Barriers and Enablers to Building Circular Supply Chains for Biobased Building Materials: A Multi-Stakeholder Analysis

Master's Thesis

Master of Science, Sustainable Entrepreneurship

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June 5th, 2024

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Abstract

The construction industry accounts for 39% of global CO2 emissions, making it the third most polluting industry worldwide. Biobased building materials (BBMs) could play an important role in reducing the environmental impact of the construction industry. This study investigates the barriers and enablers in establishing circular supply chains (CSCs) for BBMs, focusing on Flax and Miscanthus in the Dutch province of Friesland. Using a qualitative research approach and grounded theory for data analysis, this research investigates the barriers and enablers of key stakeholders involved in the transition towards CSCs. Semi-structured interviews were conducted to gather insights into stakeholder needs and barriers. The findings reveal critical barriers, such as regulatory hurdles, lack of demand, and financial and economic barriers, as well as enablers like frontrunners and pilot projects, and closer collaboration amongst stakeholders. By identifying these factors, the study aims to provide actionable strategies to facilitate the adoption of CSCs for BBMs, contributing to the broader goal of reducing the environmental impact of the construction industry.

Key words: Circular supply chains, Biobased building materials, Transition, Barriers, Enablers, Flax, Miscanthus

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1. Introduction

The construction sector is the third most polluting industry globally, accounting for around 39% of all energy-related CO2 emissions worldwide (IEA, 2022). A significant amount of the consumed energy is related to the extraction of raw materials, material production, high temperature treatment, transportation, and waste disposal (Huang et al., 2018). It is estimated that despite having residual value, more than 75% of all construction and demolition waste is neither being reused nor recycled (Purchase et al., 2022). With a projected annual growth rate of 5.7%, the construction sector is on track to further increase its CO2 emissions, consumption of raw materials, and production of waste (Onat & Kucukvar, 2020). As part of a closed-loop oriented economy, biobased building materials (BBMs) can play a crucial role in successfully reducing the environmental impact of the construction industry (Bourbia et al., 2023).

BBMs primarily contain a substance or substances derived from existing matter, such as biomass, and can either be naturally occurring or the result of advancements utilising biomass (Yadav & Agarwal, 2021). BBMs can be made from a variety of crops, such as hemp, miscanthus or flax. Throughout their lifespan, these crops capture and bind large amounts of CO2, making it possible for BBMs to be carbon negative building materials (Yadav & Saini, 2022). Additionally, BBMs also show great potential regarding reusability and recyclability (Yadav & Agarwal, 2021). Recent years have witnessed significant advancements in the field of BBMs, with the introduction of numerous novel biobased alternatives, reflecting a dynamic landscape of innovation and diversification in sustainable construction materials (Le et al., 2023; Yang et al., 2024). Due to the environmental benefits and promising end of life characteristics, BBMs are often associated with the concept of the circular economy (CE) (Caldas et al., 2021; Dahiya et al., 2020). Despite their many advantages, BBMs are yet to be adopted on a larger

scale. Earlier studies have identified that barriers to upscaling BBMs can be related to, e.g., technological, financial or knowledge related issues (Dams et al., 2023). Similarly, earlier studies focussing on the barriers of transitioning towards circular supply chains (CSCs) related to financial and operational risks, lack of incentives and policies or product complications (Roy et al., 2022). However, what remains unexplored are the specific barriers faced by each stakeholder in the supply chain and the potential solutions to overcome these obstacles.

This multi-stakeholder study aims to identify barriers and enablers for stakeholders to transition towards CSCs for BBMs. We examine stakeholder needs and barriers in establishing circular supply chains for Flax and Miscanthus in the Dutch province of Friesland. To cover both the aspect of needs and barriers, we address the following two research questions: (1) "What are the barriers to build circular supply chains for biobased building materials?", and (2) "What is needed to overcome barriers to building circular supply chains for biobased building materials?".

In the following section, we provide an overview of topics relevant to this research and explore existing literature on CSCs, circular supply chain management (CSCM), as well as BBMs.

2. Literature review

2.1. Circular Economy (CE)

As part of ongoing attempts to reduce global CO2 emissions, the concept of the CE has become a vital principle for environmental and industrial policies in China, the USA, the European Union, as well as many other countries and local governments (Corvellec et al., 2022; De Melo et al., 2022; Domenech & Bahn-Walkowiak, 2019). The concept of a Circular Economy (CE), based on the principles of refuse, reduce, re-use, and recycle, serves as an alternative to the

traditional linear economic model (Geng et al., 2019; Morseletto, 2020b). A CE can be defined as: “an industrial economy that is restorative or regenerative by intention and design” (Ellen MacArthur Foundation, 2013). Geissdoerfer et al. (2017) define the CE as 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.”. Creating a regenerative economic system that keeps resources in a usage-loop for as long as possible and minimises the loss of energy, is at the core of CE (Morseletto, 2020a). To achieve that, products in a CE need to be designed in ways in which they can be easily repaired, re-purposed, or recycled while components and materials need to maintain a maximum residual value throughout their lifespan (Bocken et al., 2016; Reuter et al., 2019).

BBMs, being derived from renewable biological sources, align perfectly with these principles. By utilising materials such as Miscanthus and flax, the construction industry can significantly reduce its carbon footprint and reliance on non-renewable resources (Barnak-Hunet et al., 2017; Ntimugura et al., 2021). These biobased materials are not only sustainable and biodegradable but also promote a closed-loop system where resources are continuously cycled back into use (Dahiya et al., 2020). Furthermore, the cultivation of these crops supports agricultural sustainability and biodiversity, enhancing the overall environmental benefits of adopting a circular economy approach in construction (Göswein et al., 2022). Over the years, sub-disciplines of CE literature have emerged that provide a more focused lens on particular circular economy principles, such as supply chains, allowing for a more comprehensive perspective on problems and opportunities of components within the CE.

2.2. Circular supply chains (CSCs) and Circular supply chain management (CSCM)

CSCs and CSCM are considered concepts closely related to or derived from CE. Both CSCs and CSCM are crucial for extending material life-cycles, narrowing supply chains, and reducing the overall environmental impact of an industry (Farooque et al., 2019; Lahane et al., 2020; Masi et al., 2017; Nasir et al., 2017). While a wide range of terms describe sustainable supply chains and sustainable supply chain management, there is no single agreed-upon definition. One description of CSCs promotes the transformation from a linear to a circular model of product flow (González-Sánchez et al., 2020). Another definition of CSCM highlights the configuration and coordination of the supply chain to close, narrow, slow, intensify, and dematerialize resource loops (Geissdoerfer et al., 2018).

The existing literature on CSCs and CSCM primarily focuses on the potential advantages these circular approaches have over conventional, linear approaches. Research has identified four main dimensions supporting the development of CSCs: greater intensity in supply chain relationships, adaptation of logistics and organisational structures, disruptive and smart technologies, and a functioning environment (González-Sánchez et al., 2020). A framework aiming to understand the underlying structure and complexities of CSCs was developed based on four building blocks: systemic approach, main drivers, levels of decision making, and mechanisms to manage full loop closure (Amir et al., 2023). Potential challenges in transitioning from linear to circular supply chains include financial and operational risks, lack of incentives and policies, product/technology innovation, and issues with information sharing, transparency, and visibility (Roy et al., 2022). Conducting a review of CSCM literature, researchers identified 20 specific barriers that manufacturing companies face in their transition toward CSCs (Roy et al., 2022). CSCs and CSCM are crucial to understanding the supply chain dynamics and the

potential barriers and opportunities that stakeholders of BBMs can face.

2.3. Biobased Building Materials (BBMs)

Although perceived by many as new technologies, BBMs have proven to be sophisticated building materials for hundreds of years (Liu et al., 2017). Due to the large spectrum of materials, BBMs can be used for almost all areas of construction. Yadav & Agarwal (2021) created an overview of current and developing types of BBMs and their characteristics. 'Common' BBMs that are already being used for, e.g., structural components, flooring, roofing or isolation are Timber, Flax, Hemp, Straw, Reed or Flax (Yadav & Agarwal, 2021). Hempcrete, a biobased alternative to concrete made out of hemp-shivs and a lime-based binder, for example, is one of the many BBMs that has the potential to bind large amounts of CO2 throughout its life, while simultaneously showing great characteristics regarding fire resistance, energy efficiency or mould (Yadav & Saini, 2022). Flax fibres can be utilised in the production of biocomposites for various applications in construction, offering excellent strength and durability while reducing reliance on non-biobased materials (Barnat-Hunek et al., 2017). Similarly, Miscanthus, a high-yielding and resilient grass, can be processed into BBMs for construction applications, such as insulation boards or composite panels, providing sustainable alternatives with great thermal and acoustic properties compared to conventional materials (Ntimugura et al., 2021). Compared to conventional building materials, BBMs are associated with a significantly lower environmental impact (Keena et al., 2022; Khoshnava et al., 2020; Yadav & Saini, 2022; Zieger et al., 2020). Governments like that of the Netherlands are starting to take actions regarding a transition towards BBMs.

In November 2023, The Dutch government published their 'National Approach Biobased

Building' (NABB), a position paper that outlines the country's ambitions to use more BBMs in future construction projects and setting up a market for BBMs (Rijksoverheid, 2023). The NABB states the ambition that by 2030, at least 30% of every new building has to be biobased. To achieve that, the NABB also outlines a step-by-step plan that sees a transformation of the agricultural sector towards growing more crops used for BBMs, such as Hemp, Miscanthus or Flax. While farmers build the backbone of the transition towards regional and sustainable building materials, the NABB also defines producers of BBMs and construction companies as key stakeholders in the transition. Despite their promising characteristics and potential advantages, BBMs are yet to be widely adopted by the mass markets. The next section will present the methods applied in this study.

3. Methodology

We employ a qualitative research design to investigate the barriers to establishing CSCs for BBMs such as Flax and Miscanthus in the Dutch province of Friesland. Semi-structured interviews were conducted with key stakeholders involved in this transition. This method of data collection provided detailed insights about the needs, challenges, and potential solutions identified by stakeholders. Grounded theory was applied for data analysis, allowing for the systematic development of theories grounded in the empirical data (Silverman, 2018). Our approach is primarily interpretive, focusing on understanding the subjective experiences and perspectives of the participants (Walsham, 2006). This aligns with a constructivist paradigm, where knowledge is co-constructed through interactions between the researcher and the participants (Adom et al., 2016). By adopting this approach, the study aims to provide a good understanding of the barriers and enablers in creating CSCs for BBMs.

3.1. Participant recruitment

Participants were recruited through our personal network. First, an introductory email was sent to possible participants, introducing the research topic and the researchers. The information sheet that potential participants received described that we wanted to explore the barriers and needs of BBM stakeholders in establishing CSCs in the region of Friesland, the Netherlands. No specific number of participants was determined before the data collection, as the aim was to achieve data saturation. To be selected, participants either needed to be part of the key stakeholder groups involved with BBMs (Farmers, producers, construction companies), or be involved with setting up parts, or the entire supply chain in the region of Friesland. The latter implies positions at knowledge institutions, municipalities, the province of Friesland or other organisations that participate in setting up CSCs for BBMs in Friesland. Figure 1 provides an overview of the participants and the general field they work in.

Participants	**Occupation**
P1	Project manager circularity at the Province of Friesland. Involved with setting up CSCs for BBMs in the region.
P2	Miscanthus farmer and real estate advisor.
P3	Biologist and Miscanthus expert. Involved in coordinating supply chain for farmers.
P4	Flax expert and coordinator of nature inclusive agriculture at the Province of Friesland.
P5	CSC coordinator for BBMs at a national organisation and producer of BBMs.
P6	Director of knowledge institution biobased economy in Friesland.

Figure 1: Overview of participants

3.2. Data collection

Data was collected by conducting a total of six semi-structured interviews of between 40-80 minutes in length. The motivation behind choosing semi-structured interviews was to leave enough room for participants to share their thoughts freely without being too constrained by a fully set interview guide. An interview guide was used as an orientation for the interviews. The interview questions aimed at identifying general issues related to establishing CSCs for BBMs, and more stakeholder specific barriers and enablers (see appendix A). Audio recordings were made during the interviews using the researchers' phones. The audio files were turned into transcripts using the transcribe function of microsoft word. While five interviews were held in English, one interview was held in Dutch. We translated the Dutch interview into English.

3.3. Data Analysis

Grounded theory was chosen as the data analysis method for this study due to its suitability for exploring complex, under-researched phenomena, and generating theory directly from the data (Silverman, 2018). In the context of establishing CSCs for BBMs, grounded theory allows for an in-depth understanding of stakeholders' experiences, needs, and challenges (Glaser & Strauss, 2014). Coding was used to categorise the qualitative data derived from the interviews. For this step, earlier findings of Roy et al. (2022) were used as a theoretical lens for the barriers, while other categories were developed by us during the analysis. Quotes were divided into first- and second-order themes for both barriers and bridges (enablers/facilitators). Miro was used to visualise how the different barriers interact with each other and how the bridges can affect the barriers.

3.4. Ethical considerations

Since this research conducted interviews with participants, several ethical considerations were made. First, every participant was asked to sign a written consent form that educated them about their rights as participants and what participating in the research entailed. They were able to withdraw their consent during the interview. Furthermore, every participant was fully anonymized in the interview transcripts and in the final report. All data generated during the interviews was stored safely and in accordance with the GDPR rules of the University of Groningen.

4. Results

Based on the results from the interviews, the different stakeholders appear to face a range of barriers influencing their engagement with BBMs. Through analysing the interviews, we identified first and second-order themes for barriers and bridges. The term bridges refers to facilitators and measures that can be taken to overcome the barriers that stakeholders face when establishing CSCs for BBMs. The analysis enabled me to identify six main barriers and two bridges that hinder/accelerate the building of CSCs for BBMs. This section is divided into two main parts: barriers and bridges. The barriers section explains the different problems stakeholders face when trying to establish CSCs for BBMs. The bridges section dives into facilitators/enablers that can help stakeholders overcome the barriers mentioned in the previous section.

4.1. Barriers

4.1.1. Technological barriers

Based on the participants' responses, technology seems to be a major barrier that keeps farmers from engaging in crops that are needed for BBMs such as Miscanthus or Flax. 'Technological barriers' refers to the inability of stakeholders to engage with BBMs due to a lack of necessary technological appliances. This barrier covers both the inability to obtain the necessary technological appliances and the fact that necessary technological appliances do not yet exist. All participants were asked what they considered the main barriers for each stakeholder of BBMs in the region. While some of these barriers overlapped and applied to multiple stakeholders, others only affected one specific stakeholder. In response to the question of what barriers farmers would face, barriers connected to non-existing or hard-to-obtain technology were mentioned multiple times. Participant 3 described how crops such as Miscanthus would bring challenges in the harvesting methods:

"I think the challenges are also the specifications. Harvesting methods, specifications, harvesting machines. […] I've seen one hectare which was only harvested two or three weeks ago. I could see there was a big machine […] and this machine is big, but maybe too heavy for those sorts (*crops like Miscanthus*). They couldn't access the harvesting fields before because it was too wet. But it's very important to have lighter machines to harvest […] so that the pressure on the soil is going to be less." (P3)

In response to the same question, participant 4 described how specialised equipment is needed to harvest flax and that this machinery is hard to obtain:

"Well, for farmers, for Flax that's a very, very simple and a very practical barrier. And that's you need three different machines that are unique to growing flax, which are also not cheap. So if none of those machines are available in the North, it's quite impossible to grow it." (P4)

4.1.2. Customer behaviour

This barrier shows that customers play an important role in the process of establishing CSCs for BBMs. 'Customer behaviour' describes difficulties regarding the decision patterns of customers and perceptions of BBMs, especially in relation to non-BBMs. Throughout the interviews, we found that customers buy building materials based on availability and price. At the moment, non-BBMs are more broadly available and cheaper, which is why BBMs are often not perceived as the better choice, affecting the entire chain:

"Well, it would be a necessary step to go head to head with the traditional forms of building materials. If it's easy to get traditional materials for nothing, for low prices, consumers will always go for that." (P6)

Additionally, participant 2 mentioned that the customers have to take into consideration that BBMs have an added value due to being an environmentally friendly and (ideally) local product. Even when BBMs might be more expensive than non-BBMs, this added value should be considered by customers:

"[…] we have to try to get a higher value for the product and it should be. The client has to be willing to pay for the value." (P2)

4.1.3. Product and process barriers

Construction companies and producers of BBMs struggle with the processing of BBMs, while farmers struggle with the transitioning to the product itself. 'Product and process barriers' outlines issues that stakeholders can face with novel products, specifically in the processing phase. This barrier appears to affect all stakeholders in different ways. According to participant 1, construction companies often do not know how to build with BBMs and thus, rather opt for conventional building materials:

"Of course we can source it and process it and make plans out of it. But if the builders can't use it, then it's still not possible to close the chain and to make it to actually use the materials." (P1)

Producers of BBMs also seem to struggle with current building practices. Participant 2 describes how most building practices are not adapted to BBMs yet, hindering a large scale adoption of BBMs:

"The products are not are not really engineered for bio based materials. […] When the Goal for miscanthus is to use it as an insulation material. However, to compete with normal insulation materials, for instance, Rockwool, you can make thinner and lighter constructions with those materials. Miscanthus is heavier and you need more space in your construction. And that blocks you when aiming for a broad adaptation." (P2)

Finally, farmers appear to struggle with the risk of transitioning to new crops such as Miscanthus or Flax:

"And of course it's a big risk to turn your whole business upside down into another and into a different crop." (P1)

4.1.4. Standardisation and regulatory barriers

Findings indicate that complicated certifications, industry standards and laws and regulations are hindering construction companies from engaging with BBMs. 'Standardisation and regulatory barriers' outline challenges that are related to (non) existing regulations and industry standards that hinder the application of BBMs. This barrier appears to be especially affecting construction companies, as participant 1 clearly stated:

"Laws and regulation is, I think, the main problem, especially for builders." (P1)

Participant 5 elaborates on that perspective by stating how Dutch and international certifications of BBMs are not aligned. The fact that producers and construction companies would have to deal with a rather confusing and unaligned landscape of certifications and regulations when producing/using BBMs scares many of them off:

"If you are European certified, you still have to try to comply with Dutch certification rules and that generally costs a lot of money. You have to have all kinds of certificates at product level, at producer level, fire safety etc. […] That cost has to be arranged centrally […] Builders want to

avoid any kind of risk, so they just have to go there. They don't get out of that pilot phase If that certification is not properly arranged." (P5)

Moreover, construction companies seem to be struggling with industry norms not fitting BBMs:

"So the design and engineering have to be adapted to the material. […] So they are all connected with each other like an industry norm for a beam, for instance, is maximum 18mm. That's probably not enough for the volume for Miscanthus. […] The industry has to adopt their methods, and engineering, to make the actual step to more biobased materials." (P2)

4.1.5. Financial and economic barriers

Financial and economic aspects appear to be a major barrier for farmers and producers of BBMs. The fifth barrier, 'financial and economic barriers', covers challenges related to the financial and operational risk of engaging in BBMs. This barrier appears to affect mainly producers and farmers. According to participant 1, farmers only tend to transition to new crops if the new business model is financially feasible:

"For farmers, for example, they want to change. But if it's not financially feasible for them, then they don't do it. I mean, that's as simple as it is, unfortunately." (P1)

Participant 2 undermines this point by highlighting that the current return on investment (ROI) takes too long for farmers to see a financially feasible business model in crops such as Miscanthus at the moment:

“The ROI is at the moment, four to five years, and that is too long for a normal farmer. So we need to reduce the cost price and then ROI will be influenced. Let's say three years, three to four years.” (P2)

Profitability also appears to be an issue for producers of BBMs, as they seem to be struggling with little demand:

“So they wanted to set up a production facility in Friesland, they had the plans ready, but they saw that there is not enough demand to actually make it profitable. So I think that it is really a shame that we can't set up the chain in Friesland, because it is not financially feasible to set it up regionally.” (P1)

4.1.6. Long-term planning

Farmers struggle with a lack of contracts that provide them with security and enable them to plan with BBMs in the long run. The sixth and final barrier ‘long-term planning’ describes the challenges related to uncertainty stakeholders face in the long run when engaging in BBMs. Based on the participants’ replies, this barrier appears to be affecting farmers the most. Uncertainty seems to be an issue for farmers as they apparently only transition to planting crops important for BBMs once the demand is there:

“[…] on the agriculture side, I think at the moment the cost price is too high and at the moment there is uncertainty in the market on the demand side. Farmers will not take the next step until everyone wants Miscanthus.” (P2)

Uncertainty also comes back in the issue of lacking contracts that ensure an income on a longer term for farmers:

“The farmer doesn't have a real contract in front of him. […] if there is any barrier coming up then we will be the loser because we will have the Miscanthus and nobody will take it. And so we have to come to a contract.” (P3)

Connecting to this, farmers can also create revenue through carbon credits if they grow crops that capture and store CO2 in the soil. However, to participate in such programs, farmers need long-term contracts:

“[…] for storing carbon in the soil, you can get carbon credits. And that's money that's actually money. But you have to, give the security, that it will be stored for 10 years in the land. So my contract also has to be 10 years.” (P2)

Figure 2 shows the distribution of barriers between the different stakeholders of BBMs. While certain barriers seem to be exclusive to one stakeholder group, other barriers are shared. The next section explores the findings for measures that can help to build ‘bridges’ to overcome barriers in the transition towards CSCs.

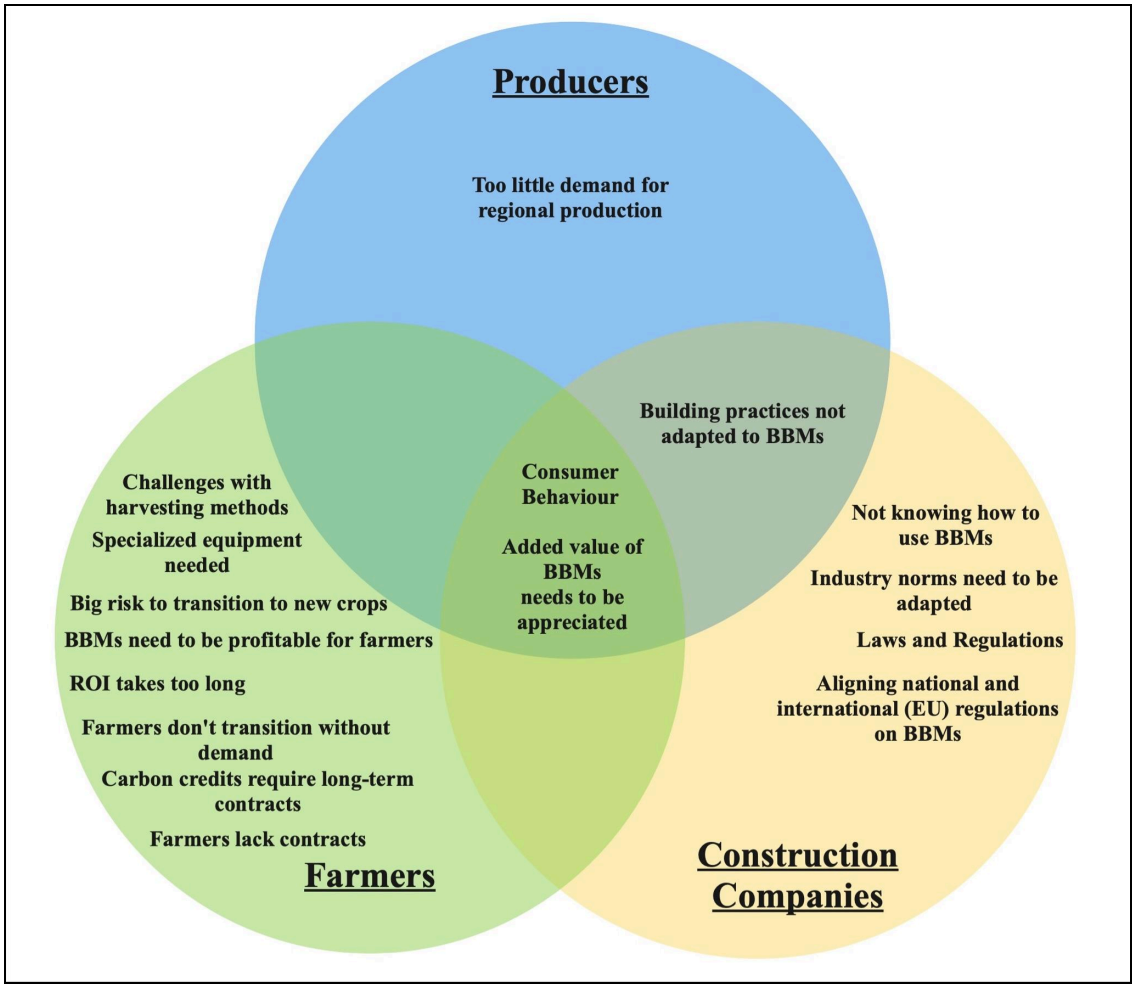

Figure 2: Overview of stakeholder barriers to building CSCs

4.2. Bridges

4.2.1. Frontrunners and Pilot Projects

Positive examples of BBMs in practice appear to be important facilitators for convincing stakeholders to get involved with BBMs and showing them how to work with such materials. The first bridge identified consists of frontrunners and pilot projects showing stakeholders how to work with BBMs and what can already be achieved using such materials. Participant 1 stressed how important positive examples are and how these can show others who are interested in getting involved with BBMs what is already possible now:

“And I think the examples are really important for other people to work with biobased materials so that you can show that it's not something that is, I don't know, a dream or what we want to achieve, but that it's really possible already and it doesn't necessarily have to be complicated or expensive”. (P1)

To have positive examples also appears to be an enabler for more farmers to get involved with BBMS. According to participant 3, agricultural politics have led many farmers to distrust the government as they were often subject to top-down approaches. Therefore, farmers need to be inspired and motivated rather than forced to transition to a new business model:

“If farmers do not turn from 1 crop or one business activity to another just like that, it's just a matter of being forced into or seeing no other opportunity, no other possibility, and the politics of the last, let's say the last 10-15 years did not help a lot. And even certain economic incentives did not. So I think the farmer does not need to be not convinced, but needs to be motivated, inspired to look at It from a different angle, from a different perspective.”. (P3)

Construction companies would also benefit from having positive examples, says participant 5. Being able to see and handle BBMs and comparing them to non-BBMs would help to show that BBMs are not fiction, but reality:

“To ultimately hold this material up in that whole process you really need a lot of good breath for that and at the moment. […] I think that once that has been broken in an organisation in such a chain and you have applied it, then it is easier, so then those people have the experience, the

trust, there are numbers. Yes, there are all those products and construction of glass wool for example already in there, so it's easier to grab something existing. Saves you a lot of work, but these kinds of materials are still all new, so that is also done through building, among other things.”. (P5)

4.2.2. Stakeholder collaboration

Collaborating more closely with other stakeholders can help overcome several barriers that stakeholders face in their transition towards BBMs. ‘Stakeholder collaboration’ covers possibilities to collaborate both within, and between stakeholder groups to overcome certain barriers to building CSCs. Such collaboration, says participant 3, is desperately needed to break with the contemporary top-down approach from construction companies who dictated processes to the rest of the SC. For BBMs, a participation model would be needed that allows all stakeholders to work together to overcome barriers to overcome different barriers while building CSCs:

“So you really have to be safe. In earlier times we had this top down model by the contractor who just said what he wanted and then the whole line had to follow. This should turn into a participation model and they have to come up with specifications. And they (*involved stakeholders*) should also be legally fixed to it because if it is not, one of the parts can just walk away from the table then it's not going to work.”. (P3)

Such a participation model could be facilitated and organised by a central party that connects the different stakeholders. Participant 5 shares how crucial such a party can be and how this is already working in the Dutch region of Friesland:

"And that's where you think an organisation like VCF (*Vereniging Circulair Friesland, Sustainable civil society organisation based in Friesland, the Netherlands*) is just one of the most important players by simply connecting all stakeholders. I think they have worked very well on the network in recent years, which makes it very easy to make those contacts and have trust and that it is now much easier to go to that implementation is still a real challenge, but that preliminary work is very well done." (P5)

Several participants stressed how such a central party would also be needed just for farmers. A cooperative was mentioned that unites different farmers involved with BBMs that shares knowledge amongst its members, and negotiates good contracts with the other stakeholders within the CSC:

"Because when it comes to a cooperative then the financing will be much easier to organise and also the risk will be spread and the revenues will be secured." (P3)

The next section explores the relationships of the barriers and bridges of each stakeholder group.

5. Discussion

Building upon the findings from the previous section, we mapped the relationships of the different barriers. Many barriers are interacting with each other. Mapping the relationship between barriers and bridges showed that rather simple solutions can have a large impact on the barriers. In this section, we start by reflecting on similarities and differences with the existing literature and outline the study's contribution. We explore interactions between the different barriers. Next, we elaborate on how the identified bridges could affect the barriers. After that, we compare the findings of this study to those of the existing literature. Finally, we propose an answer to the two research questions and elaborate on how this study contributes to the literature.

5.1. Interaction of stakeholder barriers

Mapping the interactions of the barriers showed that certain barriers can influence, or be impacted by other barriers. Figure 3 visualises these interactions. The model includes both first- and second-order themes of the barriers. The arrows indicate possible effects that one barrier could have on another. The dotted lines indicate a one-way interaction, while the solid line represents a two-way interaction.

5.1.1. Technological barriers, with product and process barriers, and financial and economic barriers

This barrier mainly affected farmers in their transition towards BBMs. Farmers appeared to experience challenges regarding harvesting methods and needed specialised equipment to harvest Miscanthus and Flax. These challenges can influence several other barriers. To start, having difficulties with the harvesting specifications can influence product and process barriers.

Farmers could perceive the difficulty of the harvest as a significant risk when transitioning to these crops. The need for specialised equipment can also affect financial and economic barriers. As such equipment can be rare and costly, farmers might not perceive crops that can be used for BBMs as a profitable business model and that their return on investment would take too long.

5.1.2. Customer behaviour, with financial and economic barriers and long-term planning issues

Customer behaviour affects all stakeholder groups, and several connections to other barriers can be drawn. Consumers going for the lowest price can influence financial and economic barriers. By opting for cheaper, non-BBMs, consumers could impact the profitability of BBMs for farmers in a negative way. This also relates to the added value of BBMs that consumers need to appreciate. If consumers do not see that additional value, farmers might be unable to sell their products for a fair price, making the business model unprofitable. Going for the lowest price and not valuing BBMs can also affect the demand for producers. If consumers do not choose BBMs, demand might be too little for producers to open up a regional production facility. Consumer behaviour can also influence long-term planning issues. As for the regional production facility, farmers only transition when the demand for a particular product exists. Farmers are unlikely to transition towards BBMs if consumers do not create a demand for BBMs.

5.1.3. Product and process barriers, with standardisation and regulatory barriers and financial and economic barriers

This barrier affects all stakeholder groups, but in different ways. As for customer behaviour, product and process barriers are also related to multiple other barriers. The fact that

building processes are not yet adapted to BBMs and that only few people know how to use BBMs can impact standardisation and regulatory barriers. If BBMs are not being adapted in the building process on a larger scale, there might not be enough reason for the industry norms to adapt to BBMs too. Therefore, a two-way relationship between these two barriers could be made. Financial and economic barriers are also affected by building processes that are not adapted to BBMs. Without building with BBMs happening on a larger scale, demand might stay too low for a regional production facility.

5.1.4. Standardisation and regulatory barriers, with financial and economic barriers, consumer behaviour, and product and process barriers

Standardisation and regulatory barriers mainly impacted construction companies, but with this barrier too, multiple connections can be made to other barriers. Financial and economic barriers can be affected in two ways. Firstly, if the industry norms are not adapted to BBMs, demand to create a regional production facility might stay too low. Secondly, if national and international regulations on BBMs are unaligned and construction companies are struggling with expensive and complicated certifications, demand for a production facility could again be negatively affected. Standardisation and regulatory barriers can also affect customer behaviour.
If laws and regulations hinder the large-scale implementation of BBMs, customers might continue to choose their building materials based on the cheapest price, making it difficult for BBMs to compete with traditional building materials. Similarly, laws and regulations can also impact product and process barriers. If certain laws and regulations are making it difficult for construction companies to use BBMs, farmers might perceive transitioning towards BBMs as too much of a risk regarding possible demand for their product.

5.1.5. Financial and economic barriers, with long-term planning issues

Financial and economic barriers primarily affected farmers and producers of BBMs. This barrier appears to be more impacted by other barriers rather than it impacts other barriers (see figure 3). However, financial and economic barriers show a relationship towards long-term planning issues. During the interviews, demand appeared to be a key barrier to producers and farmers. Whether BBMs are produced locally is determined by demand, and so is whether farmers make the transition towards BBMs. Therefore, these two barriers affect each other in both directions.

5.1.6. Long-term planning issues, with product and process barriers and financial and economic barriers

Long-term planning issues targeted mainly farmers. This barrier, too, is more impacted than it impacts other barriers. Long-term planning issues can impact both product and process barriers and financial and economic barriers. If farmers lack contracts that give them a certain level of security, the risk of transitioning towards BBMs can be perceived as too high. In turn, the lack of contracts and the perceived risk of transitioning can lead to too little demand for the local production of BBMs.

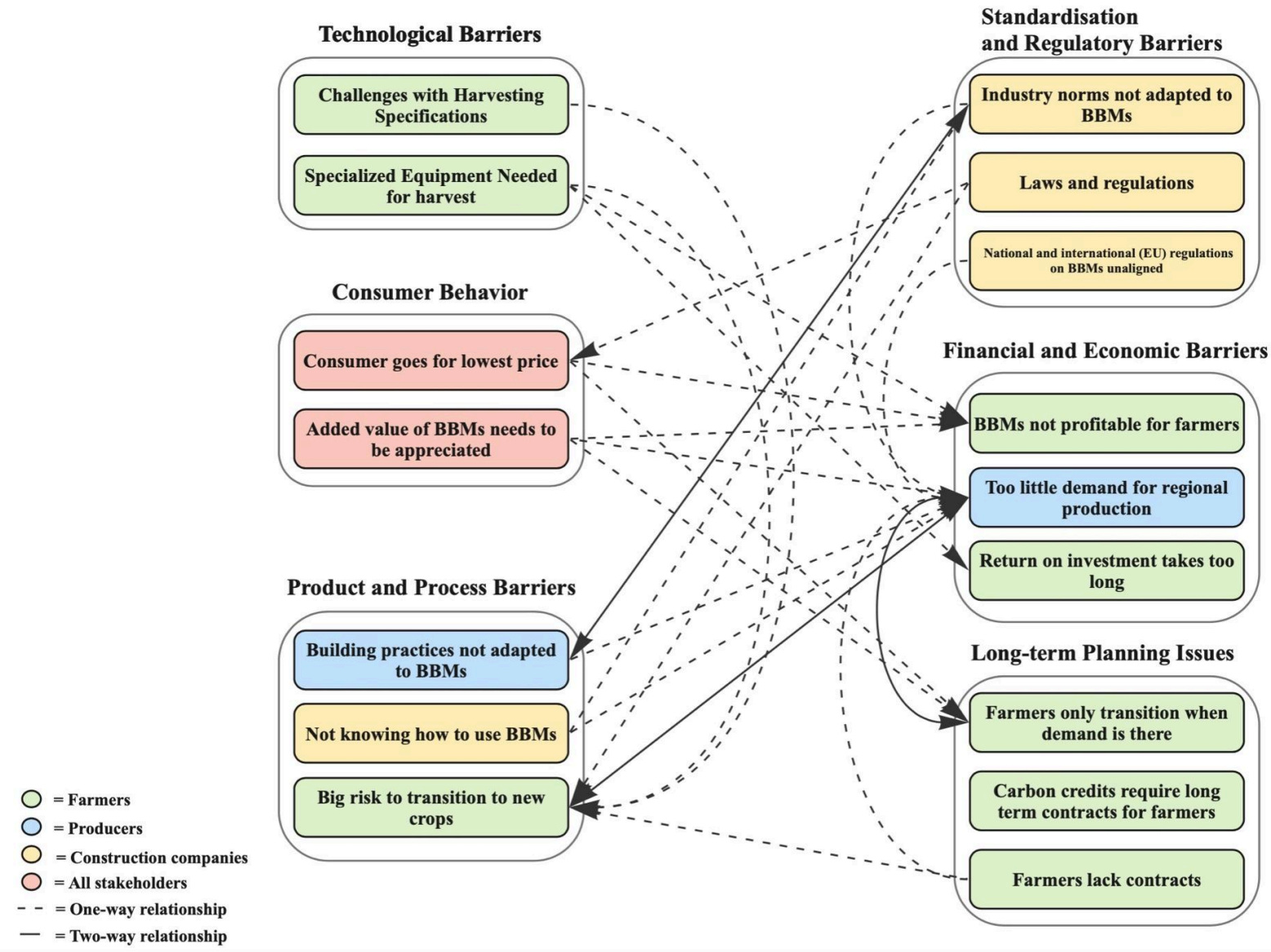

Figure 3: Barrier interactions

5.2. Possible impact of bridges

As a result of the data analysis, two possible bridges were identified: Frontrunners and pilot projects, as well as stakeholder collaboration. This section explores possible impacts that each bridge could have on the barriers.

5.2.1. Frontrunners and pilot projects

The interviews showed how frontrunners and pilot projects could help overcome specific barriers to building CSCs for BBMs. Having examples of BBMs in use could positively impact several barriers. First, it could help to overcome some product and process barriers. Pilot projects could inspire construction companies, showing them how BBMs can be used in practice. Farmers who perceive the risk of transitioning towards crops like Miscanthus or Flax as too high could be convinced by other farmers who successfully made that transition. By having more physical examples of BBMs in use, customer behaviour could also be influenced by making the added value of BBMs more visible. More frontrunners and pilot projects could also help overcome standardisation and regulatory barriers. If more companies engage with BBMs and more pilot projects are launched, industry norms might adapt more quickly to BBMs. With regards to financial and economic barriers, more frontrunners and pilot projects could help stimulate demand that is needed by the producers of BBMs.

5.2.1. Stakeholder collaboration

Stakeholder collaboration forms the second bridge that could help overcome various barriers. To start, a cooperative for farmers that would facilitate knowledge exchange and equipment sharing and would negotiate on behalf of its members could help to overcome most of

the barriers that farmers face. Such a cooperative could help farmers overcome technological barriers through knowledge sharing and possibly giving access to equipment needed for harvesting the crops. Knowledge sharing could also help with product and process barriers by lowering the perceived risk of transitioning through being part of a network that can help with possible issues during and after the transition period. Regarding financial and economic barriers, being part of such a cooperative could also help build a (more) profitable business model for farmers by having a stronger position in negotiations with other stakeholders than if they were alone. Consequently, a cooperative could also help to decrease the time it takes for farmers to make their return on investment. Having a stronger position in negotiations could also help to secure long-term contracts for farmers that can help to overcome long-term planning issues. Besides having a cooperative for farmers, sharing responsibility more equally could also help to overcome certain barriers.

By moving from a top-down approach towards more of a participation model, farmers might be able to have a lower financial burden by having a more equal role in the chain. As a result, BBMs could make for a more profitable business model for farmers. Sharing the responsibility more equally amongst all stakeholders, farmers could result in more long-term contracts for farmers. This could solve some of the long-term planning issues and help with product and process barriers by lowering the risk of farmers transitioning towards BBMs. Finally, a central party that connects all stakeholders and acts as a mediator could also help to overcome several barriers.

Such a central party was brought forward during the interviews using a real-life example from the province of Friesland. Such an intermediary body could, for example, help overcome product and process barriers. A central party could take on a similar role as the cooperative for

farmers by facilitating knowledge exchange, helping its members with problems during and after the transition towards BBMs, and bringing like-minded individuals and businesses together for the entire chain. Especially the knowledge exchange aspect could help producers and construction companies adapt building practices and familiarise them with how to use BBMs. By accelerating the adaptation process for these two stakeholder groups, farmers could also benefit as more parties getting involved with BBMs could lower the risk of transitioning to BBMs. A central party could also be important in working against standardisation and regulatory barriers.

By taking on a similar position to a union, a central party could unite the voices of BBM stakeholders and collectively work towards solving problems such as adapting industry norms to BBMs, aligning national and international (EU) regulations and adapting laws and regulations to fit BBMs. Bringing stakeholders together could also tackle financial and economic barriers and long-term planning issues. Solving barriers related to the beginning phase of getting involved with BBMs, such as product and process or standardisation and regulatory barriers, could automatically resolve the underlying problems behind too little demand.

In the next section, we outline this study's central contributions to the existing CSC and CSCM literature. Figure 4 shows the different barriers and bridges and maps potential interaction between them. The arrows going from the bridges in the middle towards the barriers on the outside indicate that certain bridges could help overcome specific barriers.

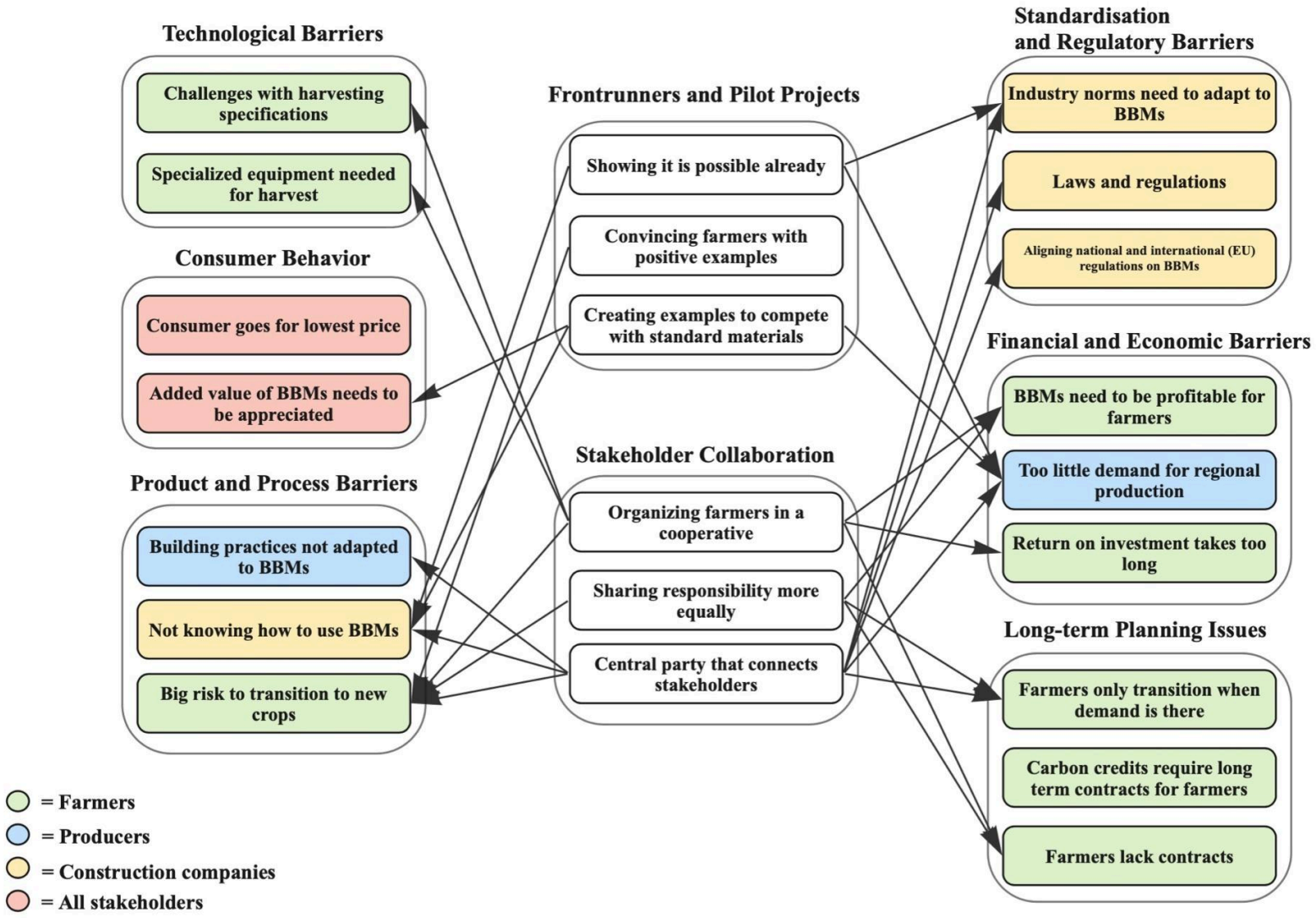

Figure 4: Possible effects of bridges on barriers

5.3. Contribution to literature

Three main lessons can be taken from this study. First, this study confirmed earlier findings of Roy et al. (2022) by applying their framework of barriers to transitioning to CSCs to multiple stakeholders of BBMs. Several barriers that Roy et al. (2022) initially identified for manufacturing companies also appear to apply to stakeholders of BBMs: Technological barriers, product and process barriers, financial and economic barriers, and standardisation and regulatory barriers.

In addition, two new barriers were identified: consumer behaviour and long-term planning issues. The second major finding of this study is that certain barriers appear to interact with each other. This shows how intertwined the different stakeholder issues are and that a multi-stakeholder perspective is needed to adequately address the barriers identified in this study. Finally, the third major contribution of this study is that rather simple solutions in the form of frontrunners and pilot projects and closer collaboration of stakeholders can help to overcome most of the barriers that stakeholders face in their transition towards BBMs. The need for stronger stakeholder collaboration also confirms earlier findings of one of the four dimensions supporting the development of CSCs by González-Sánchez et al. (2020), greater intensity in the relationships established in the supply chain.

Applying a multi-stakeholder perspective to this research allowed us to gain a more comprehensive perspective of the barriers and enablers that affect key stakeholders in their transition. Knowing which barriers affect which stakeholder provides a better overview to the problems at hand. This enhanced overview made clear that the barriers the stakeholders are facing are actually not that complicated. Furthermore, the multi-stakeholder analysis enabled us to identify stakeholder-specific solutions that can be used to bridge the barriers. These insights

are not only valuable for building CSCs for BBMs, but can also be applied to other transitions where the potential barriers and enablers of key stakeholders are unclear.

5.4. Limitations

This study has several limitations that should be acknowledged. First, the research is geographically limited to the province of Friesland, the Netherlands. Consequently, the findings may not be generalizable to other regions with different socio-economic and environmental conditions. Second, the scope of the study was confined to Miscanthus and Flax as BBMs. Other potential biobased materials were not considered, which may limit the applicability of the results to a broader range of BBMs. Additionally, the use of grounded theory for data analysis can cause researcher bias in interpreting and categorising the data. Finally, although this study included several participants who work closely with all key stakeholders of biobased building materials and thus have a comprehensive overview of the challenges each stakeholder faces, none of the participants were directly employed by a construction company.

5.5. Further Research

The focus of this study was to identify barriers and possible solutions for building CSCs for BBMs. As a result, this study did not focus on the last part of the material cycle, keeping materials within the loop. Further research could specifically focus on difficulties retrieving materials. Furthermore, this study had a specific focus on Miscanthus and Flax and was also bound to the province of Friesland, the Netherlands. Further research could use the same research approach to other geographical locations to prove whether the results of this study apply there.

5.6. Conclusion

This multi-stakeholder case study identified barriers and bridges that can hinder/enable critical stakeholders to transition towards BBMs. In total, six barriers were identified: Technological barriers, customer behaviour, product and process barriers, standardisation and regulatory barriers, financial and economic barriers, and long-term planning issues. Some barriers only appear to affect specific stakeholders, while others appear to affect multiple or even all stakeholders. Moreover, some of the barriers appear to interact, indicating a more complex relationship between the barriers. Two possible bridges were identified that could help stakeholders overcome the barriers: Frontrunners and pilot projects and Stakeholder collaboration. Mapping possible interactions between the bridges and barriers showed that rather simple solutions could already positively impact solving many barriers. This research contributes to the specific case of building CSCs for BBMs and to other transitions where the potential problems and enablers of key stakeholders are unknown.

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APPENDIX A

Archival #:

Site:

Interviewer:

Date:

Start:

End:

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1. Current Landscape and Trends:

Question 1.1)
How do you view the current landscape of Biobased Building (Materials) in the Netherlands, specifically in Friesland?

Question 1.2)
What trends do you observe in the use of biobased materials for construction projects in the region?

2. Supply Chain Dynamics:

Question 2.1)
In your opinion, who are the key stakeholders involved in the circular supply chain for biobased building materials, and what roles do they play?

Question 2.2)
Based on your experience, are there common problems related to establishing supply chains for biobased materials?

Question 2.3)
Can you think of positive examples or ongoing initiatives that show how supply chains for biobased building materials can be established?

3. Stakeholder Perspectives:

Question 3.1)
From your experience, what are the main motivations for farmers to engage in the production of biobased building material crops like Miscanthus and flax?

Question 3.2)
How do producers of biobased building materials perceive the challenges and opportunities in the market?

Question 3.3)
What are primary considerations for construction companies when considering the adoption of biobased building materials?

4. Barriers and Opportunities:

Question 4.1)
What do you consider to be the main barriers hindering the wider adoption of biobased building materials in Friesland?

Question 4.2)
Can you think of any specific challenges that farmers, producers, or construction companies face in transitioning to biobased materials?

Question 4.3)
Can you identify potential opportunities for overcoming these barriers and promoting the use of biobased building materials?

5. Crop Specifics (Miscanthus and Flax):

Question 5.1)
What are the key characteristics that make Miscanthus a suitable feedstock for biobased building materials?

Question 5.2)
Can you discuss the advantages and challenges associated with cultivating flax for use in construction?

Question 5.3)
How do you see the potential yield and sustainability of Miscanthus and flax crops in Friesland?

APPENDIX B

Barriers

Farmers

Producers

Construction companies

Applies to all stakeholders

Quotes	1rst Order Themes	2nd Order Themes
"I think the challenges are also the specifications. Harvesting methods, specifications, harvesting machines. […] I've seen one hectare which was only harvested two or three weeks ago. I could see there was a big machine […] and this machine is big, but maybe too heavy for those sorts (type of crop). They couldn't access the harvesting fields before because it was too wet. But it's very important to have lighter machines to harvest […] so that the pressure on the soil is going to be less." (P3Q06)	Challenges with Harvesting Specifications	Technological Barriers
"Well, for farmers, for Flax that's a very, very simple and a very practical barrier. And that's you need three different machines that are unique to growing flax, which are also not cheap. So if none of those machines are available in the North, it's quite impossible to grow it." (P4Q01)	Specialized Equipment Needed for harvest	

“Well, it would be a necessary step to go head to head with the traditional farms of building materials. If it's easy to get traditional materials for nothing, for low prices, consumers will always go for that.” (P6Q02)	Consumer goes for lowest price	Customer Behaviour
“[…] we have to try to get a higher value for the product and it should be. The client has to be prepared to have to be willing to pay for the value.” (P2Q10)	Added value of BBMs needs to be appreciated	
“Of course we can source it and process it and make plans out of it. But if the builders can't and use it, then it's still not possible to to close the chain and to make it to actually use the materials” (P1Q03)	Not knowing how to use BBMs	Product and Process Barrier
“The products are not are not really engineered for bio based materials. […] When the Goal for miscanthus is to use it as an insulation material. However, to compete with normal insulation materials, for instance, Rockwool, you can make thinner and lighter constructions with those materials. Miscanthus is heavier and you need more space in your construction. And that blocks you when aiming for a broad adaptation.” (P2Q01)	Building practices not adapted to BBMs	
“And of course it's a big risk to turn your whole business upside down into another and into a different crop.” (P1Q09)	Big risk to transition to new crops	

“So the design and engineering have to be adapted to the material. […] So they are all connected with each other like an industry norm for a beam, for instance, is maximum 18mm. That's probably not enough for the volume for Miscanthus. […] The industry has to adopt their methods, and engineering, to make the actual step to more biobased materials.” (P2Q02)	Industry norms need to adapt to BBMs	Standardization and Regulatory Barriers
“Laws and regulation is, I think, the main problem, especially for builders” (P1Q02)	Law and regulations	
“If you are European certified, you still have to try to comply with Dutch certification rules and that generally costs a lot of money. You have to have all kinds of certificates at product level, at producer level, fire safety etc. […] That cost has to be arranged centrally […] Builders want to avoid any kind of risk, so they just have to go there. They don't get out of that pilot phase If that certification is not properly arranged.” (P5Q07)	Aligning National and international (EU) regulations on BBMs	
“For farmers, for example, they want to change. But if it's not financially feasible for them, then they don't do it. I mean, that's as simple as it is, unfortunately.” (P1Q04)	BBMs need to be profitable for farmers	Financial and economic barriers
“So they wanted to set up a production facility in Friesland, they had the plans ready, but they saw that there is not enough demand to	Too little demand for regional production	

actually make it profitable. So I think that it is really a shame that we can't set up the chain in Friesland, because it is not financially feasible to set it up regionally." (P1Q10)		
"The return on investment (ROI) is at the moment, four to five years, OK and that is too long for a normal farmer. So we need to reduce the cost price and then ROI will be influenced. Let's say three years, three to four years." (P2Q08)	Return on investment takes too long	
"[…] on the agriculture side, I think at the moment the cost price is too high and at the moment there is uncertainty in the market on the demand side. Farmers will not take the next step until everyone wants Miscanthus." (P2Q03)	Farmers only transition when demand is there	Long-term planning issues
"[…] for storing carbon in the soil, you can get carbon credits. And that's money that's actually money. But you have to, give the security, that it will be stored for 10 years in the land. So my contract also has to be 10 years." (P2Q09)	Carbon credits require long term contracts for farmers	
"The farmer doesn't have a real contract in front of him. […] if there is any barrier coming up then we will be the loser because we will have the Miscanthus and nobody will take it. And so we have to come to a contract." (P3Q03)	Farmers lack contracts	

Needs

Farmers

Producers

Construction companies

Applies to all stakeholders

Quotes	1rst Order Themes	2nd Order Themes
“And I think the examples are really important for other people to work with biobased materials so that you can show that it's not something that is, I don't know, a dream or what we want to achieve, but that it's really possible already and it doesn't necessarily have to be complicated or expensive” (P1Q01)	Showing its possible already	Frontrunners and Pilot Projects
“If farms do not turn from 1 crop or one business activity to another just like that, it's just a matter of being forced into or seeing no other opportunity, no other possibility, and the politics of the last, let's say the last 10-15 years did not help a lot. And even certain economic incentives did not. So I think the farmer does not need to be not convinced, but needs to be motivated, inspired to look at It from a different angle from a different perspective.” (P3Q08)	Convincing farmers with positive examples	
“To ultimately hold this material up in that whole process you really need a lot of good breath for that and at the moment. […] I think that	Creating examples to compete with standard materials	

once that has been broken in an organization in such a chain and you have applied it, then it is easier, so then those people have the experience, the trust, there are numbers. Yes, there are all those products and construction of glass wool for example already in there, so it's easier to grab something existing. Saves you a lot of work, but these kinds of materials are still all new, so that is also done through building, among other things." (P5Q08)		
"Because when it comes to a cooperative then the financing will be much easier to organize and also the risk will be spread and the revenues will be secured." (P3Q02)	Organizing farmers in a Cooperative	Stakeholder Collaboration
"So you really have to be safe. In earlier times we had this top down model by the contractor who just said what he wanted and then the whole line had to follow. This should turn into a participation model and they have to come up with specifications. And they (involved stakeholders) should also be legally fixed to it because if it is not, one of the parts can just walk away from the table then it's not going to work." (P3Q04)	Sharing responsibility more equally	
"And that's where you think an organization like VCF (Vereniging Circulair Friesland, Sustainable civil society organization) is just one of the most important players by simply connecting all stakeholders. I think they	Central party that connects stakeholders	

have worked very well on the network in recent years, which makes it very easy to make those contacts and have trust and that it is now much easier to go to that implementation is still a real challenge, but that preliminary work is very well done" (P5Q01)		