Introduction of a Sustainable Alternative for Bitumen

Case study of lignin-based asphalt for the Swedish market

Introduktion av ett hållbart alternativ till Bitumen
Fallstudie av ligninbaserad asfalt för den svenska marknaden

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Abstract

For some time, sustainability has been the major principle of development across the globe, and all aspects of society are somehow affected by the concept. Companies are faced with stricter regulations and are forced to look for solutions to reduce their environmental impact. A key challenge in society is reducing dependence on fossil fuels in favour of renewable materials. The asphalt industry is a sector that has a substantial environmental impact where one of the main components of asphalt is the binder, bitumen, which is produced from petroleum.

One prominent alternative with notable binding capabilities, which resembles the chemical structure of bitumen, is lignin. The work on substituting bitumen with lignin has come the furthest in the Netherlands, where they have been able to substitute 50 % of bitumen with lignin. Several demonstration roads have also been laid, and extensive research on the concept is ongoing.

This study was conducted with the Research Institutes of Sweden (RISE) and the LignoCity initiative. The study aims to examine the current technical- and business market situation of lignin-based asphalt, and through this, present a roadmap for the introduction of lignin-based asphalt to the Swedish market. The research method is qualitative in the form of a case study with semi-structured interviews. The gathered data was analysed and presented through the processes of thematic analysis, and a systematic combining approach was utilized throughout the study.

The study highlights both obstacles and potentials for the introduction of lignin-based asphalt to the Swedish market. The main obstacles were found to be the need for long-term testing and evaluation in Swedish climate and conditions. Passive manufacturers hesitant to invest in the concept, and buyers restrained by regulations also act as significant barriers. The findings suggest that projects and collaborations between actors on the market are necessary to encourage new developments. Procurement procedures and tax-policies should also be amended to favour sustainable solutions. Benefits such as carbon sequestration, noise reduction, and lower rolling resistance should be emphasized.

The work during this study was distributed equally.

Keywords: Lignin, asphalt, bitumen, Swedish asphalt market, public procurement, sustainability

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Abbreviations

BM	Business Model
SBM	Sustainable Business Model
TBL	Triple Bottom Line
CE	Circular Economy
LCA	Life-Cycle Assessment
LCC	Life-Cycle Cost
EM	Ecological Modernization
GPP	Green Public Procurement
SIS	Swedish Institute for Standards
RISE	Research Institutes of Sweden
STA	Swedish Transport Administration
SME	Small- and Medium-sized enterprises
PBM	Polymer Modified Bitumen
CO_2	Carbon Dioxide

Contents

1. Introduction

In this chapter, the field of study intended for research is introduced with a background of the main subjects being presented. The research problem, purpose, aim and questions are then stated.

1.1. Background

The fact that we humans, due to our activities, affect most parts of our surrounding environment has long known. However, the extent of our impact and its resulting consequences has only the last few decades become better understood and given more attention (United Nations Environment Program [UNEP] 2012). A clear example of humans' non-sustainability is the fact that we use the equivalent of 1.5 earths in our activities (Isaksson et al. 2015). The idea of sustainability covers all aspects of human life and the need for sustainable solutions is ever-growing. The United Nations (UN), being an international organization with 193 member states, devised the Sustainable Development Goals which was in 2015 adopted by all member states (United Nations [UN] n.d.). Isaksson et al. (2015) further argue that the issue today is not mainly knowledge on or disagreement of our global issues, but rather how we tackle these issues practically in our activities.

Sustainability has historically not been a major issue for growth-focused companies and industries. However, as consumers change their behaviour by factoring in sustainability in their purchase decision and tougher regulations are implemented, companies are forced to adapt (Reints 2019). Manufacturers are now showing interest in environmentally friendly production, where sustainable manufacturing is about protecting natural resources from being overexploited (Gunasekaran & Spalanzani 2012). A present topic in developed countries is the recycling and reusing of waste. The suggestion for companies is to find ways to utilize waste generated by other industries in their own production.

Asphalt concretes has conventionally been the most common method to pave roads and highways (Luo et al., 2019). The asphalt industry has been conservative and frequently regulated in terms of standards and features (Robinson, 2004). These regulations have introduced many obstacles that have limited the integration of new materials in asphalt. However, in the past couple of decades, the asphalt industry is opening their barriers and engaging in innovations. Currently, the circumstances are changing with the acknowledgement that polymer-modified asphalts could, in fact, be beneficial.

Lignin is one of the many biopolymers that has recently raised attention in the asphalt industry. Lignin is a residue generated from the production of paper and ethanol and is at the time being mainly used for energy-production at paper- and pulp mills where it is produced (Bajwa et al. 2019; Constant et al. 2016). Even though it has traditionally been seen as a waste product with low value, lignin has for some time received much attention and been hailed as material with high potential of being a renewable substitution for many products and industries.

With the era of green transformation and traditional paper- and pulp producing companies striving to widen their product portfolio, the research on lignin and its applications has over the last decade intensified (Bajwa 2019). Several projects such as LignoCity2.0 have established to support the development of lignin-based products and help companies and innovators to commercialize processes and products (LignoCity2.0 n.d.).

1.2. Research problem

As with most industries, the asphalt market has shown a need for a sustainable and more environmentally friendly substitution to bitumen (van Vliet et al. 2016). One challenge the market is facing is the increasingly efficient oil-refinery processes that lower bitumen production and availability in favour of higher-value products, consequently increasing the price (Xu et al 2017).

The demand for asphalt is increasing due to a yearly growth of commercial and industrial vehicles (Morgan & Mulder, 1995). The substantial high axle loads of the increasing number of vehicles cause damages like fatigue cracking, rotting and freeze-thaw cycles (Zhu et al. 2014). Moreover, asphalt pavements require a large amount of energy for production, transportation, and implementation. There are several environmental impacts of asphalt, initially from extraction of oil sands to the application and maintenance. In order to meet the rising demand of asphalt and resolve the environmental concerns, the need to advocate polymer-modified bitumen to replace petroleum-based bitumen, is of high priority.

Regarding present environmental concerns, a certain kind of polymers are under constant development and improvements: biopolymers (Pérez et al., 2019). Biopolymers are biological polymers from biological organism such as plants and trees. Since these entities are essentially by-products from renewable resources, makes them a great environmental-friendly alternative to replace

bitumen. The use of lignin in bitumen is currently rising attention amongst several paper- and pulp industries globally. The demand for sustainable alternatives to reduce carbon footprints is growing. Lignin used as a biopolymer in bitumen has proven to reduce CO_2 emissions (van Vliet et al., 2016). Therefore, combining lignin in bitumen mixtures could potentially be a trending market to meet the UN goals for sustainability and green production.

Testing new products into an already well-established market requires substantial efforts. Evaluating if these new concepts are achievable involves a lot of research, upfront investment costs, and time. Future returns on investments are usually indeterminate or could take a considerably long time. Uncertainties and lack of trust are some of the barriers for industries to take these huge risks on investments.

Existing research on lignin-based asphalt focuses on the technical aspect of a substitution for bitumen, whereas the business aspects are not studied to a satisfactory level. Bajwa et al. (2019, p.9) argue that; "Development and design of lignin valorisation based on the principle of eco-friendly economy will help to grow integrated biorefinery industry…". They conclude that by applying means of techno-economic analysis it is possible to identify qualities and obstacles with scaling up production of products based on lignin.

Gunasekaran & Spalanzani (2012, p.45) argue that; "there is a lack of framework for both practitioners and scholars to develop insights into the sustainable business development in manufacturing and services". They further explain that researchers need to balance economic, environmental, and social challenges in order for investors to recognize the influence each has on the other.

Research on lignin-based asphalt, specifically done for the Swedish market, is non-existent.

1.3. Aim

The purpose of this research is to give a better understanding of the concept of lignin by-product in asphalt applications and study the business potential of lignin-based asphalt based on lignin from the paper- and pulp industry.

The aim is to evaluate the current technical- and market situation of lignin-based asphalt and to produce a road map for introduction into the Swedish market.

By presenting an overview of current circumstances and analysing capabilities, risks and key actors in the asphalt- and lignin industry, the market can be better

understood, suggestions and a value proposition for commercialization can be given.

1.4. Research questions

RQ1: What is the current technical- and market situation of asphalt?

RQ2: How can an environmentally sustainable alternative for asphalt be introduced to the Swedish market?

1. What are the main benefits of lignin-based asphalt?
2. What are the barriers to introducing a new sustainable alternative to asphalt in the Swedish market?
3. How can public procurements better address the need for a sustainable asphalt alternative?

1.5. Limitations

The study will require limitations in order to realize the aim and purpose within the given time frame of 20 weeks. The limitations are listed below.

- Due to limited time and resources the study will only focus on companies in Sweden.
- This study will focus on the application of lignin in asphalt, other biopolymers are neglected due to the broad area of practices.
- The focus on lignin is in the framework of asphalt application. Other applications are not considered.
- This study will research the topics broadly without examining all detail.

1.6. Thesis structure

An outline of the thesis structure is presented in Figure 1.

Figure 1: Overview of the thesis structure.

2. Theory

The first part of the theoretical framework regards public procurements. General business models and models through a sustainability perspective are then examined. The last part relates to the asphalt market and lignin developments and applications and the technical part of asphalt, lignin and lignin-based asphalt. A summary of the chapter is also constructed

2.1. Public procurement

Public procurement is the procedure for buying goods, services or works within the public sector (Konkurrensverket 2019). Public procurement is a statutory procurement process that aims to ensure that public procurement is opened up to competition and that public funds are used as efficiently as possible. In Sweden, the public procurement is regulated by the Law (2016: 1145) on Public Procurement (LOU) and (2016: 1146) on procurement in the supply sectors (LUF) (Konkurrensverket 2019). The laws are primarily established on EU directives which are an important part of promoting free movement of goods and services within the EU. By complying with the Swedish procurement regulations act (1 chap. 22 § LOU and LUF), contracting authorities and entities required to meet the obligations arising from EU law (Konkurrensverket 2019).

The laws that regulates all public procurement are based on five principles with a base from the EU law (4 chap. 1 § LOU and LUF) (Konkurrensverket 2019):

1. The principle of non-discrimination
2. The principle of equal treatment
3. The principle of transparency
4. The principle of proportionality
5. The principle of mutual recognition

The requirements from the authority or entities for the procured product or service must be clearly described and defined. Whenever possible, contracting authorities and entities should take environmental, social and labour law considerations into account when purchasing under the Swedish Public Procurement Act. Specific environmental, social, labour law and other conditions for how the execution of a contract may be set in accordance to Chap. 4 § 3 LOU and LUF (environmental, social, and labour law considerations) (Konkurrensverket 2019).

In regard to innovation, partnerships could be used when the contracting authority or entity needs solutions that have not yet been established in the

market. Through the partnership, contracting authorities and entities could grant a contract that covers research and development and procure the product that is developed through the partnership under act Chap. 6 § 1, § 30–41 § LOU (rules on innovation partnerships) (Konkurrensverket 2019).

2.1.1. Sustainable public procurement

Public procurement has a large impact on going into a sustainable direction. In Sweden, about 18 000 procurements occur every year with an estimated value of 706 billion SEK (Upphandlingsmyndigheten 2019). Clearly, the public sector accounts for a large influence for both designing and leveraging sustainable policies. Hence, several studies have been conducted on Green Public Procurement (GPP) and its importance in sustainable development (Testa et al. 2014; Uttam & Roos 2014; Sourani & Sohail 2011). The GPP is defined as the approach where public authorities integrate environmental conditions in procured goods, services and works, thus encouraging to more sustainable developments with a whole life-cycle perspective (Testa et al. 2014).

According to Testa et al. (2014) incorporating GPP would stimulate firms' innovation towards more sustainable products or services, consequently reducing CO_2 emissions. This is illustrated in a study conducted by PricewaterhouseCoopers, in seven European countries, resulted on a 25 % CO_2 decrease by implementing GPP practices (Testa et al. 2014). Numerous authors agree that GPP allows for a strong stimulus for eco-innovation (e.g. Brammer & Walker 2011; Testa et al., 2014). This is further concluded in a study done by Alvarez & Rubio (2015) demonstrating that incorporating carbon footprint in GPP encourage eco-innovation. Hence, GPP has been acknowledged as a fundamental tool in the development to reach sustainable production and consumption by the UN, the EU, and national governments (Bratt et. al 2013). In addition, GPP is evolving into incorporating social aspects and being defined as sustainable public procurement (SPP). The fundamentals of SPP are the search for sustainable developments by incorporating social approaches along with environmental and economic aspects (Uttam & Roos 2014).

It has been evident that public procurers still lean towards traditional practices (Bratt et al. 2013). A study conducted on construction procurements in Sweden showed that environmental measures is rare (Varnäs 2008). The reasons for a slow GPP integration is according to Bratt et al. (2013) a lack of higher level support, lack of competence as well as ignoring long-term benefits. There are few long-term perspectives and criteria are solely taken into consideration to

comply with procurement laws (Bratt et al. 2013). Bratt et al. (2013) further argues that the choices of standards lack guidance with clear environmental explanations and that working groups is not guaranteed to comprise strategic sustainability thinking. Arguments to address this matter involves a shift from pure product focus to a function focus. These arguments, as stated by Bratt et. Al (2013, p.314) "found to simultaneously create sustainability achievements for society at large, business opportunities, procurer/consumer advantages and improved local and regional labour markets". The evaluation procedure used by the Swedish government for public procurement include several sustainable efforts, although requires a number of possible improvement (Bratt et al. 2013).

2.2. Business models

The business model (BM) has evolved to become an essential tool for organizations and entrepreneurs, to capture key elements for their business strategy (Mason & Spring 2011). Several authors (eg. Zott & Amit 2007; Mason & Spring 2011) have emphasized the importance of BM designs as it has iteratively shown to influence a company's performance. Zott & Amit (2007) further claims that there is a noticeable correlation between firms with innovating BM designs and their progressions.

Although there has been an extensive number of published articles on this subject (Zott et al. 2011; Holtström et al. 2019; Foss & Saebi 2017) it appears that the concept of BM has yet to attain a common definition. Zott et al. (2011, p.1023) criticize many recent published articles meaning that they lack to conceptualize the BM "This lack of definitional clarity represents a potential source of confusion, promoting dispersion rather than convergence of perspectives and obstructing cumulative research progress on BMs."

A common interpretation of BM is how an organization could create and deliver value in order to capture a profit (Mason & Spring 2011; Foss & Saebi 2017; Holtström et al. 2019).

Chesbrough (2007) denotes that a BM builds on six main elements:

1. Value proposition
2. Market segment
3. Value chain structure
4. Streams of cost and revenues
5. Competitive strategy
6. Value-network position

In essence, a BM embodies the data that illustrates how businesses could potentially create and deliver value to customers (Chesbrough 2007; Teece 2010). Additionally, BM summaries the structure of revenues, expenses and profits allied with the firm delivering that value. It makes predictions about potential customers and the forthcoming demand from customers. According to Teece (2010) a good BM consists of a value proposition that is enthralling to customers, identifies a market segment and structures expenses and risks. In order for a BM to be successful in the long-term, an equilibrium between streams of cost and revenues needs to be established (Holtström et al. 2019). The awareness of the firm's situation within the value-network is vital to estimate its possibilities in the market.

2.2.1. Sustainable business model

The dominant BMs are today based on, as Stubbs and Cocklin (2008) describes the neoclassical economic theory. This view sees the main goal of corporations as maximizing profits for their shareholders and other aspects, such as environmental and social issues, are addressed only if it serves this main goal or external pressure, such as regulations, demands this. Stubbs and Cocklin (2008) further argue that these models aren't sufficient for companies to address social and environmental aspects of sustainability. The processes of production are described as a linear one where energy and resources are used inefficiently. Therefore, there have been calls from scholars for new models where integration of these aspects is included. Moreover, it is further argued that the understanding of how sustainability is done in practice is lacking.

Sustainable business models (SBM) aim to deliver more than the monetary value (Bocken et al. 2013). By taking into account other value-creating factors, an advantage is created that can offer stakeholders more value other than economical. Bocken et al. (2013) further explain that it is required for SBMs to be economically sustainable. This highlights that SBMs purpose is to produce social and environmental value while maintaining the economic value generation (Schaltegger et al. 2012).

Costanza et al. (1997) explain in their paper that there is a need for ecosystems and natural resources to be better valued or quantified in order for it to be comparable with other economic production. Bocken et al. (2014) elaborate on this, arguing that it still has not become a routine in business as natural resources tend to be seen as "free". They further argue that environmental challenges need to be addressed together with economic- and social challenges.

SBMs can create advantages over competitors through additional value creation for customers (Bocken et al. 2014). It can also help the company with a holistic sustainable development as well as benefit society. With SBMs the stakeholder perspective is seen as more important than shareholder view (Stubbs & Cocklin 2008). In this, a wider range of actors and aspects are seen as stakeholders, such as future generations and the environment (Bocken et al. 2014; Stubbs & Cocklin 2008). It is further mentioned by Stubbs and Cocklin (2008) that collaboration between actors and stakeholders is necessary as to innovate solutions for sustainability across the system rather than one individual entity working by itself, for itself.

Ecological modernization (EM) is argued by Stubbs and Cocklin (2008) to be an alternative to the neoclassical view and is explained as being based on the belief that economic growth can be achieved without damaging the environment. This is thought to be possible through innovation, technological advancement and environmental regulation.

In the EM perspective, companies strive to produce resource friendly products that decrease the environmental impact (Stubbs & Cocklin 2008). This includes reduction of waste, energy and pollutants. Furthermore, actors in the industry cooperate on environmental and sustainability issues.

Schaltegger et al. (2012) argues that business cases addressing sustainability does not come without effort, but rather require development and management. It is further explained that due to rigidness of BMs limiting corporate behaviour flexibility and flawed integration of strategy formation, business case potentials are neglected. This is particularly evident in production where more sustainable solutions haven't been able to become widely established. This can also be seen in companies with high potential to save money. Schaltegger et al. (2012) further mentions the importance of improving a company's reputation. A company's employees are also seen as a stakeholder and an important factor in SBMs (Bocken et al. 2013; Hörisch et al. 2014). Employees want to and feel proud to work for responsible and sustainable companies (Hörisch et al. 2014). A new environmentally friendly product will generate economic benefits and stability to stakeholders and the supply chain as a whole.

2.2.2. Circular economy

The concept of circular economy (CE) is not a new one but it has in recent years become a subject for creation of plans for sustainable development by decision

makers (Geissdoerfer et al. 2017). It is now also a topical subject amongst researchers and corporations. Geissdoerfer et al. (2017) combine different definitions of CE to form a new one:

> A regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling (Geissdoerfer et al. 2017, pp. 759).

Unlike the linear model, which Stubbs and Cocklin (2008) describe as an energy and resource-draining, "take-make-waste" concept, the circular model strives for a loop system where economic and environmental processes are synchronized. One major concern with the linear, neoclassical model is the externalization of negative effects and costs, waste as an example (Geissdoerfer et al. 2017; Stubbs & Cocklin 2008). This is an issue that the CE sought to address by, as mentioned in the definition, reuse and recycling, amongst other principles.

The European Commission highlights three phases in which recommendations and plans are described (European Commision 2015). These three are production, consumption, and waste management. Under waste management, it is stated:

> The Commission will launch work to develop quality standards for secondary raw materials where they are needed (in particular for plastics), and is proposing improvements to the rules on 'end-of-waste' (European Commission 2015, pp. 13).

This is aimed at making it easier for recycled materials to be sold as new raw material on the markets. It is further mentioned in the report that private entities have a role of establishing demand while public entities also can help through the public procurement processes and regulations.

2.2.3. Triple bottom line

The Hershey Food Co. is a good example of how focusing on profit alone can backfire. The "Hershey fiasco" story became a controversial topic in the early 2000s and was headlining newscast, like the Wall Street Journal, in the U.S. (Savitz 2012). The story demonstrates that even a well-known, properly managed company, with a good reputation, can downfall when principles of

sustainability are ignored (Savitz 2012). The Hershey's Co. was risking the shareholders' funds in order to maximize profits. However, in today's business market, the bottom line is to consider all aspects: social, economic, and environmental (Savitz 2012). Ignoring the environmental or social aspects and focusing solely on the economic benefits, could lead to negative outcomes, like Hershey's Co. and many more (Savitz 2012). The concept of Triple Bottom Line (TBL) was established on Elkington's journey trying to measure several firm's performance, not only by its profitability but also considering the environmental and social dimensions (Elkington 1997). Elkingon's model proposes a new approach instead of one bottom line where profit is the focus. There should be three: profit, people, and planet (Elkington 1997). It recognizes dimensions such as stakeholders, employees, health and safety, equality, and diversity (Savitz 2012).

2.3. Asphalt

Conventional asphalt has been around for centuries. It comprises a mixture of graded aggregates, bitumen, and fillers (Robinson 2004). Aggregates are the main element in asphalt pavement. They are thus fundamental in load-supporting to restrain high traffic loads from damaging the asphalt pavement. Aggregates consist of solid materials such as rock, sand, and gravel (MAPA 2014). Conventionally, large rocks are broken down into smaller desired sizes in a paving plant (see Figure 2). In this method, differences in the size of rocks are recognized and separated by a screening process. Besides size and shape, the aggregates are distinguished by toughness, soundness absorption and stripping, all of which influence the outcome of the asphalt pavement (MAPA 2014).

Figure 2: This figure serves as an illustrator of a conventional paving plant (MAPA 2014).

Bitumen, a sticky viscous liquid, is the conventional binding material found in asphalt concrete, which contributes to around 5 % of the mixture's mass. The substance has been fundamental in road pavements and construction for thousands of years due to its remarkable binding capabilities and water-repellent properties (Robinson 2004). The chemical composition of bitumen enables it to have elastic physical properties e.g., brittle in cold climate and soft in hot climate (Luo et al. 2019).

The combination of aggregates and bitumen form asphalt pavements with desirable structures such as high- skid resistance, permanence, and durability. Asphalt pavements are structured to withstand intense traffic conditions that occur on a daily basis in highways and urban areas. Subgrade, the material beneath asphalt pavement, has a significant impact of the resultant characteristics when constructing asphalt pavement (Robinson 2004). Thus, weaker subgrades need to be compensated with stronger pavements. In most cases, conventional asphalt pavements comprise of three separate layers, which are positioned on top of the subgrade, as seen in Figure 3. The surface course is the top layer of the pavement, covering about 25-40 mm in thickness, followed by the binder course layer, which is usually laid 60 mm thick. The base layer is the latter course, which is the main element to endure the structural-load-bearing, normally covers 100-200 mm in thickness.

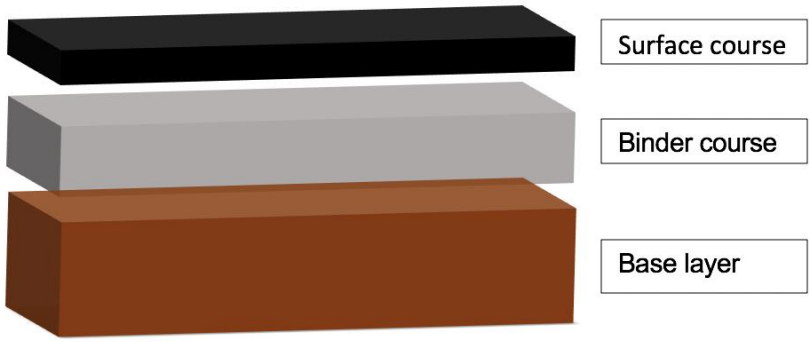

Figure 3: A model of the three main layers in a standard asphalt pavement.

2.3.1. Polymer modified bitumen

The asphalt industry has been on high demand over the world during the last few decades. Many countries, particularly in developing countries, has seen an increase of traffic load and volume. These asphalt pavements have thus gone

through rough conditions as distresses were evident in many cases. Cracking and rutting of pavement surfaces encouraged researchers to investigate other alternatives for improving the properties of asphalt. As oil resources are limited and ineffective regulation that occurs during refinery processes, along with firms' desires to maximize profit, prompted researchers to consider modifying bitumen (Becker et al. 2001).

Polymer modified bitumen (PMB) has been the most prominent approach amongst all the studied methods. Various PMB has been demonstrated that they could improve the performance of asphalt pavements, such as higher cracking and fatigue resistance, improved moisture resistance, decreased thermal susceptibility and higher stiffness (Pérez et al. 2019; Zhu et al. 2014; Becker et al. 2001). Some of the common polymers in bitumen modification include polyethylene (PE), polypropylene (PP) and ethylene–vinyl acetate (EVA) (Zhu et al. 2014). While PMB has been confirmed to improve bitumen properties to some degree, they however have some disadvantages that restrict their implementation. Certain PMBs could be very costly and have poor ageing resistance (Zhu et al. 2014). Several important issues with PMB are still not clearly understood. More studies need to be done to answer these issues and discover new techniques to modify bitumen efficiently and cheaply.

2.3.2. Biopolymer

As bitumen is a by-product from crude oil, other more sustainable alternatives to develop new binder materials have recently been studied. With the rising attention to the global emission by the UN, more entities are trying to find solutions for more sustainable alternatives to minimize bitumen consumption.

A certain kind of polymers is the biopolymers. Biopolymers are biological polymers that merge from natural organisms such as microorganisms, plants, and trees (Perez et al. 2019). Implementation of biopolymers as a binding material could replace or reducing the consumption of bitumen, which contributes to reduce CO_2 emissions. In addition, biopolymers have been shown to improve some properties of the asphalt mixture (van Vliet et al. 2016; Xu et al. 2017). In recent years, lignin has drawn considerable attention as a potential replacement or performance modifier for bitumen.

2.3.3. Lignin

Lignin, mainly produced in paper- and pulp production processes, is one of the most available natural, organic materials in the world (Bajwa et al. 2019). It is

roughly estimated that 50-75 million tonnes of lignin worldwide are made available at paper production plants and this number is expected to reach 225 million tonnes per year worldwide by the end of the this decade (Bajwa et al. 2019; Jiang et al. 2020). Traditionally, lignin has been seen as a low-value waste product and been burned to generate heat and energy. Merely 2% of all lignin has been sold for products with a higher value. Even though this number is predicted to soon grow, the technologies for processing and refining lignin have been underdeveloped for some time (Luo & Abu-Omar 2017). Strassberger et al. (2014) argues that lignin is believed to be the most applicable green substitute for oil-based aromatics because of its structure. They further describe that, in reality, limited development has been made and valorisation of lignin remains a difficulty.

A known saying in the industry has been "one can make anything from lignin except money" (Ragauskas et al. 2014 pp. 716). This has led to a greater amount of resources being invested in lignin valorisation. Luo and Abu-Omar (2017) and Ragauskas et al. (2014) suggest that continuous research will give a better understanding of its capabilities and possibilities. This will eventually lead to lignin being a successful biomaterial within a wide range of industries and applications.

There are four main methods of lignin separation from biomass that produces pure lignin (Strassberger et al. 2014). These processes are called Kraft, Soda, Sulphite and Organosolv, where the Kraft-process is the most common (Luo & Abu-Omar 2017). To better the quality of lignin in the Kraft-process, the LignoBoost technology can be used (Strassberger et al. 2014; Tomani 2010). Benefits with the LignoBoost technology are, as Tomani (2010) describes, lower investment- and operational costs as well as a purer end-product. The technology has at a testing plant, operated by RISE in Bäckhammar, achieved a production scale of 4 000 tonnes per year.

2.4. Theoretical framework

To be able to understand the connection between the theories presented, the theoretical framework serves as an outline part for which aspects intersects in lignin-based asphalt. The theoretical framework includes aspects within public procurement, BMs, and asphalt market, the framework is illustrated in Figure 4.

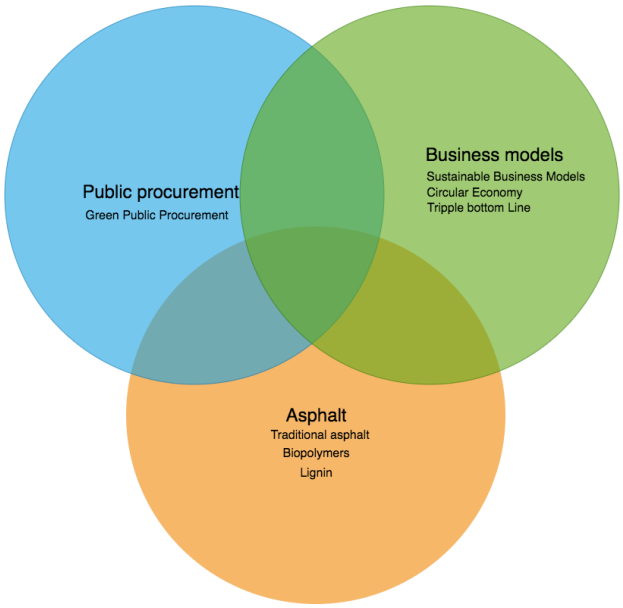

Figure 4: Illustration of the three different aspects presented in this study.

The presented theories, demonstrated in Figure 4, contributes to various perspectives and dimensions to this study. These combined allows for a holistic view that is necessary to address the current lignin-based asphalt technical and market situation in Sweden, which is the aim of this study. The presented theories on public procurement clarify the process, standards and laws included of procuring asphalt in the Swedish market. Moreover, BMs represent various essential elements, such as sustainability, that play a major role in the present business market. Lastly, the asphalt aspect provides details and insight of current asphalt and lignin market in Sweden.

3. Method

This section presents the research methodology of this study. This includes the research approach, literature review, the procedure of data collection and the data analysis. In closing, a trustworthiness discussion is presented which covers the reliability of the study.

3.1. Research approach

As the desire and need for environmentally sustainable products and solutions grow across all industries, models, and instructions for how this transformation can be done in an economically sustainable manner is needed. Current models, seeing corporations as profit machines for owners, is according to Stubbs and Cocklin (2008) not able to solve environmental and social issues. For this purpose, they claim, a new SBM is needed. The topic, acting as a frame of reference for this paper, is the utilization of lignin in asphalt applications. More specifically, the objective is to study the business opportunity and potential for environmentally friendly lignin-based asphalt and produce a roadmap for how it can be introduced to the Swedish market.

Although there are lots of conducted studies about the implementation of lignin, and other biopolymers in asphalt, there is a lack of knowledge about this matter from a business perspective. According to Gray (2017) a qualitative approach is preferable when more understanding and insight about a subject is needed, which suits with the purpose of this paper. Furthermore, a qualitative approach is also convenient when trying to capture the respondent's various perspectives in a real-life context (Gray 2017; Yin 2011). A qualitative approach also enables a holistic view.

Bryman and Bell (2015) state that both deductive and inductive research carry components from each other. Gray (2017) also mentions that for some studies a combination of both strategies is to preferer. For this study, a base of concepts is constructed and presented in the theory from which an empirical research is conducted. This part is the deductive process as Bryman and Bell (2015) and Gray (2017) describe. By conducting interviews, a better understanding of the reality, within the context of the phenomenon, can be given and a proposition can be constructed and presented. With the empirical data collected, a theory for a SBM can be composed, which is the inductive aspect of this study.

A case study is chosen for this qualitative study. Gray (2017) denotes that case studies are ideal in qualitative studies to get in-depth on a specific phenomenon. Case studies is preferable when there is a complex phenomenon in a real-life

context and when a 'how' or 'why' question is being asked (Gray 2017; Yin 2014). In this sense, this approach was arguably the best to answer our research questions.

Dubois & Gadde (2002) describes an alternative method to perform a case study by using a systematic combining approach. In other words, due to continuously changing data that occurs, the theory and data are collected through an iterative process. Hence, depending on the result collected, a new theory will be supplemented through a continuous process. In this qualitative case study, this approach seems appropriate since the result highly influences the relevant theory. As Gray (2017) explains, some qualitative researchers' ambition is high generalization while others aim for trustworthiness within a specific context. The findings of this study are also aimed at being as broadly useful as possible but due to the focus being on one case study, namely lignin-based asphalt, it is most practical in this context.

3.2. Data collection

To obtain the data on the asphalt and lignin industry, its markets and developments, interviews and literature review were used in this report. Interviews was chosen as it was seen of being the most efficient one to get an insight of the industry, their ambitions and what their plans are and also how the actual situation on the market looks like. This method is an explorative data collection method to study research questions in depth (Gray 2017). Moreover, a literature review was done in prior to the interviews to have the necessary knowledge on relevant theories in this research. Throughout this research, a systematic combining approach was used for data collection. Data saturation was also, to some extent, noticed after interview 6.

3.2.1. Literature review

Conducting a study of previous work done on the topics is essential for this study, as it is not a purely inductive one, and helps to justify it (Gray 2017; Bryman & Bell 2015). The review allows for a more precise paper as it enables identification of current research and knowledge gaps, construction of well-defined research questions and also helps with the design and method of the study.

A fundamental theory was laid as a base for constructing concept BMs by conducting a literature review on relevant topics. The review process was also,

as Gray (2017) argues, recurring as new ideas and aspects came to light during the research.

This theory was also utilized when producing an interview draft and questions presented in appendix A.

To find relevant literature and earlier work on these topics, search terms and keywords were outlined. Keywords were related to business model, asphalt, lignin and reuse of waste. Used literature is peer-reviewed articles, books and reports. Articles were searched with use of Google Scholar and Karlstad University database - OneSearch.

3.2.2. Primary data

The conducted semi-structured interviews were aimed at understanding the topic better and getting an insight in to the market and its actors. Yin (2011) describes this approach as a non-strict and adaptive as no predetermined list of question is strictly followed, but rather a conversation type of interview with open-ended questions. Semi-structured interviews allow flexibility, an opportunity for the respondents to speak open-minded, develop their thoughts accordingly, and provide more detailed answers (Gray 2017). For this purpose, a semi-structured interview method is preferred. A semi-structured interview contains a list of questions to be answered by respective respondent. These questions could be in various orders, be altered, detached, or supplementary questions could be added depending on the situation that arises (Gray 2017). Gray (2017) further emphasizes that semi-structured interview enables unexpected factors that could contribute with essential information and consequently better answer the research questions.

Procedure

The interview candidates were chosen through a purposive sampling strategy, a method that deliberately identifies key actors that could contribute with valuable information (Gray 2017). This sampling strategy enables relevant respondents with the right knowledge and experience to be recognized and selected. In this study, the chosen participants were from mainly large organizations and adequate awareness within the field of asphalt. Based on the participant and topic of interest, a rough draft of questions and subjects was constructed and used during the interviews, presented in Appendix A. As Yin (2011) argues, the interview draft was designed so that the participants can freely talk using their

own words and without a feeling of interrogation. The interview draft was constructed based on the literature review and research questions.

Initial contact with the selected respondents was by email or phone. The respondents were informed about the project and asked if they agreed to participate in the study. Once an agreement was established, further details, such as approximate interview time and an appointment, were sent to the respondents. In total, 8 participants from various organisations agreed to participate as interviewees, see Table 1.

All interviews were conducted using two online telecommunication platforms; Skype and Zoom. This option was preferred considering its time efficiency and the long distances between each respondent (Saunders et al. 2009). All interviews began with a brief introduction and were sound recorded, which according to Gray (2017) is essential to register all information and eliminate the risk of missing any detail. The interviewees were asked for their consent of them being recorded and after approval the interview could proceed. The convenience of sound recording enabled more opportunity to focus on listening and interpreting of what is being said by the interviewees rather than taking notes repeatedly, which according to Hancock & Algozzine (2006) allows for more informative and explorative interviews. After each conducted interview, the recording was retained and transcribed.

Table 1: Overview of conducted interviews.

Organization	Respondent number	Validation
PEAB	1	X
Swedish Transport Administration (STA)	2	X
Research Institutes of Sweden (RISE)	3	X
Wageningen Food & Biobased Research	4	X
Paper Province	5	X
NCC	6	X
NCC	7	X
Sting Bioeconomy	8	X

3.3. Data analysis

Contrary to quantitative data, qualitative data do not have as many and as rigorous methods of analysis (Bryman & Bell 2015). Qualitative methods also often generate large amounts of non-numerical data that require processing and analysis to be as useful as possible. This allows for construction of concepts

and theory building (Gray 2017). The method of thematic analysis was chosen for this study. Unlike methods like grounded theory, there is no commonly accepted technique or guidelines for thematic analysis (Braun & Clarke 2006; Bryman & Bell 2015). They further argue that the strategy of identifying themes in sets of data is found in most qualitative data analysis methods, however it is often not recognized as a method of its own, namely thematic analysis.

The strategy is based on analysing data while continuously relating it to the study's research questions to find important and relevant information (Braun & Clarke 2006; Gray 2017). Before the analysis, the question of what is regarded as a theme or pattern and its required size, is determined. It is also necessary to be aware of the perspective in which way data is identified, whether it is inductive or theoretical, as Braun and Clarke (2006) explains. Analysis of the gathered data in this study has an inductive nature as the coding is done without preconditions but rather result in new conceptual categories.

The thematic analysis strategy requires a level of flexibility as the qualitative data does not allow for an exact system or instructions as explained by Braun and Clarke (2006). The analysis process is conducted by following the six phases as described by Braun and Clarke (2006) and summarized by Gray (2017)

- *Data familiarization:* The interview recordings is transcribed. The written data is thoroughly read through and arising thoughts and ideas are noted.
- *Generation of initial codes*: By highlighting interesting segments of the text, interesting information, patterns, and possible themes emerges.
- *Search of themes*: In this phase, the process is to analyse the highlighted codes and sort them into potential themes. Some codes produce main themes whereas others sub-themes. Some codes are disregarded while some do not fit into any themes, so they are temporarily put in a separate category.
- *Reviewing themes*: The potential themes are gone through where some may lack enough evidence to be kept while others can be combined or separated. The remaining themes are confirmed by rechecking its validity and context in the data set.
- *Defining themes*: The themes are named and given clear descriptions of its substance and what purpose it fills in the study. Any sub-themes are recognized in the same manner.
- *Producing the report*: An analytical story is written in the paper with the use of the refined themes. Arguments are made with use of themes and in relation to the research questions.

The generated themes and the following result-chapter contain different amounts of references to each interviewee as their contribution of relevant and useful data for our study varied. A need for further theory chapters arose with

a better overview of significant information from the data gathering. This required additional literature review on certain topics.

3.4. Trustworthiness

Gray (2017) explains that critique aimed at qualitative analysis points out the weaknesses of subjectivity, insufficient evidence based on a few cases. To ensure reliability in this research, data triangulation was used, which according to Gray (2017), is one of the methods to improve or guarantee the stability of findings in a study. Data triangulation, where data is gathered using multiple strategies, was achieved by collecting data through interviews and literature studies in a set given time period. Furthermore, reliability was strengthened by interviewing respondents from different hierarchy levels, which allowed understanding the concept from different perspectives.

Some researchers claim that trustworthiness is more relevant than the reliability of a qualitative research. Lincoln and Guba (1985) demonstrates there are four criteria to address trustworthiness: transferability, credibility, dependability and confirmability.

Transferability means the extent to which the findings are applicable with other context, in other words how generalizable it is (Lincoln and Guba 1985). In this study, transferability is addressed by demonstrating thick descriptions, i.e. clear guidelines of how data was collected, analysed, and processed.

The credibility criteria involve that the findings of a qualitative study are trustworthy enough to be interpreted with confidence (Lincoln and Guba 1985). To ensure increased credibility of the findings several measures were implemented. The respondents for the study were carefully selected through a sampling strategy, ensuring that the criteria of both experience and relevant knowledge within the field were met. Additionally, the data from the respondents were transcribed and returned to the respondents for verification to prevent potential mistakes to be made. Respondent validation is presented in Table 1. The empirical findings were repeatedly ensured to correspond with literature studies to increase the credibility of the result.

Dependability concerns whether the study is consistent and replicable (Lincoln & Guba 1985). This was ensured by demonstrating stepwise procedures that were conducted in the study so that similar results can be attained if repeated with the same circumstances. To further increase dependability, Lincoln & Guba (1985) suggests researchers to conduct external audits. An external audit

involves having an outside source examine the data gathering, data analysis and the empirical findings of the qualitative study. This is essential to ensure that no errors occurred and verify the authenticity of the data and that it was endorsed with relevant data (Lincoln & Guba 1985). Moreover, the external audits need to examine the data with a rather objective perspective and interpretation. This was accomplished with the help of supervisors from Karlstad University during several meetings and seminars.

To increase conformability, and avoid biases, the study was conducted with a neutral consciousness. Gray (2017) suggests that interviews should follow a guideline, using techniques that build rapport and thrust, as well as that the 'interview effect' should be avoided by all means. The interview effect is a frequently occurred effect where there is a distortion of response from the respondents, which could inadvertently impact the result (Gray 2017). This was considered in this research and addressed by following instructions on behaviour during interviews, asking formulated unbiased questions, and maintaining objectivity throughout the study.

4. Result

This chapter presents and describes the gathered data from the conducted interviews. Respondents are referred to by number as previously presented in Table 1. Interviews conducted in the Swedish language are translated to English.

4.1. Current asphalt market

Most of today's asphalt in the Swedish market has more or less the same components: aggregates and bitumen. Many industries add fillers or additives such as polymers to achieve the desired structure and characteristics. The asphalt production process has looked almost the same for centuries. Respondent 1 explains the process of producing asphalt in Sweden. The process starts with aggregates obtained from open-pit mining ranging from coarse stone to fine sands. The aggregates later get separated into various stockpiles depending on their size and form. This is later dried in a drying drum with a gas-powered burner, which enables the aggregates to bond better with the binder materials. The binding material, bitumen, is heated into the desired temperature to reach its full potential of binding properties in a heater. Bitumen, along with possible other additives, are later mixed in a blender. The aggregates and additives vary according to what the paving asphalt will be used for. The result is a mixture of these components that are ready to enter the trucks destined to the paving sites.

Standards

The asphalt pavement needs to fulfil a set of qualifications and standards before an order is placed. In the EU, the law on public procurement follows several harmonized standard products. The European Economic Area (EEA) ensures that the product placed on the European market are safe and follows environmental regulations. For instance, in Sweden, these standards need to be complied with before any procurement process can occur. Respondent 2 elaborates on this aspect.

> It is SIS (Swedish Institute for Standards) that carries out standardization on an international level based on a mandate from the Swedish government. Since, asphalt and constituent materials (aggregate and bitumen) are categorized by harmonized product standard (EN) according to the Construction Product Regulation (CPR), the Swedish Transport Administration (STA) are obliged to

> follow these standards when setting requirements for procurement (Respondent 2)

Standards are established through a voluntary partnership between manufacturers, authorities, researchers, and environmental organisations. SIS ensures that manufacturers meet standards and that new standards are developed in regulation with the EU market. The process of revision is complicated, Respondent 2 explains.

> Every 5 years a standard is subject to systematic review and if comments from members states within EU shows that an alteration is needed, a process starts for revision. There are currently lots of difficulties to develop new or revise old harmonized product standards, due to delayed systems within the EU commission (Respondent 2).

The supplier of asphalt requires declared performance and CE-marking information for incoming constituent materials (aggregate and bitumen) since they are covered by harmonized product standards (Respondent 2). The CE-mark is a symbol that acts as a passport that allows for open market purchases. All asphalt in the Swedish market requires CE marked asphalt. Once the asphalt pavement is placed, there is usually a warranty to maintain by the contractors.

Apart from the EN-standards, the manufacturer needs to ensure that the asphalt qualities meet the requirements in the regulation and is sustained during an expected lifetime (Respondent 2). Warranties on quality tend to extend for several years and include, for example, requirements on maximum rut depth and irregularities. The asphalt industries have, during recent years, also have to adapt to some sustainable standards. For instance, Respondent 1 explains that buyers, usually public procurements, demand a limit value for the amount of CO_2 per tonne asphalt produced. It is important to assure that these requirements are met, and no boundary are crossed to avoid penalties.

4.2. Current lignin market

Lignin as a by-product has traditionally been burned for energy production, but the research on producing pure lignin for other applications has been ongoing for a couple of decades. Respondent 3 explains how work has since the 1990's been done trying to separate lignin from black liquor. This process, called LignoBoost, has since been patented and is currently used by several mills. Respondent 3 further argues for how lignin should be viewed and classified.

> Firstly, I would like to underline that lignin is not a waste. I see it as a by-product, and that is important as waste is classified differently. You cannot get paid for waste (Respondent 3).

Respondent 8 further elaborates on this, arguing that it is not a challenge to package lignin as an essential material if one can show its benefits and by creating a brand such as "green-bitumen". This implies that how lignin is labelled, affects how it is perceived and utilized. When it was burned at the mills, it was seen as a waste product with only energy value.

The interest in producing lignin is increasing as more actors see its potential in a wide range of applications. This is thought to increase the producers' focus on creating efficient processes to be able to sell high purity lignin on the market.

Respondent 4, having done a Ph.D. on lignin valorisation and maintaining decades of experience within the field, emphasizes on its possibilities. Respondent 4 mentions areas and applications for which lignin is researched and seems to have great potential.

> A lot of my work is dedicated to lignin valorisation, as you know. For lignin, we see a lot of opportunities in different applications where you can use lignin's intrinsic properties like the polyphenol structure, binding properties, and antioxidant properties. So, therefore, there are many opportunities to use lignin. Moreover, research is devoted to making lignin applicable for these applications. And applications we are looking at range from bio asphalts, substitute of bitumen, roofing, plywood panels, high-pressure laminates, fibreboard, coatings, and antioxidant antimicrobial agent in polymer- and composite applications (Respondent 4).

The LignoCity initiative in the region of Värmland is an attempt to make it easier and get results faster when ideas are scaled up to reach a commercial market. The project is a collaboration made up of several companies and financiers, both private and state. Respondent 3 explains that the project offers services such as testbeds and different processes for the production of lignin for companies interested in trying their own ideas.

> What we are trying to do is opening up value chains that are utilizing lignin in some way. We also have financing available to help start-ups, those with ideas wishing to become start-ups, and existing

> companies. We try to inspire companies to use lignin and find possibilities where lignin could be used. We also try to educate and apply for financing for specific frameworks (Respondent 3)

4.3. Lignin-based asphalt

Lignin-based asphalt has been a discussed topic for decades now. It is during recent years the matter has raised more awareness amongst researchers and practitioners. Presently, several projects, including lignin-based asphalt roads, has been laid out to test the performance. One of these projects has been done in the Netherlands, where a lot of research on this matter has been conducted. Respondent 4 explains the positive results from the laid-out roads.

> The first demonstration on the road was laid in 2015. At that time, it was our first large project on lignin used in asphalt, and we tested several types of lignin in the lab, making small test blocks. We looked at the characteristics and performance of lignin. Moreover, we found out that it is possible to substitute 50% of bitumen by lignin without losing any strength or binding properties. That was very good results (Respondent 4).

As of today, 12 demonstration roads have been carried out in the Netherlands since 2015. Several road types, such as cycling roads and larger roads that carry a larger load, have been tested in these projects. Moreover, various lignin types, such as kraft lignin and hydrolysis lignin, have been tested to investigate which types are advantageous.

Since quality is a very crucial element for the asphalt industries, many questions the actual performance and durability of lignin-based asphalt. The asphalt industry has not changed its fundamental components for centuries, thus making a drastic change of any component leaves many actors sceptical if the same qualities remain. When questioning Respondent 4 with this concern, the argument follows was addressed.

> When you mix 50% lignin and 50% bitumen then we can keep the quality constant. Which means we can achieve the same strength values before and after emerging underwater compared to bitumen asphalt. Sometimes little bit different depending on type of lignin. But we can find the same binding properties (Respondent 4).

The Netherlands' roads have been monitored in various conditions and circumstances, for instance, different climates and load scenarios over five years. Regarding the performance and durability aspects, the result has also been positive thus far, according to Respondent 4.

> If you look at the performance of the asphalt five years later, it is laid there in very good condition. It is laid in the southwest part of Holland, near the coast. So a lot of sunshine and the track can be very nicely monitored as there is regular asphalt in that area and also rubber-based asphalt. Those different tracks are monitored by the asphalt company. The people knowledgeable in asphalt can view and review the performance every day. That track is on an industrial road, which means the road is used by trucks and cars during the weak, quite a heavy loading on the road (Respondent 4).

The journey for these 12 demonstration roads has been nothing but easy, Respondent 4 remarks. Going from lab testing to an actual demonstration site requires several intermediate steps. First and foremost, the testing needs to start on a very small scale, gradually increasing the block area. The first trial was on a scale of 10 cm^2 where lignin-based asphalt moisture resistance is tested. The block is placed underwater to analyse the strengths. Once the strength potential retains at least 80 %, the binding capacity is good enough for upscaling to larger blocks (Respondent 4).

Respondent 5 argues that the demonstration roads in the Netherlands are a positive aspect but not enough to convince Swedish actors to readjust their production. To achieve this, a Swedish test road is required to test it against local climate and conditions. It is further argued that the first test road should be a small project, such as a parking lot, as to get a foot in the door. Respondent 6 further upholds this need as they have produced demonstrations for other asphalt products in the Nordic climate.

Obstacles

The processing of lignin-based asphalt is however, different from the traditional one. The consistency and viscosity between the two binders are very distinct. Bitumen has a liquid texture at high temperatures. Meanwhile, lignin is initially in powder consistency, hence making the feeding process in asphalt mills different from the conventional. First trials in the Netherlands were mixed by hand but subsequently transferred to a more automatic system. Current asphalt industries, therefore, need to make some changes and adaptation into their

systems. When asked about this matter Respondent 4 was convinced there is a solution for this.

> They can use their current infrastructure and just have to adapt their current system to feed the powder in. Asphalt mills are also adding different additives to their asphalt. Lignin can be fed as such, as an additive. We now have two asphalt mills in the Netherlands that produce lignin-based asphalt on a regular basis, which means that they have several demonstration roads in the past years. We have seen that they can adjust their process for lignin. I am convinced that they can further develop and make it more automatic feeding (Respondent 4).

Respondent 5 emphasizes the need for a smooth introduction in the production processes to convince actors and make them comfortable. If the lignin material can be introduced to the process without requiring expensive machines and investments, then this is a great benefit and essential selling point, as argued by Respondent 5.

The issue about the performance of lignin is still a concern when speaking with some of the respondents. Respondent 2 explains that there is an uncertainty of how permanent lignin-based asphalt should be considered and that further research is needed.

> Bitumen, based on crude oil, is something that has been around for several years and the properties of bitumen are superior when currently compared to other alternatives (Respondent 2).

Respondent 8 mentions three factors as difficulties to overcome. These are tradition, cost, and uncertainty of quality. Tradition appears as actors can be used to doing business in a particular manner that has worked fine for some time and therefore acts rigidly towards change. Cost is the fear of investing resources without sufficient payback. Actors being uncertain of quality is particularly apparent in the asphalt industry as a new product will require extensive and long-term testing and evaluation. Respondent 5 reaffirms this view and points towards project-driven organizations striving to minimize risk and complications.

Potentials

Although lignin-based asphalt has shown it could achieve the same binding properties when combined with bitumen, there are still more research and

testing needed to be made. As of today, the projects in the Netherlands have only tested the top-layers of asphalt pavements. Respondent 4 explains however, that this matter is currently being addressed, and testings are on the way.

> So far, our projects have been used for top layers. But we have now granted two new projects in the Netherlands recently. The last project was granted 2 weeks ago. Those 2 projects we are going to look at recycling and different layers in the road. Middle and bottom layers also. We do not have a lot of experience with that yet (Respondent 4).

Nonetheless, Respondent 4 argues that there is still lots of potential for lignin. More research is under development, and Netherlands demonstrations have shown thus far there are possibilities in lignin as a potential substitute for part of the bitumen in asphalt. Collaboration with companies such as H4A in the Netherlands is one of the steps forward, showing that production could be achieved on a commercial scale. The company H4A, using two of their commercial mills, have successfully tested the production on a regular basis. By now, around 2 000 to 3 000 tons of lignin-based asphalt has been produced.

4.4. Sustainability

Sustainable and environmentally friendly production is a high priority amongst most industries. Companies evaluate their ability to improve aspects of their activities to lessen their impact on the environment. This focus, transforming into practical change, is relatively new in the asphalt industry as Respondent 1 explains how the process differed from today, only four years ago.

> All actors have, more or less, the same type of asphalt. We do have different solutions for how the aggregate is heated. We use bio-oil or pellets. Some mills use gas, natural gas, and some heat their aggregate using fossil fuels. The bio-oil used by PEAB is a residue from the food industry, which is certified by the [Swedish] energy agency and classified as carbon neutral. If you look back four years in time, the method of heating material in an asphalt mill was by burning fuel oil (Respondent 1).

Respondent 2 tells about how they in the 80s and 90s utilized long production runs to save fuel oil and lower the temperature. The lower temperatures also benefit working conditions as less asphalt fumes are generated. In the long run,

the effects are less energy usage and lower CO_2 emissions and thus an economic gain. It is further explained that there exists a natural interest in minimizing resource usage as it gives an economic benefit. Respondent 7 explains that NCC started producing their low-temperature asphalt twelve years ago as the beginning of their environmental focus. It is further explained that earlier measures were done purely for financial reasons. However, from that point, the focus successively changed by adapting systems to measure and procedures to reduce the environmental impact of products and production processes to meet market expectations.

The reuse of asphalt is an example of a sustainability measure that also benefits the company economically.

> The asphalt is reusable to 100%. The old aggregate and bitumen are taken advantage of by subtraction. If the granular material contains 4% binder [bitumen] than this amount is accounted for. That is where the big money lies, when you are able to exploit the old binder agent (Respondent 1).

It is mentioned by Respondent 1 that about 80% of PEAB asphalt mills have, to date, been converted to allow for usage of bio-oils. Respondent 1 explains that by converting the mills not to use fossil fuels, you have come a long way. After that, further improvements can be done on different parts of the production.

> Then, if you are to continue in the same path, paving machine, drum rollers, wheel loaders in the mills, electrification of the catchment, that is the next step. After that, the big culprit, all in all, is bitumen. Finding a replacement for it (Respondent 1).

Respondent 6 explains that there is an ever-increasing focus on environmental issues in their organization. Among others, the environmental department has been widened with specialists and new systems. It is further mentioned that the sustainability focus emphasizes three aspects, namely energy use, asphalt recyclability, and the formal aspect of measuring and systemizing information on environmental effects. Respondent 3 adds that responsible asphalt producers follow up on their CO_2 emissions impact and try to minimize that impact.

Respondent 2 further acknowledges that many measures can be implemented to lower CO_2 emissions. This can, for example, be by working productively, efficient use of machines, and efficiently transporting material.

4.4.1. Lignin as bitumen substitute

Replacing bitumen with an environmentally friendly binder is, as Respondent 1 mentioned, the next big step for sustainable asphalt. Lignin has shown great potential as a replacer, at least partially for now. Several aspects have been documented as being at least as good as bitumen. The core of this solution is enabling a more environmentally friendly product. For this, the environmental footprint needs to be investigated. Respondent 4 explains that one prominent and current field of study is the life-cycle assessment (LCA).

> It is still at the demonstration level because we need to find out what the environmental footprint is of the lignin-based asphalt. We have done two studies in the Netherlands, but it is quite difficult to obtain relevant data in the production of lignin to do a full LCA. Something we have to continue, we would like to have a full LCA on lignin-based asphalt (Respondent 4)

It is further explained that the conducted studies have shown that the lignin production phase is as crucial for its overall environmental impact. Respondent 4 continues to explain that paper- and pulp mills need to focus on lignin quality and not treat it as a waste.

> We have learned from both studies that the production stage of lignin is crucial and has a significant impact on the environmental footprint. The pulp mills have focused mainly on cellulose quality. They do not care much about lignin quality. You should have a good integration in your current pulp mill to have an environmentally friendly lignin product. And I think companies as Domtar and Stora Enso are doing that, they have a nice integration of energy and trying capacity within their pulping mill to also produce lignin under environmentally friendly conditions. That is really key in our studies (Respondent 4)

One crucial factor affecting both economic and sustainability aspects is the lifespan of the paved asphalt. As Respondent 1 and 2 explain, specific requirements exist on how much an asphalt can change over some time. Respondent 1 explains that all work they do comes with a two-year guarantee but further explains that other criteria need to be met regardless of the passing of the two years. An example of maximum acceptable rut, meaning wheel path depression, is given as 5 mm in five years. Respondent 2 further tells about the

importance of life-cycle cost (LCC) and having roads that last a long time, thus requiring less maintenance.

Respondent 6 explains that most roads are expected to last between 10-40 years, depending on traffic conditions where high vehicle volumes result in frequent maintenance needs. As earlier mentioned, the demonstration roads in the Netherlands have, at the longest, been evaluated for five years. Thus, more time is needed for better data and results. Though Respondent 4 is optimistic when explaining what the early results seem to indicate.

> We would like to have more data on the lifetime and durability of the road. We have only five years of experience, and we have a very good impression based on the feedback from the asphalt industry. That this lignin is very good, but we still have to prolong the testing phase to see if the lignin-based asphalt is behaving the same or maybe even better than the conventional asphalt (Respondent 4).

An essential factor impacting energy consumption for the asphalt product is the temperature the production process requires. This issue is raised by all respondents active in the industry and Respondent 4 explains how lignin-based asphalt enables reduction of the operating temperature by 30-40℃, down from the regular 170℃.

The usage of biomaterial in roads gives another important benefit raised by Respondent 4. While the extraction and production of bitumen contribute to CO_2 emissions, the usage of lignin by-product in roads has the opposite effect.

> Because you are not only substituting bitumen, you are replacing fossil resources, which could give some benefits, of course. And we are using lignin to store CO_2 into the roads for a long time. So also, there you save and will get some credit for storage of CO_2 and lower the carbon-footprint of your product (Respondent 4).

Respondent 8 mentions that products originating from trees intuitively appear as being good. It is also argued that new, environmentally friendly products often can perform better than the traditional ones and that these aspects should be highlighted. This could, for example, be simpler transportation and logistics.

Recyclability

A vital sustainability factor of asphalt, both for traditional asphalt and the potential lignin-based asphalt, is the degree to which it is reusable. Several

interviewees have mentioned this as a topical subject and an aspect that is under research for lignin-based asphalt.

Respondent 2 explains how the STA for some two and a half years ago cancelled restrictions in the regulations which limited the amount of reclaimed asphalt allowed in production of asphalt. The approach now is instead to set specific product requirements and criteria and allow for the manufacturer to decide the amount of reclaimed asphalt, while meeting the requirements for the asphalt mixture and final pavement. According to Respondent 2, this has led to great innovation in productions techniques and saving of natural resources, thus having a positive impact on CO_2 emissions.

Even though the asphalt is completely recyclable, it is not possible to entirely use recycled material in new paving's. The climate of a country affects, to a great extent, the requirements set for a road. The high usage of studded tires in Sweden compared to, for example, Germany, limits the percentage of recycled asphalt used in paving's.

> You are still expected to deliver a proper product, according to set requirements. So, it is difficult to put in more than 30% reused material, on a yearly basis. Looking at Germany, they have completely different requirements on the finished product where they use up to 70% recycled material (Respondent 1).

Respondent 2 emphasizes on the need to maintain a circular production where old asphalt is reused in new pavements. It is explained by Respondent 1 that current asphalt production contains a maximum of 25 % recycled asphalt. The reason being a greater amount of new asphalt being produced than old asphalt recycled and thus limiting the percentage possible.

Respondent 4 mentions that ongoing and new projects are planned to investigate, amongst other capabilities, the recyclability of lignin-based asphalt. The purpose being to study if the lignin-based asphalt is at least as reusable as bitumen-based asphalt.

4.5. Business market

For some time, the Swedish asphalt market has been unchanged with a similar product and the same three major manufacturers, NCC, PEAB, and Skanska. Even though several smaller actors exist on the market, these three are the dominant ones. Respondent 1 confirms that there are few new actors and high

competition on the market. The developments that can be noticed has mainly been during the last few years and concerns the asphalt production processes rather than the product itself. Respondent 1 further explains that all actors have the same product, more or less, but with some differences in how the asphalt is heated. Other than that, it is also mentioned that PEAB has their "EKO-asphalt" and NCC their "Green-asphalt" as a way of labelling a more environmentally friendly production process. When asked why there has not been much innovation in the industry, Respondent 1 explains.

> It is probably a matter of cost, quite sure of this. Other than that, it could surely be that the oil-producers are slowing down the innovation in this area. Because, what should they do with the bitumen if they cannot sell it to the asphalt producers? This is my personal opinion. (Respondent 1).

Respondent 3 tells that it could be the case where an established actor naturally tries to counteract a new, emerging one from taking market shares. This could be by lowering the price of the product. To the contrary, it is argued that society is changing its view as the processes from raw material to finished product is increasingly playing a significant role for consumers. Consumers value environmentally conscious companies and products as it becomes an impacting factor on purchase decisions.

Respondent 2 also tells about how there has been some inertia regarding development on more eco-friendly substitutes. It is also pointed out that the bureaucracy needs to be less to simplify the handling of reclaimed asphalt. There is currently a government referral to reduce bureaucracy and increase the use of waste in an efficient way. Respondent 6 mentions that sustainability is also about the economic aspect and that a country's tax policies should benefit sustainable products over less sustainable ones.

The buyers and consumers are separated on the asphalt market. The buyers in Sweden are mainly the state, municipalities, or private organizations whereas the consumers are everyday people in vehicles... Respondent 2 informs that asphalt purchases from the STA accounts for 35-40% of the total market. This can create difficulty as consumer awareness does not affect the demand for more eco-friendly asphalt as it does with other consumer products.

When Respondent 1 is asked if it is possible to market eco-friendly solutions to the consumers, it becomes clear that this is not a direct approach.

> When we converted the first asphalt mills to bio-fuel driven ones, there were some press releases and Marie Wetterstrand [Swedish green-party co-leader] was a speaker on stage. But I do not think it is of much interest for the multitude (Respondent 1).

Respondent 7 explains that it is possible to affect the buyers in terms of getting them to set environmental requirements. Respondent 6 further elaborates that they would like to inform the road-users of their efforts for sustainability but that most of their marketing work is directed towards municipalities and transport agencies in the different countries they operate. It is also stressed by Respondent 7 that it is difficult to be sure that environmental efforts pay off in the procurement process as methods of comparison are lacking.

One crucial feature lifted by Respondent 1, 6, and 7 is retaining a practice of informing the buyer about the improved environmental impact their product choice has had. Respondent 6 emphasizes that it is important, but difficult, to adequately market and inform customers as the information can be complicated. For example, professional public clients such as traffic agencies possess specialists who understand and request Environmental Product Declarations (EPD). Respondent 7 demonstrates a relatively simpler template that other clients, including private customers, can use to get a better overview of measures and product details.

Naturally, private buyers choose whatever product and supplier they prefer, and Respondent 2 regrets that some clients do not allow for reclaimed asphalt in procurement contracts. This is explained by a lack of confidence for the product to satisfy requirements. Respondent 2 further explains that this is unfortunate as no noticeable difference has been seen when using recycled material. Furthermore, the regulations and requirements put on producers are considered fool proof. Respondent 2 describes that all in all, there are three coexisting factors controlling development—namely, regulations, standardization, and industry collaboration.

Respondent 8 highlights the importance of the younger generation since their presence both as employees and consumers increases.

> There will now start new, young co-workers at the company, and they ask questions. New, young generations will start to consume products and services, and they ask questions. The younger

> generations have entirely different demands, making it easier to sell bio-based solutions (Respondent 8).

Value-points

Some fundamental factors play a significant role when substituting a well-established and working product. First and foremost, there needs to exist significant benefits. In this case, that is the environmental sustainability aspect, through reducing the use of fossil fuels. As previously mentioned by Respondent 4, bio-material usage can also be seen as storage of CO_2. Secondly, the substitute must be available in enough quantities to be able to satisfy demand. Respondent 4 explains that different kinds of lignin from different sources have been shown to be applicable for asphalt production.

> We used a lot of kraft-lignin because it is available in large quantities. We would like to open up the markets for bitumen substitution. For that, you need a lot of lignin for sure. We hope more and more pulping companies are eager to produce lignin for these kinds of applications… Now, more and more small companies are producing lignin at the pilot- and demonstration-scale and those companies would like to test their lignin in this application. It will give more possibilities to purchase lignin from different sources. And in this application, we can use different types of lignin (Respondent 4).

It is further mentioned that around 100 000 tons of kraft-lignin are at the moment available as a product. It is expected that this number will surge in the near future as paper- and pulp companies are searching for alternatives to burning their lignin, and the demand for lignin will go up. Lignin is also the only bio-based alternative to bitumen that is available in vast quantities. Further on, Respondent 4 argues that the availability of bitumen will change in the future.

> There is a trend that less bitumen will be produced in the future, and the quality of bitumen is also changing, which means it is more difficult to reach exactly the right properties of bitumen. And that will influence the price and availability. We expect that in the future, the bitumen price will go up, and when more lignin becomes available on a commercial scale, also the lignin price will go down (Respondent 4).

Asphalts are expected to last decades, and as most respondents mentioned, testing, and confirming its characteristics and lifespan is essential for it to be

implemented on a commercial scale. Respondent 4 explains that some improved characteristics have in the demonstrations been confirmed. These are also part of a patent for lignin-based asphalt.

> "It has been found that a lignin preparation with the specific characteristics according to the present disclosure provides for an improved asphalt strength, both under dry and wet conditions" (Landa & Gosselink 2019, pp. 2).

Respondent 6 and 7 acknowledge noise reduction and lower rolling resistance as important environmental aspects. Respondent 7 mentions that there is currently a great focus on reducing rolling resistance as this lowers vehicle energy consumption. It has also recently been noticed that the Danish state requests asphalts with lower rolling resistance.

It is further explained by Respondent 4 that other improvements such as noise reduction and lower rolling resistance have been noticed in the trails. Even though the demonstration roads have been evaluated for merely five years and Respondent 4 recognizes that data is still lacking, the early results are positive. Respondent 4 goes on arguing that the real BM for this lies within additional benefits and that it would be a mistake to only focus on current costs and price. Respondent 3 agrees, as earlier mentioned, that the small percentage of bitumen in asphalt should be taken into consideration when looking at the price difference.

When introducing a new product or idea, a challenge can be to persuade the larger actors in the industry. Respondent 4 explains that small- and medium-sized enterprises (SME) are often more eager and flexible when concerning innovation. The developments in the Netherlands have shown that this is a way into the market as the SME projects caught the attention of the larger actors who are now seeking collaboration. Respondent 5 reaffirms the importance of finding a collaboration partner that is eager to innovate—preferably a smaller firm as they can be more flexible and act cooperatively.

Both Respondent 1 and 3 argue that companies would like to be proactive and ahead in development to be prepared for changes in environmental laws and regulations.

> We need to work together, and we need to create projects together…
> It is only when you work together that you start to know and learn

from each other properly. I believe projects like these are essential (Respondent 3).

4.5.1. Procurement procedure

Different from private purchases, the purchase process for state and municipality is strictly regulated. Public buyers need to abide by public procurement laws and rules when choosing which actor to hire and product to buy. The public procurement process consists of several aspects and demands that are to be met by any offers given by actors. When asked about the purchase process and how the state agency chooses an actor, Respondent 2 explains.

> We abide by the Public Procurement Act, and other than that, there are specifications based on European standards and certifications that are to be met… Today the actor is chosen by the lowest cost, in combination with all necessary requirements being satisfied. Most actors succeed in meeting them, and no tenderers fail at this today. Other than that, it is the lowest cost (Respondent 2).

Respondent 1, 6, and 7 agrees that it mostly is the lowest bid that wins. It is further mentioned by Respondent 2 that if an actor offers a longer lifespan for their product, but at a higher price, the improved lifespan could be taken into consideration. It is, however, acknowledged that no sufficient model is currently available for this purpose during procurement.

When asked if tenderers receive any environmental bonuses for offering environmentally friendly solutions, Respondent 2 continues explaining that they are looking into models for such mechanisms, but no decision has yet been made. Work is undergoing to examine if an EPD can be used as a basis for bonuses. Respondent 2 further explains that they are not able to ask for a certain eco-friendly product specifically but can instead utilize a bonus system. For example, this could be done by giving bonus in the procurement process to actors that can confirm a lowering of CO_2 emissions. Respondent 4 and 8 agrees and mentions a similar solution. Respondent 6 and 7 mentions that environmental work has given some benefits in the buying processes over the last five years.

Respondent 3, speaking on consumer and buyer awareness in the context of public procurement, gives a perspective.

> The society, municipalities and public authorities try to create a greener image. So, of course, if a eco-friendlier asphalt is available, we could expect that they would prefer this alternative where it is suitable even though the price tag is higher. However, it will be crucial to communicate the complete picture. Maybe the bitumen replacements become somewhat more expensive, but how much does the price of the total product, which consists of a small percentage bitumen, go up? The final cost is not as affected (Respondent 3).

Respondent 8 also emphasizes that organizations need to improve their image and appear as environmentally conscious and "green" corporations.

> Many organizations want to show that they operate in a conscious and green manner, which gives extra cred. I have noticed that extra costs for this cred are now accepted, unlike just some years ago (Respondent 8).

Even though Respondent 2 emphasizes that the current system and regulations are working well, some issues are highlighted. It sometimes happens that an artificial, low-cost bid is made for the purpose of winning a contract. This can lead to tedious processes where the two parts fight about the contents of the contract. Some actors looking to reach into a local market can offer artificially low bids and subsidize it with earnings from other projects.

Respondent 2 explains that there is great potential for solving these flaws.

> I believe that in the long run when we can easier take LCCs into consideration, we will have a greater ability to choose the tenderer with the best solution from the viewpoint of sustainability. I believe that we generally have a good lifespan on asphalt today… Failures do occur, and then it is up to us, as public purchasers, to follow up on the delivery. If the work is not done properly, you could be required to redo the job or pay fines (Respondent 2).

Respondent 4 highlights that certification is an essential step towards commercialization. It is further argued that public procurements should more specifically ask for lignin-based asphalt, and Respondent 4 further explains that there are examples of this. Some procurements in the Netherlands have asked for bio-based asphalts. However, this has yet been in the framework of demonstration.

Respondent 2 adds that the regulations do allow for alternative materials within the requirements, but they cannot specifically ask for lignin-based asphalt due to lack of data on its lifespan. Respondent 7 points out that an issue is the 300-something Swedish municipalities having different procurement processes with different competencies, demands, and focus.

5. Discussion

This chapter connects the theory and the results as to generate conclusions in the final chapter.

5.1. Lignin-based asphalt

Respondent 4 stresses the necessity of sufficient quantities of lignin being available as to replace the vast amounts of bitumen. The research shows that it to date, globally, is 50-70 million tonnes of lignin per year available, of which only 2 % is sold for higher-value applications (Bajwa et al. 2019; Jiang et al. 2020). This affirms that the focus needs to be on the aspect of demand for lignin-based applications. The supply of lignin on the market already has a great ability to increase. With an increasing demand for lignin-based applications and thereby pure lignin, the two-percentage of sold lignin will go up. It has already been noted that several smaller lignin producers are starting to build up production (Respondent 4).

Respondent 3 contends the view of lignin being a waste, and this is essential for the future development of its business case. As predictions imply, the lignin production is expected to reach some 225 million tonnes per year worldwide (Bajwa et al. 2019; Jiang et al. 2020). Furthermore, work in the EU strives to create trustworthy markets for 'waste' materials (European Commission 2015). This, with the increasing demand for lignin-based applications, will create an entirely new market. This new market will, in turn, require that all actors, suppliers, buyers, and consumers view lignin as a valuable raw-material and product fulfilling a purpose, rather than seeing it as a leftover. It is also, as respondent 8 suggests, advantageous to change the view on lignin by stressing its benefits and creating brands for different applications. Further on, paper- and pulp mills are looking for ways of extending their product portfolio and thereby lignin must, and surely will become an essential product for them. Production processes should be modified to produce higher quality and purity lignin while minimizing the environmental impact.

Even though Strassberger et al. (2014) argue that the development and valorisation of lignin remain stagnant, respondent 4 explains to the contrary, with great optimism, that much of lignin characteristics have shown high potential and patents on lignin-based applications already exist. Extensive research on a wide range of applications is ongoing.

Asphalt is a product expected to last decades with sustained quality, which makes the introduction of a substitute complicated. Public procurements cannot

usually ask for an asphalt type whose characteristics and quality has not sufficiently been proven. Consequently, the producers lack incentives to develop a sustainable alternative as they cannot be sure that the product will sell, and the investment repay itself. A possible solution for this could, as mentioned, be that public buyers, more extensively, utilize procurements within the framework of demonstration or innovation. This is also the case in many projects, as Respondent 4 explains.

The experience and results obtained from the demonstration roads in the Netherlands indicate several benefits, and some data is already available. It is recognized that more time and further testing is required, but the progress has already led many actors to show interest and start projects. For it to be applicable in the Swedish market, Swedish actors' extensive research and testing are essential. This is mainly because of the Swedish climate and road requirements are different.

The Netherlands' experience also implies that SMEs are easier to convince and more eager to start projects. By doing this, you allow the product to get a foothold in the market and thus attracting the major actors. This is also a way to overcome the problem of companies neglecting sustainable business cases, as explained by Schaltegger et al. (2012).

5.2. Sustainability

It is evident from the result that there needs to be changed in our consumption and production for society to become more sustainable. In Sweden, the public sectors account for a large percentage of the total asphalt consumption (Respondent 1; Respondent 2). The implementation of GPP could potentially guide production trends, thus stimulate, and encourage eco-innovations (Testa et al. 2014). One of these eco-innovations can be lignin-based asphalt to substitute a large portion of fossil-based bitumen. Partial lignin substitution for bitumen has been prominent in performance, although its overall LCC is still under research and development (Respondent 4). Consequently, government and politicians might be hesitant to invest in these types of sustainable innovations, favouring thus the traditional short-term benefits over the long-term. As Respondent 2 mentioned, evaluating the potential environmental benefits, as well as LCCs, requires a considerable amount of time, therefore making it difficult for new products to enter a market. Traditional asphalt has not made a radical change for centuries as it has been considered to have better performance over substitutes. However, with bitumen quantity gradually

decreasing along with deteriorated quality (Respondent 4), alternatives such as lignin, are being considered.

Most benefits regarding sustainability tend to be realized in the long term. Hence many entities might not see these potentials and have no interest in investing in sustainable products or eco-innovations. This phenomenon is observed by Schaltegger et al. (2012) as a result of BMs that limit flexibility and lack of integration of strategy formation. It highlights the need for newer, modern models in which the social, environmental, and economic aspects are integrated.

The improvements and developments of the asphalt production process previously done are, as Stubbs and Cocklin (2008) explained, examples of the neoclassical theory as these have been done for economic gain. Another reason for developments that have been done is to ensure that procurement criteria are fulfilled, and contracts can be won. But as Schaltegger et al. (2012) argues, it can be beneficial to make voluntary efforts for sustainability.

The recycling of asphalt has increased over the last few years as restrictions have been eased. This is also due to the companies being able to save money through the reuse of old bitumen, as Respondent 1 argues. Recyclability is highly connected to the concept of a CE. Nevertheless, as more new asphalt is produced than recycled, this loop is not ideal. By utilizing lignin instead of bitumen, a CE can be achieved to a higher degree. Further on, as Respondent 4 mentions, the use of biomaterial in asphalt enables storage of carbon, which can be seen as subtraction of CO_2 emissions. This will give benefits such as environmental bonuses or credits in procurement processes.

Respondent 4 emphasizes on the necessity to look at other value-creating factors and not solely the price. Potential benefits such as longer lifespan and lesser maintenance need together with proven benefits such as noise reduction, and less rolling resistance are significant value points to take into consideration. Noise reduction and lowering of rolling resistance are, as respondent 6 and 7 argues, relevant factors and demand for this has been noticed. It is also the case, as Respondent 8 tells, that environmentally friendly solutions often can exceed the traditional ones. Replacing bitumen with lignin also decreases the need to transport fossil fuels from distance locations as lignin is vastly available locally, in Sweden.

Being a conscious company by having a sustainable product and production will also bring meaningful benefits as the actors' employees are seen as influential

stakeholders. The younger generations entering the labour- and consumer market and having new, differing values will also increase demands and expectations on corporations. This is argued by Bocken et al. (2013), Hörisch et al. (2014), and Respondent 8.

5.3. Business market

An essential factor in long-term business is trust. Buyers and consumers need to trust a product or supplier for it to succeed. As it is mentioned by Respondent 2, there exists an issue with some buyers rejecting the use of recycled asphalt material in their orders. Respondent 2 further maintains the importance of standardisation which is in line with the European commission's plan for the development of standards for recycled materials. Ensuring producers on the limited investments and risk required for the implementation of lignin-based asphalt is also crucial as respondents 5 and 8 mention risk and investments as hurdles for new solutions.

The dynamic of the asphalt market is, as Respondent 1 explains, a state of high competition with few dominant actors, and also with an expensive and high quantity, long-term product where each order is worth many millions. This, together with its history of passive innovation, requires cooperation on a larger scale, consisting of producers, buyers, and researchers. This is strongly related to Stubbs and Cocklins (2008) view on the need for inter-organizational cooperation, and as Respondent 3 emphasizes the need for joint projects.

Although work in the form of collaborations and by joining efforts lacks in Sweden, the LignoCity project is an excellent example of possibilities. With many partners from different areas of society and several funding sources, this project shows that the potential is there. Other than that, policymakers must play an active role by minimizing bureaucracy and acting proactively, by implementing policies for sustainability, and reactively, by observing potential sustainable solutions and lowering the barriers for them. It is also of great essence that tax-policies reflect sustainability by favouring sustainable solutions over non-sustainable ones, as argued by Respondent 6.

As there lies a great value in having a good reputation and public appearance, companies strive to enhance this by creating a green corporate image, as stressed by Schaltegger et al. (2012). In the same manner, municipalities would like to be seen as environmentally conscious, as Respondent 3 and 8 argues. Therefore, it is of the essence to recognize and address this value in lignin-based asphalt.

Trying to reach the general public through media and other channels could also be beneficial as they have a substantial impact on public policymakers and thus resources.

Most respondents agreed that there are many challenges to introducing a new sustainable product into a business market. As sustainability has become a fundamental global concern (UN n.d.), many have recognized the striving for sustainability. The obtained results point out that there need to be changes within policies, government, and organisations. As highlighted by Sourani & Sohail (2011) these problems occur at all levels in an organisation, and holistic approaches should be established for changes to occur. Achieving sustainability requires changes i.e. new methods, activities, and new ways of thinking (Sourani & Sohail 2011). This argument is also supported by Respondent 4, stating that in order to recognize changes markets, specifications and expectations need to be clearly understood. Going towards a CE is one approach to make these changes. By increasing recyclability, reducing fossil fuel, and using natural green resources allows for a long-term cyclical model.

Many measures have been implemented to increase asphalt recycling and substitute traditional fossil-based fuels, such as bio-oil for heating the asphalt (Respondent 1; Respondent 6; Respondent 7). Acknowledging environmental concerns and increasing research and development is the next step forward for eco-innovations such as lignin-based asphalt (Respondent 4). Establishing a sustainable asphalt market is about attaining a balance between the environmental, economic, and social aspects, in accordance with the TBL model. Therefore, these aspects need to be integrated with costs and benefits, for full optimization.

Procurement

The public purchases, accounting for most of the market, makes the procurement process a crucial aspect to consider when attempting to introduce a new product to the asphalt market. It is understood that the STA is continuously working to involve environmental aspects to a higher degree in their purchases. Even though the agency cannot specifically ask for a specific product, they could utilize systems such as credits or EPDs to force producers to find more eco-friendly solutions. Both the European Commission (2015) and scholars argue for the implementation of GPP, and potential for improvements of Swedish procedure is identified by Bratt et al. (2013).

Creating uniform procurement procedures with similar requirements, criteria, and competencies throughout the Swedish municipalities would create more transparent and efficient frameworks for the actors. This could be done in collaboration with the STA.

6. Conclusion

This chapter will present the conclusions and key points and will respond to the aim of the study. The research questions act as a basis for the structure. In the last part, contributions of the study and suggestions for future research are given.

This research has been investigating the Swedish asphalt market in line with public procurement and business dimensions. The purpose of this master's thesis is to give a better understanding of lignin-based asphalt and investigate how it can be introduced to the Swedish market. This final chapter presents conclusions based on theoretical and empirical findings. The research questions serve as a guide to reach the study's aim and will be answered in this concluding part.

RQ1: What is the current technical- and market situation of asphalt?

The asphalt production processes, and its market has, historically, for the most part, been unchanged. The product is consisting of aggregate, bitumen as a binder, and other additives. In recent years, the process has undergone some development in the form of conversion of mills to make them more eco-friendly by using biofuels for heating. One substantial improvement is the increased use of recycled asphalt in production that has been enabled as a result of eased restrictions. 100 % of all asphalt is recyclable, and new asphalts contain 25-30 % recycled material. The producers are free to decide how much recycled material to use but are bound to requirements and regulation. Other improvements are made to surrounding factors such as machines and tools.

The binder in asphalt, bitumen, is produced from petroleum and accounts for 5-7 % of asphalt content. Bitumen is found to account for a significant portion of asphalts carbon footprint and an obstacle to the development of eco-friendly asphalt. Although other substitutions, such as rubber, have been examined, there is no sufficient alternative for bitumen. The potential bitumen alternative needs to be both environmentally sustainable and available in vast amounts to satisfy demand.

For a long time, the market has been dominated by the three largest producers, NCC, PEAB, and Skanska. Other than that, several smaller actors are operating in Sweden. The market is characterized by small margins and a high level of competition. Buyers of asphalt comprise the STA, which accounts for 35-40 % of the market, municipalities, and private clients.

The purchase process differs whether it is a private or public client. Public buyers are by law required to employ public procurement procedures. These procedures are regulated by law, and the procurement documents contain requirements based on policies and regulations. Further on, European standards and CE-markings are used for the asphalt contents. These standards are revised every five years.

RQ2: How can an environmentally sustainable alternative for asphalt be introduced to the Swedish market?

Lignin-based asphalt has been on the agenda for some years, and the Netherlands is thought to be at the forefront of development. Learning from the Dutch experience is the first step in introducing the concept in Sweden. The experience they have and the data that is already available should be thoroughly examined. Assembling a delegation of people from asphalt companies, state and municipalities, policymakers, and researches for a study trip to the Netherlands is recommended.

It is necessary for the Swedish actors, including buyers, producers, and researchers, to start cooperation through projects. These large-scale projects could be coordinated through institutions like RISE and their LignoCity project. In the framework of demonstration and innovation, funding through state actors such as the STA is also practical.

The transport administration should, other than that, intensify its efforts in establishing standards and classifications for by-products such as lignin. This is in line with the European Commission's (2015) plan. Work, in the Swedish agency, is currently ongoing as to find models through which environmentally sustainable solutions are credited in procurement processes, and the lowest bidder is not necessarily the winner. This is of great essence.

When facing a lack of interest from the dominant actors on the Swedish market, the focus should switch to SMEs as these have proven to be more flexible and eager to start projects in the Netherlands.

It is also essential to change the view of lignin by-product from waste to valuable raw material. Creating brands for lignin-applications as an example “green-bitumen” could also simplify this change of view. Awareness of the future of bitumen must also be spread. This includes the unstable price of oil and the probable decrease in availability and quality.

Generally, it is also necessary to recognize the full range of benefits that comes with the use of lignin, and focus must not be at current costs as this will predictably improve. Barriers to the product's implementation need to be addressed to allow it to get a foothold in the market. The benefits and barriers found by this study are presented below.

What are the main benefits of lignin-based asphalt?

- Environmentally sustainable: The most crucial benefit of lignin is that it is a renewable raw material. Opposite to bitumen, which is produced from petroleum. This aspect further enables the implementation of a CE and TBL. It also allows companies, the state, and municipalities to better their reputation and image.

- *Price and availability*: Lignin exists in large quantities, and its availability will increase substantially in the near future. This is essential for it to become a substitution to bitumen. The price of lignin is already near that of bitumen but is thought to become much lower, as explained in this study, while bitumen will become scarcer.

- *Lower temperature*: The use of lignin in asphalt production has proved to enable a lower operating temperature when producing the asphalt. This saves energy, emissions and allows for a cleaner working condition.

- *Infrastructure and systems*: The tests in the Netherlands have shown that manufacturers can, to a high degree, utilize their current systems and processes. Further development in this area will allow for more automatic feeding processes, but it is not necessary for the early stages as the lignin can be added as an additive.

- *Carbon sequestration*: Although an aspect of eco-friendliness, the storage of CO_2 in asphalts trough lignin is a particularly important feature and should be highlighted as such. This enables producers to claim negative CO_2 emissions is essential for the climate.

- *Bonuses and credits*: As public buyers work to better address sustainability in their purchase processes, using the renewable lignin will enable producers to comply with requirements. In future models, it will give companies environmental bonuses and credits in the procurement process.

- *Partially proved*: Lignin-based asphalt has already shown positive results, and many of its characteristics and qualities have been proven. Data in the form of patents and studies are available from the tests in the Netherlands.

- *Potential benefits*: Other benefits currently studied and early results point to the improvement of the asphalt lifespan and reduced maintenance needs, which have a positive effect on the environment and economy.

What are the barriers to introducing a new sustainable alternative to asphalt in the Swedish market?

The asphalt market is a rigid market where developments rarely occur. Both the product and the actors are relatively reluctant to change. The development in the Netherlands has come relatively far and passed initial technical- and business hurdles, and much can be learned from their progress.

- *Long-term testing*: Even though more than five years of data is available from the Netherlands, it is necessary to conduct tests in Sweden. This due to different climate, requirements, and regulations. Demonstration roads should be produced and studied over at least a decade.

- *Product confirmation*: Data and results are still lacking in some areas as to be able to confirm lignin as a sufficient substitute. More extensive research is necessary.

- *Passive producers*: Producers are not to a satisfactory degree active in developing an alternative for bitumen. This is partly due to them not being sure the long-term investment and trails will pay off.

- *Passive buyers*: Although public buyers claim to aim for sustainability, this development in their purchase processes is rather slow. Public buyers need to revise their procurement processes to put greater weight on sustainability factors.

- *Policies and requirements*: In connection with public procurement, laws, and regulation is not in line with current needs. Bureaucracy is, therefore, slowing down development. Tax-policies should also better benefit the usage of lignin over bitumen.

- *Standards and certifications*: For lignin to be accepted, trusted, and implemented, standards and certifications must be utilized. A market for by-products and waste is the goal, as outlined in the European Commission (2015) where the need for standards is recognized.

- *Public awareness*: As the buyer and consumer are separate entities in the asphalt industry, the greater population lack awareness of the issue and can, therefore, not demand a sustainable asphalt as they can with other products.

How can public procurements better address the need for a sustainable asphalt alternative?

Current public procurement on asphalt construction favours price over other factors. As value for money is not always from the lowest buying price, other considerations such as quality, LCA, and environmental impact should be taken into consideration for an optimal combination. The public sector accounts for a large portion of the total asphalt consumption in Sweden, and this high

purchasing power could alter trends and orient demand for sustainable products. To make changes and develop alternative products, risks are certainly inevitable. It can be deemed that public procurers are reluctant to take these risks to avoid uncertainty, which might have delayed new eco-innovations from happening. In order to make changes and stimulate eco-innovations, more awareness and progress on GPP practices are required. These practices include a long-term way of thinking, hence changing the mindset from a "purchase-cost" to a "life-cycle-cost."

Uniform procurement procedures with similar environmental criteria and competencies should be developed and implemented throughout the municipalities.

6.1. Contribution and future research

This study's contributions are mainly practical as it can be used to better understand the current market and technical situation of asphalt and developments in the area. The findings could also work as a basis for a sustainable business model in the asphalt industry. The results can be utilized as a roadmap for the introduction of lignin-based asphalt to the Swedish market. Both researchers and actors striving to introduce lignin-based asphalt could benefit from the given overview as their focus and resources can better be aimed at critical aspects and areas

Due to time limitations and the effects followed by the Covid-19 pandemic, the scope of the research was narrowed down. There were also some difficulties with reaching several interesting persons to interview, such as bitumen producers, thus limiting perspectives to some degree.

Future research could conduct full LCAs for lignin-based asphalt to study its long-term effect and its environmental footprint. Research could also focus on reusing industrial residue and by-products in a more general manner to allow for greater generalization of findings. Other subjects could be in the area of similar biopolymers that could be a potential substitute for bitumen. Further knowledge is needed on different types of lignin and its overall impact on asphalt construction. Moreover, lignin-based asphalt pavements need to be tested on the Swedish environment to study if it can withstand the Swedish climate along with studded tires.

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Appendices

Appendix A

Interview guide

Part 1 - Introductory Questions

1. What role do you have in your work and what are your main tasks?
2. How long have you been in that role?
3. Have you had other roles related to lignin, asphalt, sustainability or business development?
4. What role does your organization / company have in the chain?

Part 2 - Technical Issues

5. How is the process current construction asphalt production / How is the public procurement process of asphalt?
6. Who orders roads?
7. How is it determined which actor gets the assignment?
8. What kind of asphalt do you manufacture?
9. How much can be recycled?
10. How does the technical aspect of asphalt look like at present?
    - Development over time?
    - Is there a lot of research currently going on?
    - What types of development trends do you see?
    - What qualities and qualities are sought after?
    - Is there a difference between different actors' asphalt?
    - What are the current Problems / Any Opportunities?
    - Own experience?

Part 3 - Finance aspect

11. What does the business situation for asphalt look like?
    - What trends do you see?
    - Demand of any specific asphalt?
12. How is the current situation compared to before?
    - Any price variations?
    - How has the availability of bitumen changed/affect your organisation?
    - Any current Problems / Any opportunities?
    - Own experience?

Part 4 - Environmental aspect

13. Do you see that there is a need for change in the industry and the market?
    - How?
    - Is there a need / demand for environmentally friendly alternatives?
14. Why has there not been so much innovation in this area?
15. What are the obstacles to an environmentally friendly alternative being developed and used?
    - Technical / business?
    - Business Model?

- Authorities, requirements, regulations and laws?
- What opportunities / Risks do you see?

16. How can an environmentally friendly alternative be introduced in the market?
    - Is there an interest from today's actors?
    - Is change and pressure required from authorities and regulations?
17. What could be "selling points" for environmentally friendly asphalt?
18. Is there a need for a sustainable business model for asphalt and how do you think this might look?

Part 5 – Lignin questions

19. Have you considered implementing lignin-based asphalt?
    - If so, what benefits do you see in that?
    - If no, why not?
20. Other environmentally friendly alternatives?
21. What opportunities do you see with lignin-based asphalt?
22. Do you think lignin is the most suitable substitute in asphalt?
    - What other environmentally friendly substitutes are there?
23. What factors do you consider important to transition from bitumen to lignin-based asphalt?
    - Any risks?
24. Do you think using lignin-based asphalt would be economically sustainable?

Part 6 - Completion

25. Do you have any questions for us? Something we missed or something you want to add?