such a significant constraint in their evaluations. The US has many states that do not have any coastline in proximity, whereas many European locations have access to the sea via harbours and rivers. Therefore, a detailed assessment of how feedstock availability limits biorefineries should be carried out for each specific case with regard to type of feedstock and geographical constraints.

6.2.1 Weather argument

The weather argument is based on that weather may constrain the possibility to extract feedstock in different locations. It was mentioned seven times in three different reports, and all were pro biorefineries (Table 4.1). The arguments were not very specific on why the weather would be constraining, but Ha, (2012) mentioned that it could affect feedstock production and feedstock hauling costs.

Hard weather could potentially affect the possibility to gather feedstock if conditions are deemed unsafe to work in because of e.g. hard storms. Since a stationary refinery has a more limited gathering area, if the local weather makes it impossible to extract feedstock locally, it may pose problems for keeping the production constant. In that case, a mobile unit with access to a larger gathering area could potentially move somewhere else where the weather is currently better and thereby keep the production more constant. The problem with this argumentation is that it does not seem very likely that a stationary refinery would not keep a buffer of stored raw material in proximity to its production. If that is the case, the production would continue as normal by using the buffer and wait for the bad weather to pass and then go back to business as usual.

Another aspect of weather is that it could potentially harm feedstock and prevent it from growing if e.g. hard storms or draught occur. The question is whether that actually constraints biorefining? Provided that the crops had time to grow to a reasonable size and then were ruined, they may be ruined for e.g. eating, but not necessarily for biorefining. The biomass that remains could still potentially be used in a biorefinery. If a storm breaks e.g. the corn stalks or trees and thereby kills them, they cannot grow anymore, but the biomass is still available to the biorefinery.

The weather argument also depends a lot on the type of feedstock and geographic region considered. In the US, where crops such as corn and sorghum are cultivated to be used as biomass in biorefineries, hard storms and draught can prove devastating if the crops are sensitive. If one considers using another feedstock in a different geographical region e.g. forest biomass in Sweden, the situation may prove different. Draughts are generally not of a big concern in Sweden because of its geographical location and forests are generally not sensitive to changes in weather and is likely less sensitive compared to sorghum and other crops (Thompson, 2010). Secondly, big storms with significant effects on the forestry industry are not a common in Sweden. Between 1902 and 2005, three devastating storms have occurred, with the most severe one taking place in 2005 where 75 million cubic meter of wood was destroyed due to heavy winds (SMHI, 2011). This could potentially affect young forests and thereby decrease the available feedstock, but it is not common.

It is difficult to determine to which degree weather could potentially impact feedstock availability since it depends on case-specific aspects. Therefore, a more detailed assessment of the potential impacts should be performed for each specific case.

6.2.2 Production problems argument

The production problem argument is mentioned two times in the *corpus* and both times the arguments are pro biorefineries. They entailed that if there are problems with cultivating the raw material for a biorefinery locally, due to e.g. bug infestations, a mobile unit could go to another region where these problems are not present and still extract biomass.

For example in Sweden, there is an increasing threat of bug infestations in trees, such as the common pine shoot beetle (Skogsstyrelsen, 2015). These bugs eat trees and can potentially harm them, which is a problem for the Swedish forest industry. Similar to the weather argument, production problems caused by e.g. bug infestations does not necessarily mean that the feedstock is wasted for biorefining purposes. The trees can still potentially be used as feedstock in a biorefinery and could even prove to be a way to take advantage of the dying trees instead of letting them rot. There may be implications in utilising these trees because of their lower quality after bug infestations. To which degree this affects the biorefineries output is hard to determine and needs to be further investigated.

Other production problems which are not mentioned in the *corpus* could be environmental factors such as eutrophication, degrading of soils, and local toxicity. These are examples of other constraints that potentially could limit a stationary biorefinery, provided that it is limited by a small gathering area within which these problems are present. In such a case, a mobile unit could potentially take advantage of its larger gathering radius by relocating to a region which does not have any current problems with producing feedstock, thus increasing feedstock availability.

6.3 Rural development

Rural development as a primary argument can be found in the biomass action plan by the Commission of the European Communities, (2005). As discussed in section 4.3, it was not specified how the mobile biorefineries actually will contribute to rural development. The authors write that *"EU structural funds or its rural development programme can be used to study their optimal location in relation to biomass availability, transport infrastructure, grid connection possible and labour market"*. This argument claimed that with help of different instances, the rural development could potentially be improved.

Rural development and rural jobs are closely coupled, and if rural jobs are created, the development of the rural area will typically increase (Saraceno, 1999). An increased activity in a specific geographical area may be an efficient way of combatting unemployment locally. An increased level of employment increases income in the area, but may also increase social protection and integration (Food and Agriculture Organization of the United Nation, 2013). Therefore, rural development and rural jobs will be discussed together in section 6.3.1.

6.3.1 Rural jobs

There are two arguments related to rural jobs in the *corpus*. The two articles mentioned rural jobs as being pro mobile refineries. United States Secretary of Agriculture, Tom Vilsack, said: *"We are interested in determining ways we can help restore the health of our forests* [...] *and create jobs in rural areas"* in the context of finding ways to produce energy out of wood by making the biorefineries mobile (Finley, 2013). In the argument in Finley, (2013), it was not explicitly claimed that there would be more jobs created, but it was indicated that it was an expected outcome, since they mentioned that decentralised plants often create rural jobs. However, there was no explanation for how the mobile units specifically would help create rural jobs. It could be that the type of feedstock used affects the creation of new jobs. The articles where the two arguments where found considered mobile biorefineries in the US, where the feedstock was energy crops which had been cultivated specifically for biorefining. This means that if the industry would expand and the feasible feedstock gathering area increase, more people could potentially work as farmers and supply feedstock to the biorefineries. If one instead considered the input forest residues, the supply of feedstock may have a limited influence on job creation. Forest residue is a secondary product from other forest products and is therefore dependent on the production of the primary product. This implies that to get forest residues, the forest first have to be deforested for other purposes. Therefore, the extraction of forest residues will likely not affect the extraction of the primary product.

Another perspective is that the mobile biorefinery jobs will likely be located in rural areas, but they will be mobile and move between different places. In such a case, the jobs will be performed rurally but not necessarily by rural personnel. There is a possibility that staff will commute from cities close by, or other cities, thus working rurally but not being rural inhabitants. This may instead lead to other social issues, such as workers being away from their families.

A more detailed assessment on the creation of rural jobs should therefore be carried through. This could be performed by e.g. using an existing approach outlined in the S-LCA field by Hunkeler, (2006). This method is different from the guidelines and the handbook. It is meant to be a complement to LCA and environmental LCC, and together these three methods are supposed to assess all three pillars of sustainable development (Hunkeler, 2006). The approach involves calculating employment hours in different geographical regions and allocating them to a product and service throughout its entire life cycle. The rationale for calculating employment hours is that they are seen as the basis for income to households and to the public sector in the form of taxes, thereby contributing to important welfare factors such as education. This approach can be used to assess how rural development is affected by changes in production. The method uses the same concept of system boundaries and functional unit as in E-LCA. In Hunkeler, (2006), a case study was conducted to illustrate the method. The case study investigated the number of employment hours that occurred in different regions for a number of different detergents. The geographical locations considered were large regions and countries. To adjust the method for mobile biorefineries, the geographical locations could potentially be divided into smaller regions, and it could be specified which regions that are rural.

In addition to the method suggested by Hunkeler, (2006), as mentioned in section 5.1.1, an evaluation of the subcategories local employment and contribution to economic development according to the guidelines should be performed. In the hand book, the social topic employment should also be assessed accordingly. There are thus three different methods suggested in the S-LCA literature that could potentially be used for assessing the impact on rural jobs from mobile biorefineries.

6.4 Forest fire

Forest fire was mentioned two times in the same article published in the Denver Post from 2013. The argumentation was expressed in an interview of Tim Vilsack, United States Secretary of Agriculture (Baragona, 2011). The risk of wildfire in Colorado is high and during the years 2012 and 2013 there were six wildfires in Colorado (Skillern, 2014). Vilsack argued that with the new mini biofuel refineries, it would be possible to reduce the risk of fire because the diseased wood could be collected faster. Although it is possible to gather diseased wood with regular trailers, it is possible that the cost of this prevents it from happening, and that mobile biorefineries is an option that will actually make this happen. However, further studies are needed to confirm this potentially positive social impact.

Forest fires with large social impacts are more common in some parts of the world than others. Australia is an example of a country with many large forest fires. For example, in 2009, they had the Black Saturday Bushfires where 173 people died and 2133 houses were destroyed (Teague, et al., 2009). Bush fires also occur in Europe. In 2014, Sweden had their largest wildfire in modern time (Dagens Nyheter, 2014). The fire spanned over an area of 150 km^2 and thousands of people were evacuated from their homes (BBC, 2014). Wildfires also have an economic impact through the cost to fight fires and amend destruction caused by fires. Preventing and fighting fires in Sweden cost approximately 1 billion SEK annually (Gustavsson, 2014).

However, the wildfire started next to forestry equipment and was probably caused by a spark, and due to the dry ground and the strong wind the fire spread fast (Dagens Nyheter, 2014). In fact, 50% of the wildfires in Sweden are derived from anthropogenic origin (either through accidents, negligence or intentional arson e.g. carelessness close to camp fires, discarded cigarettes and sparks), and 40% are classified as “other”, “unknown” or “not specified” (Enoksson, 2011). Part of these fires could potentially have been caused by humans as well. This implies that dry wood could potentially increase the risk of fires to spread fast, but the actual risk of starting a fire may possibly increase with more people and machines present in the forest, which may be the result of implementing mobile biorefineries. Especially if mobile units using pyrolysis, which processes biomass at 300-600°C, would be implemented, it could possibly increase the risk of forest fires. Therefore, an evaluation and risk assessment associated with implementing mobile biorefineries, with focus on risk of forest fire, should be performed.

7 Discussion

This chapter discusses the outcome and use of methods in the report to present the some important aspects of the results:

7.1 Relevance of the guidelines and the handbook in a developed country context

The social factors identified in the CA did not match the social topics and subcategories already existing in the S-LCA guidelines and the handbook for PSIA. In the comparison in this study, only 2 out of 31 impact categories in the guidelines and 1 out of 19 social topics in the handbook were deemed applicable to 1 out of 4 identified factors (Table 5.1). This is likely because these two approaches are mainly developed in a developing country context and the factors identified in the CA originate mainly from a developed country context.

The remaining impact categories and social topics in the guidelines and the handbook, which were not similar to the factors identified in the CA, are e.g. child labour, forced labour, respect of intellectual property rights and secure living conditions. Factors like these can generally be hard to implement in a developed country context where e.g. laws against child labour and secure living conditions are generally regulated by the state. Important to note is that in some nations and specific cases, they could potentially be relevant in a developed country context as well.

With this in mind, it is also important to note that the distinction between developing and developed countries is getting narrower. China is an example of a nation which is developing rapidly and could in some aspects be considered as being a developing country with regard to e.g. amount of population in poverty, which is roughly 20% (World Bank, 2012). On the other hand, in some aspects, China could also be considered as a developed country with regard to e.g. its rapidly increasing economy (annual GDP growth of 7.7% in 2013 compared to Sweden’s 1.5% the same year) (World Bank, 2013).

In addition, many products have a big part of their life cycle situated both in developed and developing countries. This implies a difficulty in applying the same assessment framework for both these two parts of the life cycle of product.

There is a challenge in developing frameworks for assessing social impacts because of their complexity and subjectivity, especially if they are to be implemented in regions with very different prerequisites. It also makes sense to initially develop them for developing countries that have more acute occupational and social issues which in many cases are caused due to demand for products in developed countries. However, frameworks such as the handbook and guidelines also need to be expanded to better fit in a developed country context.

7.2 The identified factors' link to socio-economy

The purpose of the report was to investigate the socio-economic factors of developing the new technology with mobile biorefineries. The expression socio-economy is a broad expression which incorporates many different factors on a scale from pure economic factors to pure social factors. In this study, four primary arguments are discussed, all from different parts of the spectrum. Cost is mostly a question of economy, and could have been excluded in the socio-economic factors and associated to economic implications, while rural development is more of a social factor. Feedstock availability and forest fire are more difficult to determine how they should be defined in relation to the three pillar model of sustainable development.

After analysing the result, it seems that feedstock availability mainly focuses on economy. The increased availability that will be apparent with the implementation of the mobile units will mostly affect transport and production costs, and when analysing feedstock availability, the discussion often ends in discussing economic factors. On the other hand, the feedstock availability may also have an indirect impact on the working opportunities in rural areas if the financial profit of the industry, as whole, increase. This could then lead to an increase in the number of units, which could potentially increase the number of working opportunities.

Forest fire can have a great economic as well as social impact. As presented in section 4.4, wildfires can cost the society large amount of monetary assets, and also cause major social issues, such as inhabitants losing their homes. Depending on the broadness of socio-economy as a term, the factors could be examined from different angles depending on what is most important in the opinion of the observer. Another reason why feedstock availability and forest fires factors are hard to define on the socio-economical scale is that they relate to environmental issues which have been excluded from the scope of this study. Fire could relate to habitat and biodiversity loss and feedstock availability to resource use constraints.

7.3 Technological change aspects

From a technological change perspective, the technology of biorefining is still at an early stage of its development and is in a demonstration phase, slowly moving towards a nichemarket phase (development stage) in Europe and Sweden (Hellsmark, et al., 2014) (Figure 7.1). This implies that there is likely improvement capacity left for the technology, which could potentially increase economic feasibility. In an early stage of development, most new technologies are inefficient and expensive, and therefore not yet economically viable. To push the development forward, monetary assets and political initiatives (such as subsidies) are often required. This may help the technology to become mature enough to be economically feasible through e.g. increased efficiency (Hekkert, et al., 2011).

In Figure 7.1, the different development stages of technologies over time are illustrated and one can see how the development initially is slow until it takes off and has a rapid diffusion.

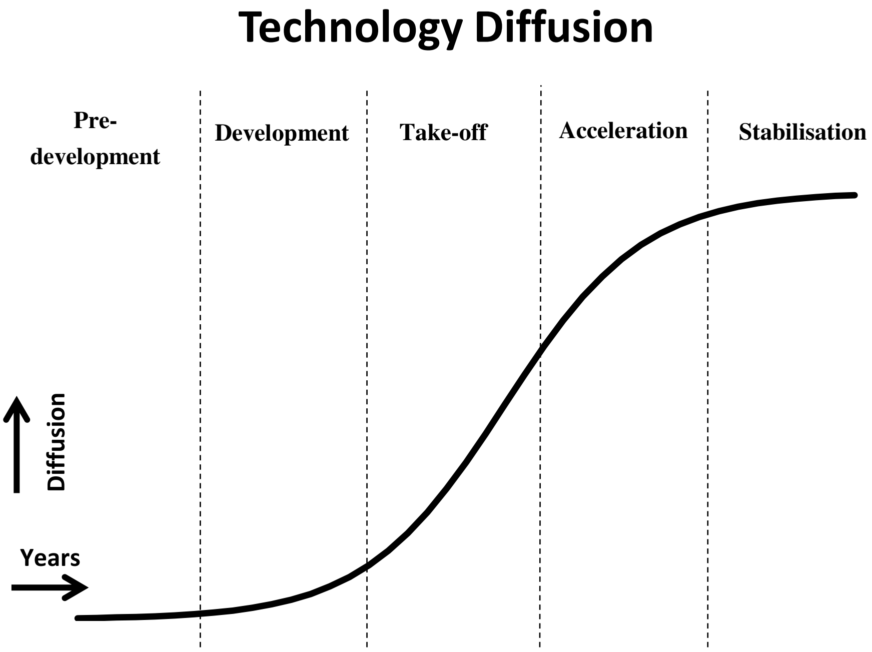

Figure 7.1: The diffusion of new technologies over time, developed from Hekkert, et al. (2011).

Most arguments contra mobile biorefining refer to different costs. This can likely be derived from the fact that the technology currently is in an early stage of its development. Among other things, Palma, et al. (2011) concluded that an increase in feedstock conversion efficiency was needed to make the technology economically feasible. The conversion efficiency is typically a factor which may be inefficient today because of the early stage of development of the technology. If money is invested in developing biorefining technologies, however, the conversion factor could potentially increase and possibly reach an economically feasible level over time.

There are a few obstacles that need to be overcome to achieve this development. According to Hellsmark et al. (2014), in Europe, and specifically Sweden, there are currently many system weaknesses and challenges for policy-makers to overcome for the development of biorefineries. In general, there is a combination of actions needed to successfully commercialise biorefining, such as implementing policy instruments to create a good local market for bio-based products. If the technology of biorefining is to diffuse and develop further, there is a high need of incentives for industry to invest in more R&D for biorefining. The organisation and the financing of current research infrastructure also need to be strengthened.

7.4 Rural development and economic profit

Two of the socio-economic factors that emerged from the CA were cost and rural development. To both reduce costs and increase rural jobs seem to be potentially important factors when implementing the mobile biorefineries. However, it is important to note that these factors may not always go hand in hand. In the texts, the authors often focus on one main argument – either cost or rural development. However, it is possible that there is a conflict between reducing cost and creating jobs. Firstly, these two social benefits are not equally distributed over all actors in the product chain. Lower costs would primarily benefit producers of bio-products, while rural jobs would benefit the local community, and indirectly the whole region and even the nation where the production takes place. Secondly, employing more personnel could potentially lead to an increased cost, which the commercial organisation wants to keep as low as possible. Of course, enough employment to run organisations will be required in order to maintain the production at maximum capacity, regardless of the cost. Considering the high share of the total costs that personnel costs typically constitute, it seems difficult to obtain both low costs and many jobs at the same time (Davidsson, et al., 2009). This is an unfortunate antagonism, which is why future studies should keep this, possibly inverse, relationship in mind. If both of these factors are deemed important, they should be assessed in parallel to avoid optimisations that only focuses on one factor. By using the proposed method by Hunkeler, (2006) (see section 6.3.1), rural jobs can become quantified and thereby possible to assess in parallel with economic costs.

7.5 Subjectivity of the texts of the corpus

The identified factors in this study are a result of subjective opinions of authors on the topic of mobile biorefineries. Therefore, factors may be associated with negative or positive values because of the individual perceptions of authors in the *corpus*. This may have implications for the objectiveness of the CA results. It is important to note that if another *corpus* with other literature would have been analysed, the outcome may have been different because then other authors' opinions would have been analysed instead.

Another aspect that affects the outcome of the CA is also the low amount of available literature on the subject and which authors that has written the literature. Mobile biorefineries is a new concept, and therefore the amount of literature is limited and is mostly written by people who work with either developing these technologies (e.g. researchers writing scientific reports) or people who have an established interest in the technology (e.g. reporters writing articles for interest organisations). This may have an influence on the authors' opinions of mobile biorefineries. It seems fair to assume that authors with these interests believe in the technology, and therefore potentially expresses more positive values (pro arguments) rather than negative values (contra arguments) in relation to mobile biorefineries. The low amount of literature also implies a relatively low public knowledge about mobile biorefineries. This could potentially mean that not many people who are not working within this specific field have formulated an opinion about the technology. If the technology had been more exposed in e.g. public media, there would likely be a more public opinions about it. This could potentially generate more opinions on different factors related to implementing mobile units contrary to the potentially subjective, homogeneous, positive opinions of current authors.

8 Conclusions and recommendations

8.1 Conclusions

This chapter presents the conclusions from this study. They all relate to the four aims stated in section 1.3.

8.1.1 Identify important socio-economic factors related to making biorefineries mobile

Four socio-economic factors with seven subsequent factors related to mobile biorefineries were identified in the CA. The primary factors are cost, feedstock availability, rural development and forest fires and the subsequent factors are transport cost, production cost, development cost, storage cost, weather, production problems and rural jobs.

8.1.2 Compare the socio-economic factors with established scientific methods for social assessments

The identified factors in this study proved to have few analogues in the S-LCA guidelines and the handbook for PSIA. This was likely because they are implemented on different contexts. This study concerns socio-economic factors which are present in a developed country context, whereas the guidelines and the handbook mainly concern socio-economic factors in a developing country context. This likely caused the difficulty in comparing them to each other and entails the need to develop methods that are applicable in both contexts.

8.1.3 Assess the identified socio-economic factors

The four primary arguments identified in the CA should all be assessed further to gain a more objective understanding of their factual significance. Cost depends on individual factors for each case such as type of feedstock and geographic location which is why each specific case should be assessed. The feedstock availability for mobile biorefineries have potential to increase compared to using trucks for transporting feedstock but if boat transports are available it is unclear to what extent it increases. Therefore each specific case should be assessed to evaluate possible feedstock availability constraints with regard to type of feedstock and geographical location. It is hard to determine how rural development will be affected by implementing mobile biorefineries. Rural jobs may be created but it is unclear whether rural workers or commuting workers from other locations will claim the jobs. Forest fires may inflict great social impact and they are often caused by human activities. Therefore there might be an increased risk of forest fires if forestry equipment and humans are to be employed in forests.

8.2 Recommendations

The identified factors in this study should be further investigated to gain a more detailed assessment. The following recommendations for the specific factors are recommended:

Cost – NPV calculations combined with CDF calculations should be done for each specific case. As a compliment to NPV calculations, LCC could also be implemented. Feedstock price, crude oil prices and conversion efficiency are important parameters which affect the economic feasibility of mobile biorefineries. They should therefore be taken into consideration when assessing the cost factor.

Transport cost – Each specific case should be evaluated in terms of economic sensitivity to changes in transport distances based on available transport options locally. This should be done to ensure constant inflow of raw materials.

Production cost – The impact on production costs due to relocation of the mobile refineries and possibility to utilise economies of scale is complex and hard to determine. Therefore, it is recommended to perform a detailed assessment to confirm their actual impact on production cost.

Development cost – Developing new concepts for biorefining is costly because of needs to invest in R&D to develop them further as well as their inability to utilise economies of scale. The actual impact on the total costs derived from development costs is hard to determine and should therefore be investigated further.

Storage costs – It is indicated that avoiding storage costs could be considered advantageous for mobile biorefineries compared to stationary biorefineries. To what extent it impacts the total cost savings for a mobile concept compared to a stationary concept should be further investigated.

Feedstock availability – To what extent mobile biorefineries have an advantage over stationary plants in terms of better access to feedstock depends on local density of feedstock and local transport options. An assessment should therefore be performed for each specific case with regards to type of feedstock and geographical constraints.

Weather – How weather constrains a biorefinery is complex because it depends on individual factors for each case with respect to geographical location and type of feedstock. Therefore, detailed assessments for each specific case of the potential impacts from weather on biorefineries' feedstock availability should be performed to determine whether the mobility is advantageous or disadvantages in this regard.

Production problems – Production problems related to feedstock are affected by individual factors such as type of feedstock and geographic location. Detailed assessments of the impacts it may have on feedstock availability should therefore be performed for each specific case.

Rural development – To what extent rural development will occur due to the implementations of mobile biorefineries is not obvious. To better assess this, it is suggested to perform a societal LCA according to Hunkeler, (2006). It is also suggested to evaluate this with the help of the two subcategories “percentage of workforce hired locally” and “percentage of spending on local suppliers” from the guidelines. The two social topics “employment” and “training and education” in the handbook could also be applied for assessing this factor.

Forest fire – It is hard to determine how a mobile biorefinery would affect the risk of starting forest fires, but because the severe consequences forest fires cause it is deemed important to assess. As a recommendation, a risk assessment associated with implementing mobile biorefineries, with focus on risk of forest fire should be performed. Both risks related to presence of dead biomass and presence of people and machines in the forest should be taken into account.

9 Bibliography

Agrawal, R. & Singh, N. R., 2010. *Solar Energy to Biofuels,* West Lafayette: Annual Reviews.

Arvidsson, R., Baumann, H. & Hildenbrand, J., 2015. On the scientific justification of the use of working hours, child labour and property rights in social life cycle assessment: three topical reviews. *The International Journal of Life Cycle Assessment,* 20(2), pp. 161-173.

Arvidsson, R. & Boholm, M., 2014. Controversy over bacterial silver: implications for environmental and sustainability assessments. *Journal of Cleaner Production,* 68(1), pp. 135-143.

Baragona, S., 2011. Company Takes Biodiesel from Field to Fryer to Fuel. *Voice of America*, 26 August.

Battelle, 2013. Battelle develops mobile technology to produce bio-oil. *Biomass Magazine*, 08 November.

Baumann, H., 2012. *Using the life cycle approach for structuring organizational studies of product chains.* Linköping, Greening of Industry Network 2012 conference.

Baumann, H., Arvidsson, R., Tong, H. & Wang, Y., 2013. Does the production of an airbag injuremore people than it saves in traffic? Discussing an alternative approach to S-LCA methodology. *Journal of Industrial Ecology,* 17(4), pp. 517-527.

Baumann, H. & Tillman, A.-M., 2004. *The Hitch Hiker's Guide to LCA.* Lund: Studentlitteratur.

Baystreet, 2015. *XTRM Announces Mobile Cannabis/Hemp To Biodiesel Unit.* [Online] Available at: http://www.baystreet.ca/viewarticle.aspx?id=411621 [Accessed 19 March 2015].

BBC. 2014. [Movie] Directed by BBC. England: Wildfires rage in Sweden.

Benoit Norris, C. et al., 2011. *The Methodological Sheets for Subcategories in Social Life Cycle Assessment,* Paris: United Nations Environment Programme and SETAC.

Benoit, C. et al., 2009. *Guideline for Social Life Cycle Assessment of Products,* Paris: United Nations Environment Programme.

Berg, B. L., 2007. *Qualitative research methods for the social sciences.* 6 ed. Boston: Allyn & Bacon.

Bergek, A., Jacobsson, S. & Sandén, B. A., 2008. 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems. *Technology Analysis & Strategic Management,* 20(5), pp. 575-592.

Boholm, Å. & Corvellec, H., 2008. *The risk/no-risk rhetoric of environmental impact assessment,* Gothenburg: Gothenburg University: School of Business, Economics and Law.

Boholm, M. & Arvidsson, R., 2013. *The value of environment in the controversy over antibacterial silver: A Swedish case study,* Uppsala: Conference on Communication and the Environment.

Business Dictionary, 2015. *Business Dictionary.* [Online] Available at: http://www.businessdictionary.com/definition/socioeconomic.html [Accessed 21 May 2015].

Cambridge University, 2015. *Cambridge Dictionary.* [Online] Available at: http://dictionary.cambridge.org/dictionary/british/decentralize [Accessed 25 March 2015].

Capunitan, J. A. & Capareda, S. C., 2010. *Corn Stover Pyrolysis in a High-Pressure/High-Temperature Batch Reactor: Evaluation of Product Yields and Conversion Efficiencies,* Texas: Texas A&M University.

Carlsson, A. & Antonsson, H., 2011. *Andra generationens biodrivmedel: en litteraturöversikt,* s.l.: VTI.

Commission of the European Communities, 2005. *Biomass action plan,* Brussels: European Commission.

Cushion, E., Whiteman, A. & Dieterle, G., 2010. *Bioenergy Development: Issues and Impact and Natural Resource Management,* Washington: World Bank.

Dagens Nyheter, 2014. Skogsbranden dag för dag. *Dagens Nyheter*, 10 August.

Davidsson, M. C., Timo, N. & Wang, Y., 2009. A case study of Australian four- and five-star hotels. *How much does labour turnover cost?,* 22(4), pp. 451-466.

Defreitas, 2010. *EarthTechling.* [Online] Available at: http://earthtechling.com/2010/07/mobile-biorefinery-concept-tackles-leftover-biomass/ [Accessed 02 March 2015].

Dorminey, B., 2012. The Pine Beetle Problem: Making Renewable Energy Lemonade from Biomass Lemons. *Renewable Energy World*, 12 October.

Dreyer, L. C., Haschild, M. Z. & Schierbeck, J., 2006. A framework for social life cycle assessment. *International Journal of Life Cycle Assessment,* 11(2), pp. 88-97.

Energimyndigheten, 2013. *Energimarknadsrapport - biobränslen,* Stockholm: Energimyndigheten.

Energimyndigheten, 2014. *Trädbränsle och Torvpriser,* Stockholm: Energimyndigheten.

Enoksson, P., 2011. *Naturliga skogsbränder i Sverige,* Kalmar: Länsstyrelsen Östergötland.

European Commission, 2013. *Horizon 2020 - work programme 2014-2015: Leadership enabling and industrial technologies, Part 5,* s.l.: European Commission.

European Commission, 2008. *Assessment of Biorefinery concepts and the implications for agricultural and forestry Policy: Description of the general biorefinery concept,* s.l.: Research Institute Biopos e.V., Germany.

European Commission, 2011a. *Bio-based economy in Europe: state of play and future potential - Part 2,* Brussels: European Commission.

European Commission, 2012. *Innovation for Sustainable Growth: A Bioeconomy for Europe,* Brussels: Europe Commission.

Finley, B., 2013. Feds launch CSU-run research into tapping forests for liquid fuel. *The Denver Post*, 11 July.

Finnveden, G. & Moberg, Å., 2005. Environmental systems analysis tools - an overview. *Journal of Cleaner Production,* Volume 13, pp. 1165-1173.

Fontes, J., Gaasbeek, A., Goedkoop, M. & Evitts, S., 2014. *Handbook for Product Social Impact Assessment,* Amersfoort: Pre Consultants.

Food and Agriculture Organization of the United Nation, 2013. *Guidance on how to address decent rural employment in FAO country activities,* Rome: 2.

Francescato, V., Antonini, E. & Zuccoli Bergomi, L., 2008. *Wood Fuels Handbook,* Legnaro: Italian Agriforestry Energy Association.

GAO, 1989. *Content Analysis: A Methodology for Structuring and Analyzing Written Material,* s.l.: United States General Accounting Office.

Garzia-Perez, M. et al., 2009. *New Bio-refinery Concept to Convert Softwood Bark to Transportation Fuels,* Washington: Washington State University.

Göteborg Energi. 2015. [Movie] Directed by Lasse Sergård. Sverige: Filmserien om GoBiGas.

Gunnarsson, I., 2015. *Project manager for GoBiGas* [Interview] (19 Mars 2015).

Gustavsson, K., 2014. *Skogsbranden i Västmanland 2014: En dokumentation utgiven av länsstyrelsen i Västmanlands län,* Västmanlands Län: länsstyrelsen Västmanlands län.

Hackl, R. & Harvey, S., 2010. *Opportunities for Process Integrated Biorefinery Concepts in the Chemical Cluster in Stenungsund,* Göteborg: Chalmers University of Technology.

Ha, M., 2012. *Optimizing Feedstock and Assessment of Hydrologic Impacts for Sustainable bio-energy production,* Texas: Texas A&M University.

Ha, M. et al., 2011. *GIS Program to Optimize Feedstock Utilization for Mobile Pyrolysis Units.* Louisville, American Society of Agricultural and Biological Engineers.

Ha, M., Munster, C. L. & Provin, T. L., 2014a. A Geographic Information System Program to Optimize Feedstock Logistics for Bioenergy Production for Mobile Pyrolysis Units. *Transactions of the ASABE,* 57(1), pp. 249-257.

Ha, M., Munster, C. L. & Provin, T. L., 2014b. Optimized Feedstock Logistics for Mobile Pyrolysis Units in the North Central Region of the U.S. *Transactions of the ASABE,* 57(4), pp. 1131-1140.

Hekkert, M., Negro, S., Heimeriks, G. & Harmsen, R., 2011. *Technological Innovation Systems Analysis,* Utrecht: Universiteit Utrecht.

Hellsmark, H. et al., 2014. *Teknologiska Innovationssystem inom energiområdet: Biorafinaderier,* Göteborg: Statens energimyndighet.

Hunkeler, D., 2006. Societal LCA Methodology and Case Study. *The International Journal of Life Cycle Assessment,* 11(6), pp. 371-382.

Jönsson, B., 2013. Etanolpilot blir Biorefinery Demo Plant. *Kemivärlden Biotech, Kemisk Tidskrift*, 10 05.

Jørgensen, A., Lai, L. & Hauschild, M. Z. H., 2010. Assessing the validity of impact pathways for child labour and well-being in social life cycle assessment. *The international Journal of Life Cycle Assessment,* 15(1), pp. 5-16.

Kamm, B., Gruber, P. & Kamm, M., 2012. *Biorefineries – Industrial Processes and Products,* Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA.

King, D., 2010. *The Future of Industrial Biorefineries,* Geneva: World Economic Forum.

Kolaei, A., Rakheja, S. & Rickard, M. J., 2014. Effects of tank cross-section on dynamic fluid slosh loads and. *European Jornal of Mechanics B/Fluids,* Issue 46, pp. 46-58.

Kondracki, N. L., Wellman, N. S. & Amundson, D. R., 2002. *Content Analysis: Review of Methods and Their Applications in Nutrition Education,* Washington: EBSCO Publishing.

Lane, J., 2013a. Seaweed-based ethanol technology gets boost in Vietnam. *BiofuelsDigest*, 15 January.

Lane, J., 2013b. Biorefinery 2015 - The Shape of advanced biofuels to come - Part II. 26 March.

Libra, J. A. et al., 2011. Hydrothermal carbonization of biomass residuals: a comparative review of the chemistry, processes and applications of wet and dry pyrolysis. *Biofuels,* II(1), pp. 89-124.

Lydenberg, S., 2012. *On Materiality and Sustainability,* Cambridge: Hauser Center for Nonprofit Organizations.

Markard, J. & Truffer, B., 2008. Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy,* 37(4), pp. 596-615.

Mayring, P., 2000. *Qualitative Content Analysis,* s.l.: FQS.

Nickerson, C., Ebel, R., Borchers, A. & Carriazo, F., 2007. *Major Uses of Land in the United States, 2007,* Washington: United States Department of Agriculture.

O'Brien, M., Doig, A. & Clift, R., 1996. Social and environmental life cycle assessment. *International Journal of Life Cycle Assessment,* 1(4), pp. 231-237.

Oxford University, 2015a. *Oxford Dictionaries.* [Online] Available at: http://www.oxforddictionaries.com/definition/english/mobility [Accessed 24 March 2015].

Oxford University, 2015b. *Oxford Dictionaries.* [Online] Available at: http://www.oxforddictionaries.com/definition/english/flexible [Accessed 24 March 2015].

Palma, M. A. et al., 2011. *Economic Feasibility of a Mobile Fast Pyrolysis System for Sustainable Bio-crude Oil Production,* College Station: International Food and Agribusiness Management Association.

Perelman, C. & Olbrechts-Tyteca, L., 1958. *Traité de l'argumentation nouvlle rhétorique,* Bruxelles: Bruxxels University.

Prasad, B. D., 2014. *Content Analysis, A method in Social Science Research,* s.l.: Centre for Social Studies.

Reddy, M. M., Misra, M. & Mohanty, A., 2012. Bio-Based Materials in the New Bio Economy. *CEP Magazine*, May, pp. 37-42.

Roberts, K. G. et al., 2010. Life Cycle Assessment of Biochar System: Estimating the Energetic, Economic, and Climate Change Potential. *Environment, Science, Technology,* Issue 44, pp. 827-833.

Saraceno, E., 1999. *Creating jobs in rural areas, European Commission.* [Online] Available at: http://ec.europa.eu/agriculture/rur/leader2/rural-en/biblio/emploi/art02.htm [Accessed 20 April 2015].

SCB, 2010. *Sweden - one of Europe's most heavily forested Countries,* Stockholm: SCB.

Skillern, T., 2014. Colorado’s 2014 Wildfire Season Mild Compared To Recent Devastation. *CBS Denver*, 04 August.

Skogsstyrelsen, 2015. *Insekter.* [Online] Available at: http://www.skogsstyrelsen.se/Aga-och-bruka/Skogsbruk/Skador-pa-skog/Insekter-/ [Accessed 23 April 2015].

SMHI, 2011. *Gudrun - Januaristormen 2005.* [Online] Available at: http://www.smhi.se/kunskapsbanken/meteorologi/gudrun-januaristormen-2005-1.5300 [Accessed 23 April 2015].

Söderberg, A., Hammarskjöld, D. & Nilsson, M., 2012. *Genomlysning av projekt GoBiGas, Göteborg Energi AB,* Göteborg: Göteborgs stad.

Sorrel, S. et al., 2009. *Global Oil Depletion: An assessment of the evidence for a near-term peak in global oil production,* s.l.: Technology and Policy Assessment function of the UK Energy Research Centre.

SP, 2013a. *Bioekonomi.* [Online] Available at: http://www.sp.se/sv/index/research/bioresurser/Sidor/default.aspx [Accessed 23 March 2015].

SP, 2013b. *Pilotanläggningen i Örnsköldsvik blir Biorefinery Demo Plant.* [Online] Available at: http://www.sp.se/sv/press/news/Sidor/20130502ovik.aspx [Accessed 27 March 2015].

Stuiver, M., Burk, R. & Quay, P., 2012. 13C/12C ratios in tree rings and the transfer of biospheric carbon to the atmosphere. *Jornal of Geophysical Reser,* 89(D7), pp. 11731-11748.

Teague, B., Mcleod, R. & Pascoe, S., 2009. *2009 victorian Bushfire,* State of Victoria: Royal Commission.

The Energy & Environmental Research Center, 2012. ND research center demos methanol from wood for off-grid power. *Boimass Magazine*, 17 April.

Thompson, I., 2010. The relevance of resilience - A forest manager'sprimer on linkages between biodiversity and forest resilience. *Tropical Forest Update,* 20(1), pp. 16-18.

Thornberry, T., 2012. *UK project looks at creating biofuel on the farm.* [Online] Available at: http://bizlex.com/2012/11/uk-project-looks-at-creating-biofuel-on-the-farm/ [Accessed 13 March 2015].

United States Department of Agriculture, 2013. *Turning agriculture into oil, bio oil, that is.* [Online] Available at: http://www.ars.usda.gov/Main/docs.htm?docid=24151 [Accessed 02 April 2015].

Venere, 2014. New versatile process efficiently converts biomass to liquid fuel. *Purdue University News*, 11 November.

Venere, E., 2010. New biofuels processing method for mobile facilities. *Purdue University News Service*, 6 July.

Viêt Nam News, 2013. Nation eyes bounty from bio-fuels push. *Viêt Nam News*, 14 January.

World Bank, 2012. *Poverty Headcount ratio at 2$ a day (PPP) (% of population),* s.l.: World Bank.

World Bank, 2013. *GDP Growth (annual %),* s.l.: World Bank.

World Bank, 2015. *World Bank Commodoties Price Forecast (nominal US dollars),* s.l.: World Bank.

Wright, M. M., Brown, R. C. & A, B. A., 2008. Distributed processing of biomass to bio-oil for subsequent production of Fischer-Tropsch liquids. *Biofuels, Bioproducts and Biorefining,* Volume 2, pp. 229-238.

Yancey, N. A., Wright, C. T., Conner, C. C. & Shankar Tumuluru, J., 2011. *Optimization of Preprocessing and Densification of Sorgum Stover at Full-scale Operation.* Louisville, American Society of Agricultural and Biological Engineers.

Appendix A

Argument	**Pro or contra**	**References**
Primary argument: costs		
Cost, overall	Contra	(Garzia-Perez, et al., 2009)
Same price for end product as regular diesel	Pro	(Baragona, 2011)
Positive NPV	Contra	(Palma, et al., 2011)
Probability of economic feasibility	Pro	(Palma, et al., 2011)
Probability of economic feasibility	Pro	(Palma, et al., 2011)
Positive NPV	Pro	(Palma, et al., 2011)
Positive NPV	Contra	(Palma, et al., 2011)
Positive NPV	Contra	(Palma, et al., 2011)
Positive NPV	Contra	(Palma, et al., 2011)
Positive NPV	Contra	(Palma, et al., 2011)
Probability of economic feasibility	Contra	(Palma, et al., 2011)
Probability of economic feasibility	Contra	(Palma, et al., 2011)
Higher receipts (incomes)	Contra	(Palma, et al., 2011)
Higher probability of economic feasibility	Contra	(Ha, 2012)
Higher probability of economic feasibility	Contra	(Ha, 2012)
Higher probability of economic feasibility	Contra	(Ha, 2012)
Cost effective to convert biomass	Pro	(Ha, 2012)
Cost, construction	Contra	(Commission of the European Communities, 2005)
Cost, construction	Pro	(Finley, 2013)
Secondary argument: Transport costs		
Transport costs	Pro	(Battelle, 2013)
Reduce waste transport	Pro	(Battelle, 2013)
Reduced transport costs	Pro	(Venere, 2010)
Avoid low density transports	Pro	(Venere, 2010)
Reduced transport costs	Pro	(Defreitas, 2010)
Reduced transport costs	Pro	(Dorminey, 2012)
Transport costs	Pro	(Garzia-Perez, et al., 2009)

Feedstock transportation issues due to small-size	Contra	(Palma, et al., 2011)
Avoid low density transports	Pro	(United States Department of Agriculture, 2013)
Reduced transport costs	Pro	(United States Department of Agriculture, 2013)
Reduced transport costs	Pro	(Lane, 2013a)
Reduced transport costs	Pro	(Viêt Nam News, 2013)
Reduced transport costs	Pro	(Venere, 2014)
Reduced transport costs	Pro	(Palma, et al., 2011)
Transports	Pro	(Finley, 2013)
Minimize cost of feedstock logistics	Pro	(Ha, 2012)
Minimize transport cost	Pro	(Ha, 2012)
Reduced transport costs	Pro	(Ha, 2012)
Minimize feedstock hauling distance	Pro	(Ha, 2012)
More cost effective transports	Pro	(Ha, 2012)
Reduced transport costs	Pro	(Ha, 2012)
Reduced transport costs	Pro	(Ha, 2012)
Minimize feedstock transport costs	Pro	(Ha, 2012)
Reduced delivery costs	Pro	(Ha, 2012)
Reduced transport costs	Pro	(Ha, 2012)
Reduced transport costs	Pro	(Ha, 2012)
Reduced hauling costs	Pro	(Ha, 2012)
No additional transport costs	Pro	(The Energy & Environmental Research Center, 2012)
Feedstock transportation constraints	Pro	(Ha, 2012)
High expenses for transportation	Pro	(Ha, 2012)
Transportation costs for returning biochar	Pro	(Ha, 2012)
Reduce transport distance	Pro	(Ha, et al., 2014a)
Reduce transportation costs	Pro	(Ha, et al., 2014a)
Minimize transport distance	Pro	(Ha, et al., 2014a)
More cost effective transport	Pro	(Ha, et al., 2014a)
Reduced transport costs	Pro	(Ha, et al., 2014a)
Reduced transport costs	Pro	(Yancey, et al., 2011)
Reduced biomass density = reduced cost	Pro	(Ha, et al., 2014b)

Reduced transport costs	Pro	(Ha, et al., 2014b)
Costly to transport biochar	Pro	(Ha, et al., 2014b)
Reduced transport costs	Pro	(Ha, et al., 2014b)
Reduced transport costs	Pro	(Ha, et al., 2014b)
Reduced transport costs	Pro	(Ha, et al., 2014b)
Minimize transport distances	Pro	(Ha, et al., 2014b)
transp. of feedstock cost	Pro	(Garzia-Perez, et al., 2009)
Secondary argument: Production cost		
Lower production cost	Pro	(Garzia-Perez, et al., 2009)
Constant production	Contra	(Palma, et al., 2011)
Higher production rate	Contra	(Palma, et al., 2011)
No additional energy costs	Pro	(The Energy & Environmental Research Center, 2012)
Secondary argument: Development cost		
Research cost	Contra	(Agrawal & Singh, 2010)
Not use economies of scales	Contra	(Garzia-Perez, et al., 2009)
Not use economies of scales	Contra	(Palma, et al., 2011)
Secondary argument: Storage cost		
expenses for biomass storage	Pro	(Ha, 2012)
Expensive to store biomass	Pro	(Ha, et al., 2014b)
Primary argument: Feedstock availability		
Feedstock availability	Pro	(Battelle, 2013)
Maximise output	Pro	(Battelle, 2013)
Availability of feedstock	Pro	(Palma, et al., 2011)
Seasonal feedstock availability	Pro	(Palma, et al., 2011)
Increased feedstock availability	Pro	(Ha, 2012)
Constrained feedstock availability	Pro	(Ha, 2012)
Take advantage of seasonal feedstock supplies	Pro	(Ha, et al., 2014a)
Reduced feedstock collection cost	Pro	(Ha, et al., 2014a)
Constrained availability of feedstock	Pro	(Ha, et al., 2014b)

Availability of feedstock constrains probability of economic feasibility	Pro	(Ha, 2012)
Availability of feedstock constrains probability of economic feasibility	Pro	(Ha, 2012)
Secondary argument: Weather		
Weather constraints	Pro	(Palma, et al., 2011)
Less constrained by weather	Pro	(Ha, 2012)
Constrained by weather	Pro	(Ha, 2012)
Increased flexibility helps with weather constraints	Pro	(Ha, 2012)
Constrained by weather	Pro	(Ha, et al., 2014b)
Weather constrain probability of economic feasibility	Pro	(Ha, 2012)
Weather constrain probability of economic feasibility	Pro	(Ha, 2012)
Secondary argument: Raw material production problems		
Possibility to move unit if crop fails	Pro	(Ha, et al., 2014a)
Limiting losses due to crop failure	Pro	(Ha, et al., 2014b)
Primary argument: Rural development		
Rural development	Pro	(Commission of the European Communities, 2005)
Secondary argument: Rural jobs		
Rural jobs	Pro	(Baragona, 2011)
Rural jobs	Pro	(Finley, 2013)
Primary argument: Forest fire		
Reduced risk of forest fire	Pro	(Finley, 2013)
Reduced risk of forest fire	Pro	(Finley, 2013)

Appendix B

Calculations related to section 6.2.

- Definitions:

$$Stationary\ biorefinery\ (SB) maximum\ transport\ distance = x$$
$$Mobile\ biorefinery\ (MB)\ maximum\ transport\ distance = y$$

- Equations for gather areas (circles):

$$SB\ gathering\ area = x^2 * \pi$$
$$MB\ gathering\ area = y^2 * \pi$$

- "Worst case": In the case of the most energy efficient tree and limited by weight (used number calculated in 6.1.1):

$$0.68 * y = x$$
$$y = x/0.68$$

Equation B.1: Calculations of ratio for "worst case" in terms of increased gathering area.

$$y = \left(\frac{x}{0.68}\right)^2 * \pi \approx 2.16\ (x^2 * \pi)$$

Equation B.2: Calculations of "worst case" gathering area.

$$Increase\ in\ gathering\ area = \frac{2.16\ (x^2 * \pi)}{(x^2 * \pi)} = 2.16$$

Equation B.3: Calculations of "worst case" in terms of increased gathering area.

This means that the gathering area is approximately 2 times bigger.

When calculating the "best case", the same calculations but with volume as limiting factor, and with the least energy dense type of wood (number from section 6.1.1):

$$0.10 * y = x$$

$$y = x/0.10$$

Equation B.4: Calculations of ratio for "best case" in terms of increased gathering area.

$$y = \left(\frac{x}{0.10}\right)^2 * \pi \approx 10.00\ (x^2 * \pi)$$

Equation B.5: Calculations of "best case" gathering area.

$$Increase\ in\ gathering\ area = \frac{10^2(x^2\ *\ \pi)}{(x^2 * \pi)} = 100$$

Equation B.6: Calculations of "best case" in terms of increased gathering area.