The Role of the FAST Technology as a Driver for Sustainable Business Models within the Biobased Chemical Industry: The Case Study of DAB

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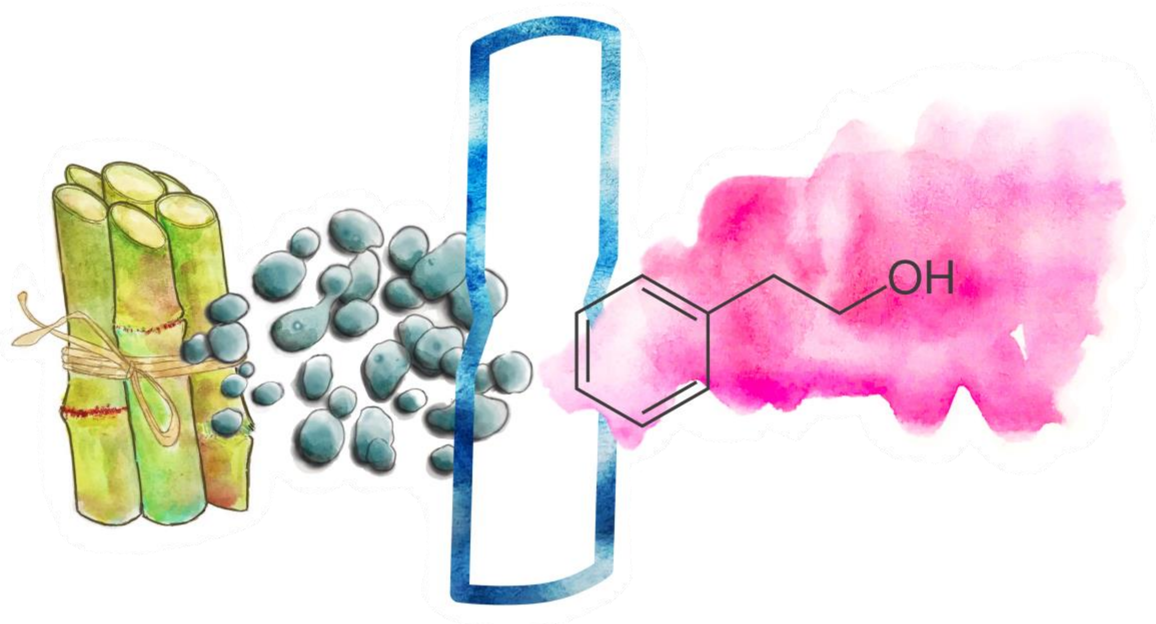
Ignacio Andrés Quinzacara Sánchez



MSc Management of Technology
Faculty of Technology, Policy and Management
Delft University of Technology

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Ignacio Andrés Quinzacara Sánchez
5211751

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Thesis Committee:

Chair: Dr. Robert Verburg
First Supervisor: Dr. Hanieh Khodaei
Second Supervisor: Dr. Robert Verburg
External Supervisor: Dr.ir. Arjan Oudshoorn

“The present is big with the future, the future might be read in the past, the distant is expressed in the near”- Gottfried Wilhelm Leibniz

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Delft, August 2022

Executive Summary

Addressing climate change is a challenge that governments, society, and companies have to face. For companies this becomes a major challenge as they are required to innovate in order to become more sustainable whilst still remain competitive. However, carrying out technological innovation may be useless if it cannot be diffused in the market. Due to this, ventures must go further and modify their current business models to change the way they are doing business and thus generate sustainable value and remain competitive. Within this context, a research gap that relates sustainability, business model innovation, and technology can be identified. To address this gap, an empirical exploratory case study is used as approach. The case study analysed is the Fermentation Acceleration by Separation Technology (FAST), a breakthrough technology in the biotechnology industry that is able to produce chemicals by means of a more cost-effective fermentation process. The technology was developed by DAB, a Dutch biotechnology spin-off from TU Delft. The main research question that was proposed to address the research gap was: "*How can the FAST technology be a driver for sustainable business model innovation of biobased chemical companies?*". To answer the question, two business models were generated using the triple layered business model canvas for assessing and visualising, under a Life Cycle Assessment (LCA) perspective, to what extent and in which elements of a business model the FAST technology drives sustainability. The models assessment considered DAB as a producer and a licensor for 2-phenylethanol (2PE) production by means of FAST, respectively. The main finding of this thesis project is that it has proven that FAST drives sustainable business model innovation within the biobased chemical industry. This is as sustainable business model innovation is found in both *value proposition* and *value creation & delivery* of the two sustainable business models generated by complementing FAST with the use of organic raw materials and solvents, and renewable energies as power source. More specifically, FAST sustainable innovativeness can be seen in the elements of *value proposition*, *key resources*, *key partners*, and *customer segments* of these novel sustainable business models. FAST drives sustainable business model innovation within these four elements by being a breakthrough innovation (*key resources*) that includes a sustainable and efficient production of biochemicals within its *value proposition.* Moreover, innovation is also driven within *key partnerships* as FAST requires strain designers to adopt a different approach when engineering new microorganisms. Here, the technology has an effect outside its business model, modifying the value chain. Furthermore, FAST can reach new *customer segments* and be competitive with current production processes of chemicals as it was shown for the case of 2PE. This sustainable innovativeness differs from the practices other companies within the industry have implemented which are focused on changing the fossil origin of raw materials but do not consider the creation of new value propositions/business models to balance the financial, environmental, and social aspects of sustainability. Regarding the theoretical contribution, this thesis presents a comprehensive analysis of the two business models outlined from the biotechnology sector and shows how they are able to capture the value of a novel sustainable innovation. By doing this, the research gap among business model innovation, sustainability, and technology is reduced. The generation of the sustainable business models was performed by: carrying out a literature review, a questionnaire on sustainability indicators, the Delphi method to obtain a consensus, and simulations of processes for 2PE production. The contribution for practitioners is an example on how they can design business models for a novel technology using a tool that offers a comprehensive analysis of its effects on sustainability. Moreover, the integrated LCA allows practitioners to have a quantitative analysis for measuring the impact of their technology, processes and activities. Furthermore, it may be also useful for redesigning current business models by assessing which components may be modified or kept to achieve sustainability.

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List of Abbreviations

2PE: 2-Phenylethanol
BBE: Biobased Economy
BM: Business Model
BMC: Business Model Canvas
BMD: Business Model Dynamics
BMI: Business Model Innovation
BMfS: Business Models for Sustainability
BMF: Business Model Framework
CAGR: Compound Annual Growth Rate
CBM: Circular Business Models
CMO: Contract Manufacturing Organization
CAPEX: Capital Expenditure
CO_{2eq}: CO_2 equivalent emissions
CRO: Contract Research Organization
DAB: Delft Advanced Biorenewables
DC: Dynamic Capabilities
EU: European Union
FAST: Fermentation Acceleration by Separation Technology
GHG: Greenhouse Gas Emissions
GMO: Genetically Modified Organisms
IP: Intellectual property
IPCC: Intergovernmental Panel on Climate Change
KPI: Key Performance Indicator
LCA: Life Cycle Assessment
LUC: Land use change
MDG: Millennium Development Goals
NECP: National Energy and Climate Plan
OI: Open Innovation
OPEX: Operational Expenditure
PDO: 1,3-Propanediol
PE: Polyethylene
PHA: Polyhydroxyalkanoate
SBM: Sustainable Business Model
SBMC: Sustainable Business Model Canvas
SDG: Sustainable Development Goals
SME: Small Medium Enterprises
SVCI: Sustainable Value Capture Innovation
SVC&DI: Sustainable Value Creation and Delivery Innovation
SVPI: Sustainable Value Proposition Innovation
TLBMC: Triple Layered Business Model Canvas
UN: United Nations
VT: Value Triangle

Chapter 1: Introduction

The following chapter elaborates on the problem statement, objectives, and the research questions of this thesis project that explores, through a case study, how the FAST technology, a new radical innovation, can be a driver for sustainable business model innovation within the biobased chemical industry.

1.1. Problem Statement

Climate change is one of the most relevant and challenging wicked problems that society must address because it is linked to several issues that involve for example, increase of the sea level, droughts, and extreme weather. Besides these climate events, climate change also has detrimental effects on the societies' economic development that can exacerbate inequality and poverty (Bocken et al., 2019). Additionally, as of 2020, human population was estimated in 7,3 billion and the levels of consumption demanded are around 1,5 Planet Earths. This intense demand will be higher by 2050 as it is estimated that population will increase up to 9,7 billion (Bocken et al., 2014; Daou et al., 2020).

To face climate change, the Intergovernmental Panel on Climate Change (IPCC) has been emphatic on limiting global warming to a maximum increase of 2 ºC by 2050, preferable by 1,5 ºC, as stated on the Paris Agreement (IPCC, 2019; United Nations, 2015). To fulfil this goal, the adhering state members must promote changes in the current policies and businesses as well as the creation of new ones to achieve a sustainable development that aims for increasing the benefit and welfare of the so-called *triple bottom line* that comprises economy, society and environment (IPCC, 2019). To formalize these development objectives, the United Nations (UN) proposed in 2015 the so-called Millennium Development Goals (MDG) that include: take action on eradicate extreme poverty and hunger; access to education; gender equality; reduce child mortality; improve maternal health; combat several diseases; develop a global partnership for development; and ensure environmental sustainability (United Nations, n.d.). Tackling these challenges may be considered as an opportunity in which civil society, researchers, governments, and businesses may cooperate to develop new solutions on behalf of a sustainable development (Bocken et al., 2019).

The way for businesses to comply with these goals is by moving towards sustainability. This transition is not trivial as it requires organisations to innovate in both services and products (Bocken et al., 2019). One way to make it is through technological innovation, as innovation has been acknowledged to be an important means to address sustainability because it improves the triple bottom line (Rantala et al., 2018). Nevertheless, technological innovation by itself may not be sufficient if it cannot be commercialized and diffused properly. This is due to off-sets that can exist between the innovation and the context in which it its used (Chesbrough, 2010; Long et al., 2016). Consequently, companies will need to go further and change their Business Models (BM) by modifying the way they are currently doing business and thus, find an appropriate model that enables the adoption of sustainability within their strategy (Bocken et al., 2014; Rantala et al., 2018). By developing sustainable BMs, companies can generate sustainable value within the triple bottom line for the current and future generations. A correct implementation of these BMs allows businesses to address challenges in regulations, markets, and new customer needs & demands and thus, remain competitive. (Cosenz et al., 2020; França et al., 2017).

Sustainability is a transversal matter that reaches every productive sector, and the chemical industry is not an exception. Despite the important role the chemical industry plays in the production of chemicals, materials, and fuels for other productive sectors and society, it has been severely criticized because it is highly pollutant and is responsible for approximately 7% of the global Greenhouse Gas (GHG) emissions (Yu et al., 2019). Initiatives and policies are focused on encouraging sustainable development for transforming the current economy that is based on fossil raw materials into a sustainable one. Such is the example of *Renewable Carbon*, which stands for creating a circular economy for carbon by avoiding or replacing carbon from fossil origin by carbon from the atmosphere or the biosphere (Carus et al., 2020). It is in this latter source whereby carbon in biomass becomes the main raw material for the development of the so-called Biobased Economy (BBE) (Tait & Wield, 2021).

Research on fermentation processing by the Technische Universiteit Delft (TU Delft) and one of its spin-offs, *Delft Advanced Biorenewables* (DAB), have developed the so-called *Fermentation Acceleration by Separation Technology* (FAST). The technology enhances fermentation processes to increase volumetric productivity and has been used since 2012 by DAB (Biology Online, 2022; DAB, n.d.-b; HollandBIO, 2020; Innovation Quarter, 2019a). The company is about to start with its commercialisation phase, and it is expected that FAST will have financial impact and impact in the environmental aspect of sustainability on biobased chemicals production. Achieving these impacts is challenging for DAB because a biobased economy does not guarantee sustainability per-se. Biotechnology can potentially decrease GHG and ecotoxicity. However, these effects may come with negative impacts such as soil degradation, pollution of water, and land use change (LUC). Therefore, a proper BM that considers sustainability can contribute to commercialise FAST and thus comply with DAB's strategy and goals (Van Schoubroeck et al., 2019). Furthermore, the BM can also show the effects of FAST on the financial, environmental, and social aspects.

1.2. Research Gap

Environmental commitment has been acknowledged as a driver for developing technological sustainable innovations. To deploy the value of these technologies within the market, BMs play a role as they are a means for their commercialisation (Chen et al., 2006). Nevertheless, the link between technology and BMs is complex because technological innovations may lead towards the need of BMs to be adapted to create, develop, and capture value (Baden-Fuller & Haefliger, 2013; Bashir & Verma, 2016). Therefore, modifying BMs also represents a way of innovation which is called Business Model Innovation (BMI) (Zott et al., 2011).

Due to the complexity of implementing BMI, incorporating sustainability within BMs is a challenging task. Recently, this complexity has called the attention of scholars which have incorporated sustainability under the scope of BMI research (Foss & Saebi, 2017). There is still lack of empirical research on this novel field that involves aspects of sustainability and BMI related to corporate sustainability management, sustainable organisational development, organizational structure, organizational culture, organizational inertia, leadership, sustainable innovation, and technology (Bashir et al., 2020; Gjøsæter et al., 2021).

Regarding these eight gaps from the research field of sustainability and BMI, the one of technology is addressed in this thesis project by carrying out an empirical case study to explore how FAST can be a driver for sustainable business model innovation within the biobased chemical industry. By doing this, the research gap is reduced as the research provides empirical findings on how technology (the last topic in the previous paragraph), BMI, and sustainability relate each other.

1.3. Research Objective

The main objective of the thesis project is to determine under what conditions FAST contributes towards sustainable business model innovation.

To structure the research, the following specific objectives (SO) for this thesis project are:

SO1: Define sustainable business model innovation and its main aspects

SO2: Identify the traditional business models of biobased chemical companies

SO3: Identify how the current business models of biobased chemical companies can be modified towards sustainable business models by FAST technology

SO4: Design a sustainable business model for DAB based on FAST

1.4. Research Questions

The main research question is defined based on the main objective:

Main research question: *How can the FAST technology be a driver for sustainable business model innovation of biobased chemical companies?*

To guide the research and comply with the specific objectives, the following sub-research questions are posed:

SQ1: *What is Sustainable Business Model Innovation?*

The aim of this question is to define the concept of Sustainable Business Model Innovation, describe its main components, and identify its main research areas.

SQ2: *What are the traditional business models of biobased chemical companies?*

By answering this question, the most common business models used by companies within the biobased chemical industry will be found. This is relevant as it provides insight on how the industry operates.

SQ3: *How can traditional business models of biobased chemical companies transform themselves towards more sustainable business models using the FAST technology?*

This question explores different alternatives biobased chemical companies may have for carrying out sustainable business model innovation that can be addressed by FAST.

SQ4: *How can the FAST technology be used to design sustainable business models for DAB?*

Within this question, sustainable business models using the FAST technology are proposed for DAB. The importance of this lies in exploring the effects and limitations of the FAST technology in these models.

1.5. Research Approach

The thesis project has a research approach that consists of seven stages. Stage 1 begins with the problem definition and the formulation of the main research questions and sub-research questions. Stage 2 comprises a literature review on Business Models (BMs), Business Models for Sustainability (BMfS), Business Model Innovation (BMI), Sustainable Business Model Innovation (SBMI), Technology towards BMI, BMs of biobased chemical companies, and the fermentation process (secondary data). This second stage allows to develop a conceptual framework in which the thesis project is developed and also to answer the sub-questions 1 and 2 that are related to SBMI and BMs within the biobased chemical industry, respectively. Stage 3 is related to designing the research methodology for data collection that involves the use of questionnaires (primary data), the Delphi method (primary data), and desk research and data provided by DAB (primary and secondary data). Stage 4 elaborates on the case study and presents the company (DAB), market data, and describes the FAST technology. In this fourth stage, sub-question 3 that is related to the transformation of BMs within the biobased chemical industry by FAST is answered. This fourth stage also uses input from Stage 2 related to the current BMs of the biobased industry. Stage 5 answers sub-question 4 by proposing two business models based on the FAST technology. Stage 6 elaborates on the discussion of the findings of the research and the main contribution of the thesis. Stage 7 concludes the thesis by answering the main research question and elaborates on limitations of the project, further research, and recommendations for DAB. Figure 1 shows a diagram of the research approach.

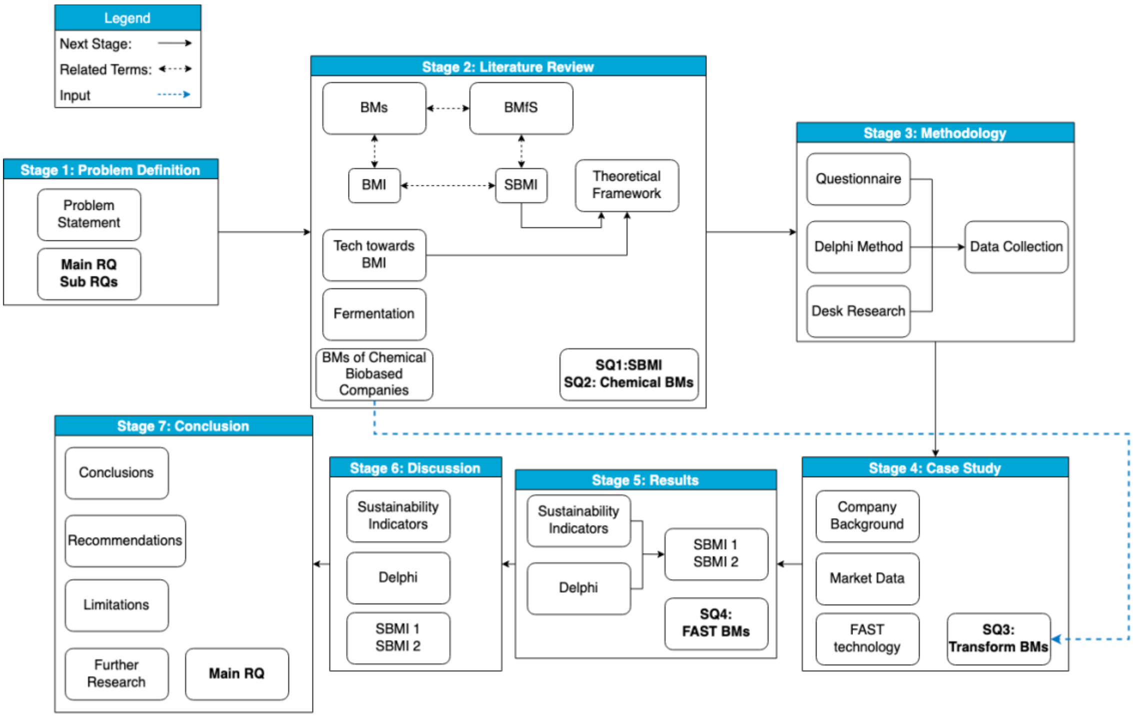

Figure 1: Research approach

1.6. Thesis Structure

The thesis project begins with Chapter 1 whereby the research gap, research objectives, and research questions to address the research problem are presented. Then, Chapter 2 presents the current state of research and provides the theoretical support for a conceptual framework in which the thesis is developed. The next chapter, Chapter 3 elaborates on the research methodology and describes the unit of analysis and the research methods that are used to answer the research questions. The chapter *Case Study*, which is Chapter 4, presents the background of DAB, the company in which the thesis project is carried out. Moreover, FAST and the current market segment the company is aiming to are described. Then, Chapter 5 presents the results obtained with the research methods mentioned in Chapter 3, this is, a questionnaire on sustainability indicators, the Delphi rounds applied on DAB members, and a comparison between the FAST technology and the petrochemical route for 2PE production using data provided by DAB. With the collected data, two business models including sustainability aspects are proposed. Here, a value proposition is created based on FAST. The next chapter, Chapter 6 discusses the results obtained in Chapter 5 and presents recommendations for the proposed sustainable business models. Finally, Chapter 7 presents the conclusions and limitations of the thesis project. Additionally, future research and recommendations for DAB are given. Figure 2 shows a scheme with the structure of the thesis.

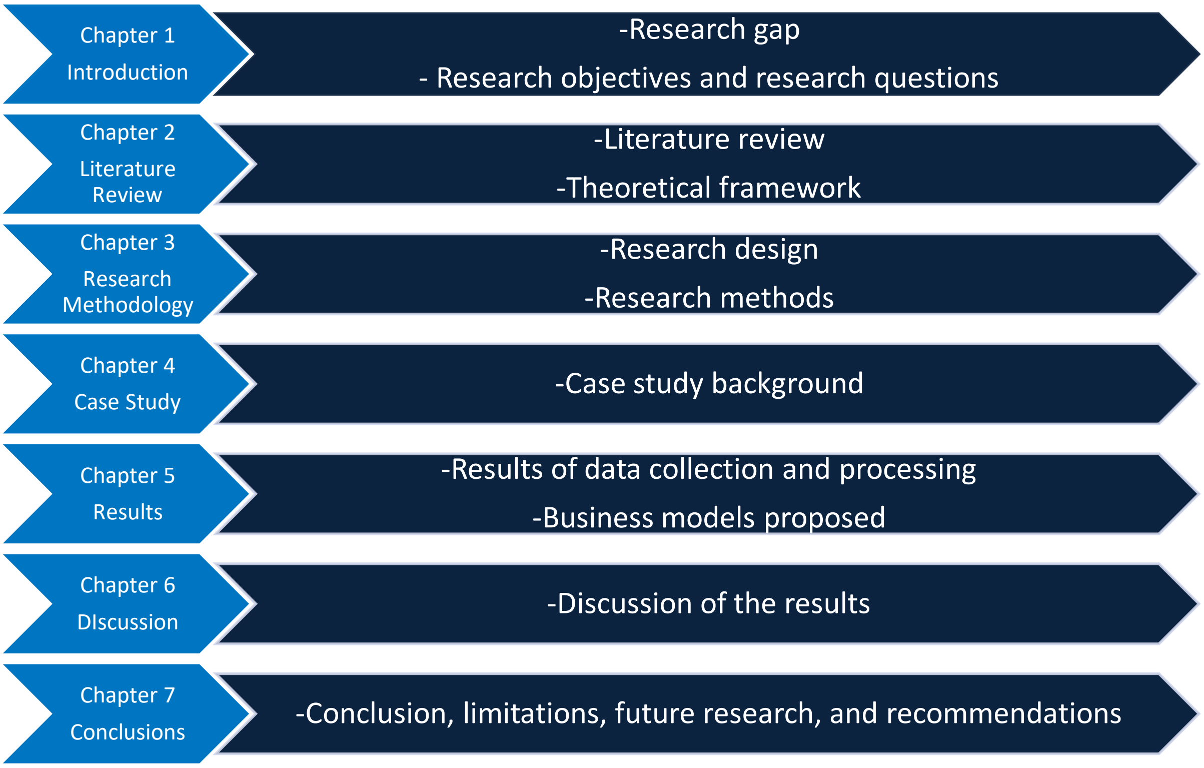

Figure 2: Structure of the thesis

Chapter 2: Literature Review

The following chapter presents a literature review of the theoretical framework in which the thesis project is developed. The review commences with the topic of Business Models. Here, their definitions, structures and main research areas are presented. The second topic involves Business Model Innovation. This research field is also depicted in terms of definition and main research areas, the third topic is related to Business Models for Sustainability in which a description of the field is made and also its state of the art. The fourth topic comprises literature that elaborates on how technological innovations can be a driver for developing sustainable business models. The fifth and sixth topics describe the business models that are applied in biotechnology for the chemical sector and a brief description on the fermentation process, respectively. Finally, the chapter ends with a proposed conceptual model that is based on the literature review topics related to BMI and sustainability.

2.1. Business Models (BMs)

It is argued by several authors that the concept of BM emerged and gained relevance during the 1990's due to the internet era, the rapid growth of emerging markets, and the interest in the so-called *Bottom of the pyramid* market. This latter concept refers to the market segment with the lowest income (Bashir & Verma, 2016; Seelos & Mair, 2007).

Despite the increasing in literature on BMs, scholars have not agreed yet on its definition and they usually define BMs according to the scope of their studies which brings difficulties in finding a generalized definition for the concept (Zott et al., 2011).

One of the first definitions is the one given by Timmers (1998) that is based on e-commerce, the author defines BMs as "an architecture of the product, service and information flows, including a description of the various business actors and their roles; a description of the potential benefits for the various business actors; a description of the sources of revenues". Within the article, components such as the actors and their respective roles, their potential benefits, and sources of revenue can be identified. Another definition is given by Amit & Zott (2001), they state that BMs are "the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities". Here, elements such as product, information, resources, capabilities, output, value creation, business opportunities, transaction content, transaction governance, and transaction structure are proposed by the authors.

One of the most known definitions is the one by Chesbrough & Rosenbloom (2002) which defines a BM as "the heuristic logic that connects technical potential with the realization of economic value", this definition can be considered general as it aims to describe BMs on a more abstract but at the same time vague as it does not elaborate on concrete elements. Despite this vague definition, the authors argue that the functions of BMs are related to elements such as: market, value proposition, value chain, cost and profit, value network, competitive strategy, revenue/ pricing, competitors, output (offering), and value creation.

Magretta (2002) came with a definition of BM, but with a more economic perspective that is based on the so-called *Peter Drucker's age old questions*, here Magretta identifies economic logic, customers, profit, cost, and value proposition as the key elements of a BM. Additionally, Morris et al., (2005) have also an economic point of view but they have a broader perspective that considers a BM as: "a set of decision variables on venture strategy, architecture, and economics that are addressed to create sustainable competitive advantage in defined markets". This definition may be considered novel as the authors include components such as the strategy and scale of the organization as elements within the BM.

Another definition was proposed by Osterwalder et al., (2005), here the authors define BMs as a tool or means for expressing the logic of a firm by describing its value offered to market segments of customers, the architecture of the incumbent firm, and its network of partners for creating, marketing, and delivering value. The main elements these authors recognise on a BM are value proposition, key relationships, key partners, customer relationships, channels, key activities, key resources, revenue streams, and cost structure. These elements are also present in the definition by Osterwalder & Pigneur (2010). For the authors a BM is still considered a tool that describes the rationale of how an organisation creates, delivers, and captures value. Teece (2010) is also a scholar that considers a BM as a tool. For him a BM "articulates the logic, the data and other evidence that support a value proposition for the customer, and a viable structure of revenues and costs for the enterprise delivering that value". He identifies fewer elemental components of the BM but remains in the main idea of benefit delivered, benefit delivery, and value capture.

Other authors as Zott and Amit have changed the scope of their BM definitions throughout time. They first stated a definition that was based on different kinds of abstract transactions (not only economic). However, they adopted an approach which considers a BM as a system of interdependent activities that allows firms to create and capture value (Amit & Zott, 2001; Zott & Amit, 2010).

Finally, the most recent definitions have considered BMs as just descriptive tools, for example, Gassmann et al., (2013) think that BMs "describe how the magic of a business works based on its individual bits and pieces". On the other hand, Wirtz et al., (2016) argue that a BM "is a simplified and aggregated representation of the relevant activities of a company". Additionally, other scholars such as Saebi & Foss and Geissdoerfer et al., also share similar aspects on their definitions and components of the BMs as the value proposition, revenue model, customers, and value delivery (Geissdoerfer et al., 2016, 2018; Saebi & Foss, 2015). A more extended version of the definitions and elements of BMs can be found in Table 13 (see Appendix I).

Despite all these conceptual differences, four emerging commonalities within BM research can be identified. First, BMs are considered as units of analysis that are focused on the incumbent firm. Second, BMs aim to have a holistic approach for explaining how companies do business. Third, activities for both the incumbent firm and its partners have role within business models conceptualizations. Fourth, BMs aim to explain value creation and value capture (Zott et al., 2011). Based on this fourth commonality and according to Foss & Saebi (2017), BM definitions move around Teece's (2010), who argues that a BM is the "design or architecture of the value creation, delivery, and capture mechanisms". For the thesis project, Teece's definition is considered.

Regarding the research areas on this field, it is possible to distinguish three main streams of research that go in line with BMs' definitions (Foss & Saebi, 2017). The first stream aims to use BMs as a means to classify and understand the value drivers for e-commerce and the use of information technologies within organizations (Amit & Zott, 2001; Magretta, 2002). The second stream is focused on studying BMs as a factor for firms' performance, strategy, and competitive advantages. Additionally, scholars also analysed which BMs where better than others and which ones were imitated (Foss & Saebi, 2017; Teece, 2010). The third stream, set an interesting perspective because it considers BMs by themselves as a unit for innovation and technology management. (Zott et al., 2011).

In practice, BMs can help companies, entrepreneurs, and scholars to display the hypotheses they may have regarding customers' needs, how an organization can meet these needs and obtain profit for it (Bidmon & Knab, 2018). In other words, BMs are useful for developing, describing, and analysing how a companies operate (Gassmann et al., 2013). The way for doing this is by means of the so-called Business Model Frameworks (BMF) such as STOF, VISOR, BM Navigator, Business Model Cube, and the Business Model Canvas (BMC) which are tools for designing BMs (Haaker et al., 2017). The latter model, created by Osterwalder & Pigneur (2010), is considered the most known and the *de facto* dominant model as it is used both in companies and academia (Geldres-Weiss et al., 2021). The BMC is a tool that consist of nine building blocks that must be taken in account to design a BM (Osterwalder & Pigneur, 2010). The blocks are described as follows:

1) **Customer segments:** Different groups of people or organizations an enterprise aims to reach and serve.

2) **Value proposition:** Products and services that create value for a specific customer segment. It is the reason why customers turn to one company over another. It solves a customer problem or satisfies a need.

3) **Channels:** How a company communicates with and reaches its customer segments to deliver a value proposition. This comprises communication, distribution, and sales channels.

4) **Customer relationships:** Relationships a company establishes with specific customer segments. This involves customer acquisition and customer retention.

5) **Revenues:** How a company generates cash from each Customer segment.

6) **Key resources:** Most important assets required to make a business model work.

7) **Key activities:** Most important activities a company must do to make its business model work.

8) **Key partnerships:** Network of suppliers and partners that make the business model work.

9) **Cost structure:** Costs incurred to operate a business model.

The BMC layout with its blocks is shown in Figure 3.

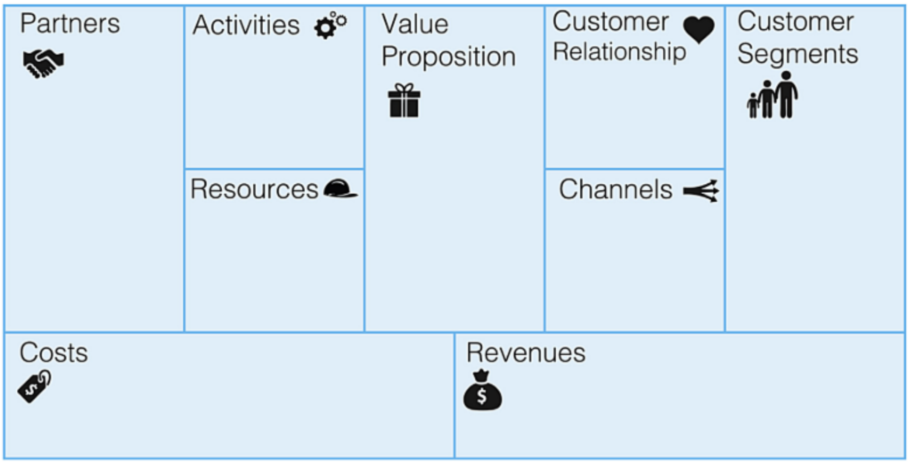

Figure 3: BMC framework (Joyce & Paquin, 2016; Osterwalder & Pigneur, 2010; Strategyzer, 2020)

Criticisms of this model involve its lack completeness as is does not include others aspects that can be relevant such as *unfair advantage*, key metrics, goals, competitors, and limitations. Moreover, the model is also criticized for being too simple to show the dynamics of the interaction and interrelations among the blocks over time (Khodaei & Ortt, 2019). Moreover, the canvas only considers the economic impact of a BM and overlooks aspects that concern environmental and social impact. This gap is aimed to be addressed by the so-called Sustainable Business Models (SBMs) that are described in section 2.3.

Another critic for BMC is that the methodology on how it was created is not described. Additionally, it does provide neither the necessary tools for filling each of the blocks nor assessing its consistency, leaving task to the designer. Nevertheless, its simplicity is useful for businesses to design and iterate several models and then, develop a thorough strategy with a proper market research.

2.2. Business Model Innovation (BMI)

The idea of BMI relates to changing a BM due to either external or internal factors (Foss & Saebi, 2017; Geissdoerfer et al., 2018). Similarly, as BM, BMI has several definitions that also depends on the authors' research scope. For example, one of first definitions of the term is given by Mitchell & Bruckner Coles (2004), they state that BMI is "business model replacements that provide product or service offerings to customers and end users that were not previously available". Osterwalder et al., (2005) also have a similar definition that relates to experiment with the blocks of a BM to create a new one.

The concept has also been addressed as a means for improving a current BM that may be considered *basic* without not much value towards a more *advanced* one that offers mores value to the organisation (Chesbrough, 2007). This definition may be considering implicitly that the current BM lacks value, but it does not consider the context and the conditions in which the was designed. The definition is also vague as it does not state what an *advanced* BM is or means. Furthermore, the author does not even elaborate on how these changes are done.

Romero & Molina (2009) propose a more evolutionary definition in which BMs should be constantly reviewed as a response to changes that may occur in the market to evolve the firm's strategy and thus address new market conditions and new customer needs. This point of view can be considered novel because states that BMI is not making just one change on the initial

BM, but a series of successive changes that may emerge within an organisation to adapt to external conditions given by the market.

Amit & Zott, (2012) and Abelkafi et al., (2013) adopted an approach whereby BMI is defined as redefinitions, modifications or improvements that a firm can have on its activities, the activities' interactions, and the entities that perform the activities (value dimensions). This conceptualisation offers a more practical approach because considers that BMI modifies BMs in certain aspects that may be distinguished.

Another group of BMI definitions in which among is Casadesus-Masanell & Zhu's (2013) define BMI as a "search for new logics of the firm and new ways to create and capture value for its stakeholders". Other definitions as Khanagha et al.,'s (2014) also have a similar perspective but state that BMI may be on a spectrum of changes that moves from incremental changes to replacing the current BM with a new one. It can be seen that these definitions give emphasis to the notion of change but in a broader perspective rather than the practical approach of Amit & Zott, (2012) and Abelkafi et al., (2013).

One of the most recent definitions is the one given by Geissdoerfer et al., (2016), the authors state that "Business model innovation describes either a process of transformation from one business model to another within incumbent companies or after mergers and acquisitions, or the creation of entirely new business models in start-ups". It can be noticed in this definition that the authors' scope not only pays attention on the incumbent company, but also considers that the incumbent firm may change due to mergers and acquisitions. This approach is novel if compared to the previous definitions that only consider BMs as the changing element while the firm remains static.

As it can be seen, the definition for BMI varies according to the author's points of view and scope of their research. Nevertheless, an element these definitions have in common is the notion that something within the current BM will be subjected to change. Based on this definition some authors argue that BMI is driven by a changing environment of firms, while others are more focused on companies achieving competitive advantages to overcome their competitors. A more extended version of the definitions of BMI can be found in Table 14 (see Appendix I).

For the thesis project, two definitions are considered that complement each other. The first one groups Amit & Zott's (2012), Abelkafi et al.,'s (2013), Casadesus-Masanell & Zhu's (2013), and Khanagha et al.,'s (2014) which considers BMI as an outcome that comes within a spectrum of changes. Whilst the second definition given by Romero & Molina (2009), argues that BMI is a response to changes within the market.

Regarding the origins of BMI, Bucherer et al., (2012) identify two cases. The first one occurs when an organization is forced to innovate its BM, this is called *threat*. In the second case, the organization innovates voluntarily to seize an opportunity, which is called *opportunity*. Additionally, the authors also identify that the origins of BMI can be internal or external to the organization. One example of an internal threat is the increase in the price of certain resources, while an example of internal opportunity may arise when resources are underutilised and may be exploited for other activities. On the other hand, external threats and opportunities may come when there are changes in technologies, competitors, markets, and regulations. Table 1 summarises the four types of BMI origins.

Table 1: Categorizations of BMI origins (Bucherer et al., 2012)

Internal Opportunity	External Opportunity
Internal Threat	External Threat

BMI is also a phenomenon that occurs in different degrees that are related to the extent of novelty (to the firm or the industry) or the scope of the changes (individual components or systemic/architectural structure) (Foss & Saebi, 2017). According to this, four main categories for BMI can be identified:

Evolutionary BMI: relates to fine-tuning processes involving voluntary and emergent changes.

Adaptive BMI: relates to changes within the BM that are new to the firm but not necessarily new to the industry.

Focused BMI: relates to innovations in one area of the BM, such as targeting a new market segment that has been ignored by its competition but keeping the other components of the BM.

Complex BMI: relates to BMI that changes the BM's entirety.

Table 2 summarizes BMI dynamics and groups them by extent scope and degree novelty.

Table 2: BMI dynamics (Foss & Saebi, 2017)

<table>
<tr><td rowspan="4">Novelty</td><td colspan="3">Scope</td></tr>
<tr><td></td><td>Modular</td><td>Architectural</td></tr>
<tr><td>New to firm</td><td>Evolutionary BMI</td><td>Adaptive BMI</td></tr>
<tr><td>New to industry</td><td>Focused BMI</td><td>Complex BMI</td></tr>
</table>

Regarding the research lines in BMI, Foss & Saebi (2017) classified four main categories. The first is related to the conceptualization and definition of BMI and the dimensions in which firms can innovate their BMs. The second focuses on BMI as a process and analyses how this type of innovation has effects on leadership, learning mechanisms, and capabilities of a firm.

Moreover, the stages of BMI, the required capabilities by the companies and managers, and the design of tools for managing the process of BMI are also studied. The third line studies BMI as an output and uses a descriptive and exploratory approach based on case studies to understand which and why new BMs emerge within a certain industry. The fourth category studies the effects and implications of BMI on companies' performance and organizational structure. Here scholars use a more quantitative approach as they carry out their research based on surveys.

The main research gaps within BMI are related and addressed by the aforementioned research streams. The first gap involves definition and conceptualisation of the BMI concept. Additionally, scholars also aim to define the proper unit of analysis that differs if BMI is considered as a process or as an outcome. The second gap is related to study the antecedents, drivers, and effects and consequences of BMI. Here, not many studies have been able to study rigorously the effects of BMI due to the complexity of linking the concept to performance. This occurs because when innovating on a BM, one or more of its components can be modified, which makes hard to understand the relationships between BMI and the components. Moreover, to measure the performance of BMI, the new BM needs to be put in practice, so a time dimension may be required to obtain and measure results (Foss & Saebi, 2017).

The third research gap focuses on contingency and moderating variables for BMI. Within this body of research, the role of leadership and organisational capabilities as moderator variables is analysed. Furthermore, the effects of learning and experimentation as well as cognition are also included. Another gap that is addressed by scholars is understanding the role of organisational structures in BMI design. On the other hand, the fourth research gap addresses the boundary conditions on BMI. This has to do with the antecedents and consequences that BMI will have depending on the type and characteristics of company in which is applied. For example, it could be applied on start-ups, traditional or high-tech companies. A new gap that has emerged recently is the use of BMI in other research fields. Within these new fields, the use of BMI in sustainability has gain popularity. Here, the authors carry out research on how a BM can be a means to achieve the triple-bottom-line of sustainability (N. Bocken et al., 2014; Foss & Saebi, 2017).

Literature on BMI has expanded throughout recent years. However, there is still a small body of research compared to other related topics. Figure 4 shows the number of scientific articles on BM, BMI, Open Innovation (OI), and Dynamic Capabilities (DC) that appear on Scopus search engine by filtering by the research areas of "Business, Management and Accounting", "Social Sciences", and "Arts and Humanities ". It can be seen that the recent literature on BMI is barely over 300 articles per year, while other bodies of research surpass this amount by at least the double. So far, the concept still lacks clarity what it makes difficult to operationalize and measure. Moreover, BMI is still missing research models that allow studying properly the antecedents, moderating and mediating variables that affect BMI. Due to this lack of research, BMI offers opportunities to carry out further research that still need to define its core constructs and principles (Foss & Saebi, 2017).

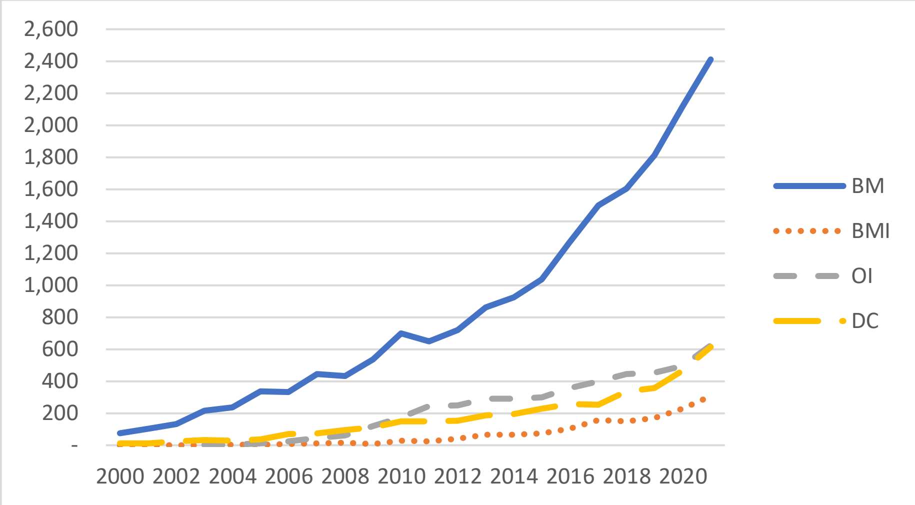

Figure 4: Number of articles on BM, BMI, OI and DC(self-elaboration, based on (Foss & Saebi, 2017)*)*

2.3. Business Models for Sustainability (BMfS)/Sustainable Business Models (SBM)

From now onwards the term Business Models for Sustainability (BMfS) is used interchangeably with the term Sustainable Business Models (SBMs) (Lüdeke-Freund & Dembek, 2017).

Sustainability has to with creating value for shareholders, as well as maximizing environmental and societal wellbeing. For companies to adopt sustainability and gain competitive advantages, the concept of BMfS emerged. The idea is relatively recent and has received several definitions by scholars (Abdelkafi & Täuscher, 2016; . Bocken et al., 2014; Cosenz et al., 2020). Stubbs & Cocklin (2008) define as "a model where sustainability concepts shape the driving force of the firm and its decision making [so that] the dominant neoclassical model of the firm is transformed, rather than supplemented, by social and environmental priorities". This definition sets environmental and social aspects a priority over the economic development of a business which may be considered novel as BMs are aimed to maximise profit. Other definitions tend to harmonise the three components of the triple-bottom line, for example, Schaltegger et al., (2012) say that BMfS is related to "create customer and social value by integrating social, environmental, and business activities". Garetti & Taisch (2012) also have an harmonizing approach.

Other authors complement the concept by including stakeholders within the definition (Bocken et al., 2014; Bocken et al., 2013; Boons & Lüdeke-Freund, 2013). For example, Bocken et al., (2014) state that BMfS "aligns interests of all stakeholder groups, and explicitly considers the environment and society as key stakeholders". This group of definitions addresses a more comprehensive point of view as it considers that companies are one stakeholder among several and the interests of all the rest must be considered when doing business.

A third category of definitions includes elements such as the value proposition and value creation. For example, Abdelkafi & Täuscher (2016) state that BMfS "incorporate sustainability as an integral part of the company's value proposition and value creation logic. As such, BMfS …provide value to the customer and to the natural environment and/or society". While Geissdoerfer et al.,'s (2016) definition also keeps these elements, they adopt a more practical scope that defines BMfS as a tool for representing the links among all the elements of a firm and its related stakeholders.

A recent conceptualization is the one given by Evans et al., (2017), that adopt a different approach to characterize the concept. The definition is perhaps novel because it explicitly states what is required for a BM to be considered sustainable, instead of just remaining in descriptive definitions as Stubbs & Cocklin (2008) or Schaltegger et al., (2012) do.

The most recent definition for BMfS is proposed by Geissdoerfer et al., (2018). The authors state that BMfS are "business models that incorporate pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and hold a long-term perspective". The authors proposed this definition based on the literature review they carried out on the BMfS concept and aimed to englobe a concept that includes value proposition, value creation, value delivery, stakeholders, dynamism (pro-activity), and long-term development. It can be seen that society and environment are not explicitly included in the definition, but it can be assumed they are included within the stakeholders. For the thesis project, this definition is used.

As is can be noticed, the common element present within these definitions is the inclusion of goals and more *entities* such as the environment or society, rather than just focussing on the incumbent firm. Other definitions adopt a more general scope and refer to stakeholders and the interrelations among them. An extended version of the definitions and elements of SBMs can be found in Table 15 (see Appendix I).

Within Sustainable Business Models, a subset called Circular Business Models (CBMs) can be identified. These BMs are underpinned by the concept of *closing the life cycle* of products by means of reducing the consumption of resources and considering end-of-life materials as raw materials that can be reintroduced within the production cycle (Daou et al., 2020). Figure 5 shows a diagram of the sets for BMs within the context of BMfS.

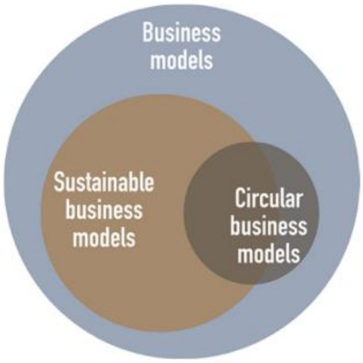

Figure 5: BMs and its subsets (Geissdoerfer et al., 2018)

SBMs can be considered as intermediate step between traditional BMs and CBMs. SBMs enhance BMs by introducing sustainable value, long-term perspective, and a pro-active multistakeholder management that aim to provide solutions for sustainability. On the other hand, CBMs go further as they aim to close the loops within the production chain by for example, intensifying the use of resources, narrowing resources or dematerialising resource loops. Figure 6 shows a scheme that depicts the evolution from BMs to SBM and CBM.

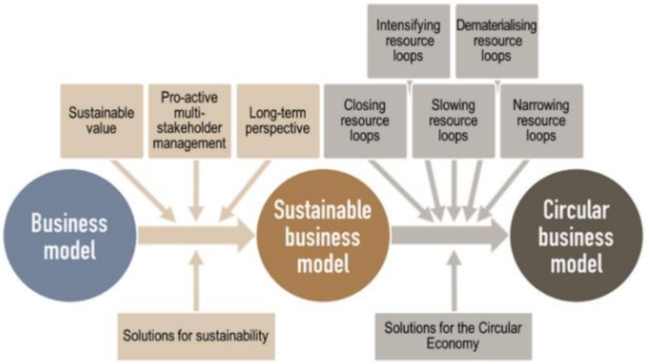

Figure 6: BM, SBM, and CBM (Geissdoerfer et al., 2018)

SBMs offer several ways to achieve sustainability. Bocken et al., (2014) categorized these options in the so-called *Sustainable business model archetypes*. The authors defined eight archetypes to classify SBMs in three main categories that are related to technological, social, and organizational aspects (see Figure 7). The categorization aims to be a practical guideline for companies and entrepreneurs to assess which archetype may be suitable for their company's strategy by modifying the very core of their value proposition, value creation, value capture, and value delivery. Nevertheless, the archetypes have some limitations. They just explain how to change the value proposition but now how to change other components on the BM nor how to implement those changes. Additionally, the archetypes are just a classification of current SBMs and do not include BMs that may arise in the future.

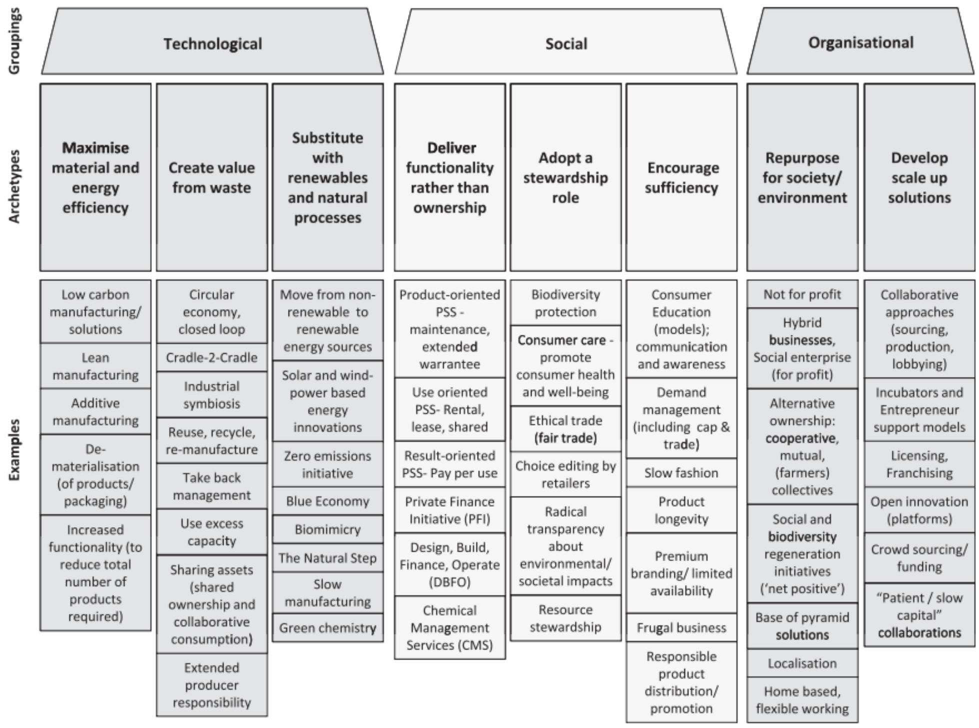

Figure 7: SBMs archetypes (N. Bocken et al., 2014)

The design, adoption, and research within SBMs has been increasing mainly due to the hype for sustainability in both business and academia that has been triggered mainly to tackle climate change and at the same time remain completive (Geissdoerfer et al., 2018). The creation of SBMs considers a new perspective that not only focus on the company, but also includes the stakeholders involved and affected by the firm's operations (Geldres-Weiss et al., 2021). Some firms may consider that innovation towards SBMs may be risky and challenging, mainly because technology towards sustainability in general is incremental, which may be difficult for firms to comply with sustainability targets (Rashid et al., 2013). Nevertheless, technology is just one element from which innovation may come. As it has been shown, BMs are also a source for innovation and can be useful for leveraging technological innovations and at the same time profits. As Chesbrough (2007) states, BMIs may lead to higher returns than product or process innovations. Therefore, a more entrepreneurial scope for companies may be adopted to consider BMI as an opportunity to become sustainable and differentiate from competitors (Joyce & Paquin, 2016; Rashid et al., 2013).

The link between BMI and BMfS is a recent research stream that started around 2015. It stands for emphasizing sustainability a key element for BMI because the inclusion of stakeholders such as the environment and society can create competitive advantages for companies to bring sustainable products and services to the market and at the same time, fulfil customers' requirements and comply with the increasing sustainable agenda of global businesses (Hossain, 2017).

To design BMfS several frameworks have been developed. One SBM framework is the so-called *Triple Layered Business Model Canvas* (TLBMC) (Joyce & Paquin, 2016). This model aims to integrate the social and environmental aspects of sustainability by adding two extra layers (sheets) to the traditional Osterwalder & Pigneur's (2010) BMC from Figure 3. The social layer is focused on stakeholders and aims to explore firms' social impact to balance the interest of the stakeholders rather than just maximizing profit for the firm, in this way, the definition the authors are using for stakeholders is: "the groups individuals or organizations which can influence or is influenced by the actions of an organization". On the other hand, the environmental layer builds the Life Cycle Assessment (LCA), a tool to measure the environmental impact of a product or service throughout its life. Although the layer does not include a formal LCA, it integrates its life-cycle point of view when assessing the environmental impact of a BM. The TLBMC is a useful tool as allows users to visualise the BM's elements and the interrelations among the components.

The blocks from the second layer, the social, are described as follows:

1) **Social value:** It is related to the organization's mission which focuses on creating benefit for its stakeholders and society more broadly.

2) **Employee:** Considers the role of employees as a core organizational stakeholder. Elements that may be included comprise the amount and types of employees, demographics such as variations pay, gender, ethnicity, and education.

3) **Governance:** Focuses on the organizational structure and decision-making policies of the organization. It also defines which stakeholders an organization is likely to identify and engage with and how the organization is likely to do so. Additionally, aspects related to ownership of the company and internal organizational structures can be included.

4) **Communities:** Comprises social relationships with suppliers and their local communities. It is important for an organisation that operates in different countries to

consider each community as a different stakeholder with different cultural needs and realities.

5) **Societal culture:** Relates to the potential impact of an organization on society as a whole. This component leverages the concept of sustainable value to acknowledge an organization potential impact on society and how, though its actions, it can positively influence society.

6) **Scale of outreach:** Describes the depth and breadth of the relationships an organization builds with its stakeholders through its actions over time. This may include long term, integrative relationships, and the outreach of impact geographically. Moreover, it addresses societal differences such as local interpretation on ethics or cultural actions.

7) **End-users:** Is the individual that *consumes* the value proposition. This block relates with how the value proposition addresses the needs of the end-user. End-user is not always the customer as defined in the economic layer of the BMC.

8) **Social impacts:** Addresses the social costs of an organization. It complements and extends the financial costs of the economic layer and the bio-physical impacts of the environmental layer. Some indicators on this block may include working hours, cultural heritage, health and safety, respect of intellectual property rights. The focus depends on the organization and may create its own indicators.

9) **Social benefits:** Correspond to the positive social value creating aspects of the organization's action.

The social layer of the TLBMC is shown in Figure 8.

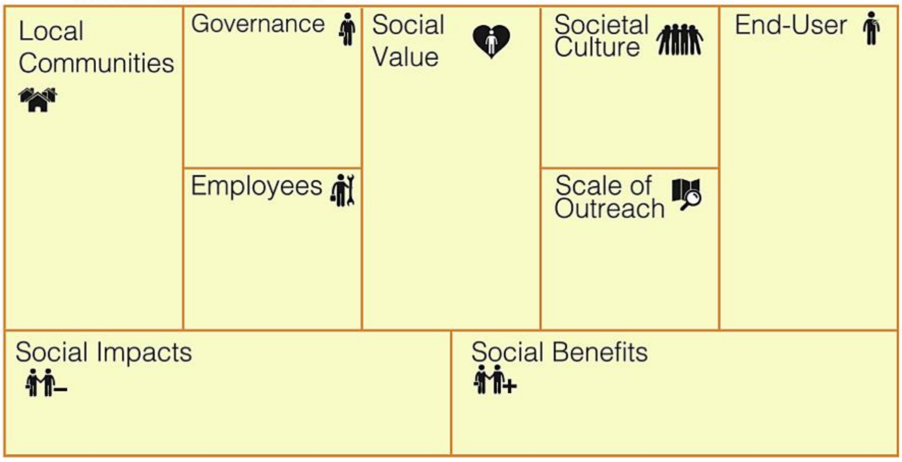

Figure 8: Social layer of the TLBMC (Joyce & Paquin, 2016)

The blocks from the third layer, the environmental, are described as follows:

1) **Functional value:** Describes the outputs of a service (or product) of the organization. It emulates the functional unit in a life cycle assessment, which is a quantitative description of either the service performance or the needs fulfilled.

2) **Materials:** Is the environmental extension of the key resources component from the original BMC. It refers to the bio-physical stocks used to render the functional value. It is recommended not to introduce all the materials within the canvas, otherwise it becomes unpractical.

3) **Production:** Extends the key activities component from the original BMC and captures the actions that the organization undertakes to create value.

4) **Supplies and outsourcing:** Represents all the other various material and production activities that are necessary for the functional value but not considered *core* to the organization. It may also be conceived of as the actions that are outsourced.

5) **Distribution:** It combines transportation modes, distances travelled and weights of what is shipped.

6) **Use phase:** It focuses on the impact of the customer's partaking in the organization's functional value, or core service and/or product. This may include maintenance and repair of products when relevant. It should include some consideration of the customer's material resource and energy requirements through use.

7) **End-of-life:** Is when the customer chooses to end the consumption of the functional value and often entails issues of material reuse such as remanufacturing, repurposing, recycling, disassembly, incineration, or disposal of a product. This component supports the organization exploring ways to manage its impact through extending its responsibility beyond the initially conceived value of its products.

8) **Environmental impacts:** Addresses the ecological costs of the organization's actions based on LCA. The indicators may be related to bio-physical measures such as CO_{2eq} emissions, human health, ecosystem impact, natural resource depletion, water consumption.

9) **Environmental benefits:** Extends the concept of value creation beyond financial value to the ecological value the organization creates through environmental impact reductions and regenerative value. This component provides space for an organization to explicitly explore product, service, and business model innovations which may reduce negative and/or increase positive environmental through its actions.

The environmental layer of the TLBMC is shown in Figure 9.

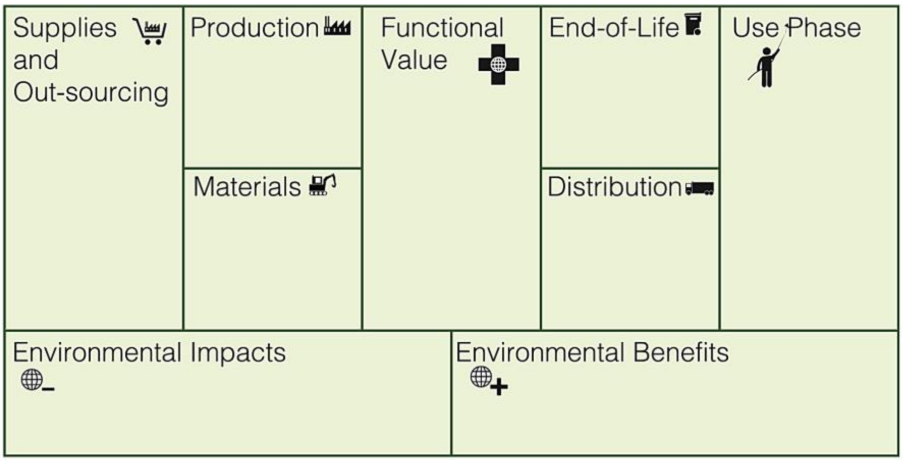

Figure 9: Environmental layer of the TLBMC (Joyce & Paquin, 2016)

The TLBMC also allows to carry out a more comprehensive analysis on consistency of a BM design as it analyses the *horizontal and vertical coherence*. Horizontal coherence refers to coherence within a layer, while vertical coherence refers to coherence within layers. Figure 10 shows a representation of this dynamic.

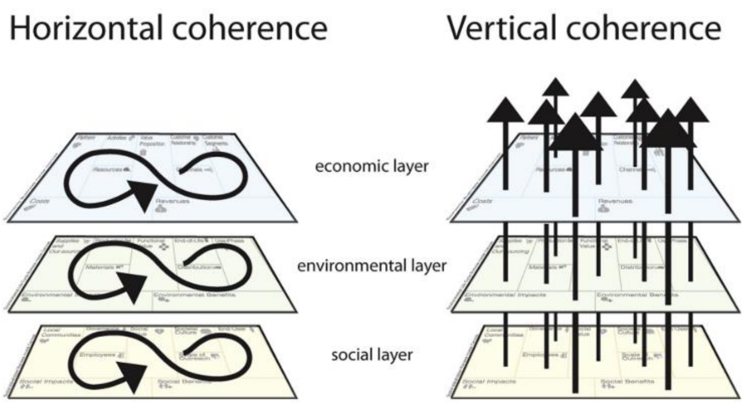

Figure 10: Horizontal and vertical coherence of the TLBMC (Joyce & Paquin, 2016)

In the article, the authors show the application of the model on a study case, the Nespresso business model, and make a comprehensive analysis of it that may be used as a reference for other case studies (Joyce & Paquin, 2016). One critic of the article is that, although the rationales for creating the framework are mentioned, it does not show the methodology on how it was created.

Another framework that was found in the literature is the Value Triangle (VT), proposed by Biloslavo et al., (2018). The model aims to represent how a firm can co-create and co-deliver value within its stakeholders in a circular value system and at the same time be profitable. The VT does this by having a value proposition that explicitly states the company's commitment to co-create value for its stakeholders, society, environment in a way to fulfil their needs. The main features this model has are: explicit orientation towards value co-creation for society at large; more comprehensive consideration of costs and benefits produced by the firm's activities; broad consideration of capital that includes anything that has a capacity to generate benefits. Additionally, the VT building blocks are displayed as triangles to reflect the relationships that exist among the actors involved in the business activity; and a circular conception of value co-creation and co-delivery (see Figure 39 and Figure 40 on Appendix II).

To build the VT, the authors carried out a systematic literature review on business models. Then, according to ranking and relevance criteria, 20 BMs were selected and analysed under the scope of the so-called *eco critical perspective*. This perspective compared the definitions of the BMs and its components considering criteria such as the triple bottom line, long-term orientation, environmental limits, and resilience (Biloslavo et al., 2018).

The main findings of this article are that there is not yet a consensual definition of BMs as it varies among discipline's point of view (business model innovation, management, entrepreneurs). Furthermore, based on the eco critical perspective the definitions have explicitly or implicitly a market or profit orientation that just considers customers and shareholders, overlooking the interrelations with society and the environment. After proposing the VT, the authors applied it on a case study that was Loccioni, an Italian company that designs and manufactures control systems. The authors state that by using the VT, they were able to show thoroughly the societal and environmental contributions of the company (Biloslavo et al., 2018).

Compared to the TLBMC, the VT can integrate the triple bottom line and their interrelations in just one framework, which makes it easier for BM creation and analysis. This can also be practical for entrepreneurs when showing the VT to potential investors that may be able to see all in one scheme. Regarding criticism, the VT may be hard to visualise and understand due to its layout. Furthermore, this model may be more comprehensive than the traditional BMC, but it may be hard to introduce as the BMC already became the dominant model.

Bocken et al., (2018) also proposed a framework called the Sustainable Business Model Canvas (SBMC) that builds on the ideas of Osterwalder & Pigneur's (2010) BM generation and their BMC, Richardson's (2008) business model framework, and Bocken et al.,'s (2014) conceptualization of SBM. According Osterwalder & Pigneur's (2010), the design of a BM is an iterative process that begins with defining a value proposition that fits a certain customer segment's needs in which the BMC allows to visualise the BM's components. The framework proposed by Richardson (2008) not only includes the concept of *value proposition* but also incorporates the terms *value creation and delivery system*, and *value capture*. The author defines the *value proposition* as *"what the firm will deliver to its customers, why they will be willing to pay for it, and the firm's basic approach to competitive advantage"*. The *value creation and delivery system* are described as *"how the firm will create and deliver that value to its customers and the source of its competitive advantage"*. While *value capture* is defined as *"how the firm generates revenue and profit"*. Finally, Bocken et al., (2014) build on Richardson's (2008) value proposition and state that for a SBM, the value proposition gives a measurable environmental and social value that go in-line with the financial value (see Figure 41, Appendix III).

This framework can be considered useful for companies and entrepreneurs because it is based on Osterwalder & Pigneur's (2010), which is the *de facto* dominant framework that has been widely used and tested, and it incorporates sustainability aspects that allow the firm/entrepreneur to have a general overview of its activities and its effects within the environment and society. Nevertheless, this overview may be limited because it does not offer a comprehensive analysis of the BM, its effects, and interrelations among the components.

The most recent framework is the Ecocanvas. It aims to design a SBM to achieve *Circular Economy* (Daou et al., 2020). The model builds on the existing BMC and includes aspects related to current and future economic and legal matters, environmental challenge, and technological and societal challenges (Daou et al., 2020; Osterwalder & Pigneur, 2010). Additionally, the model is novel as it incorporates innovation within its blocks (see Figure 42 and Figure 43, Appendix IV) (Daou et al., 2020). This framework has the objective of being a practical modular tool (gather tools) that is composed by 15 tools that are linked to the building blocks and thus, offer a systematic methodology that can guide enterprises, entrepreneurs, and scholars to develop and analyse circular BMs (Daou et al., 2020). Regarding the features of the Ecocanvas, the model differs from the BMs already explained as it gives the possibility to firms to shift and operate under a different economic paradigm, the circular economy. The inclusion of innovation also offers room for companies to think their strategy and development in the long-term. One limitation for the model is that it was developed in 2020 and still need to be tested in different industries and sizes of companies to be validated and incorporate changes if necessary.

2.4. Sustainable Business Model Innovation (SBMI)

SBMI is a recent subset of SBMs research that started around 2013. There are not many definitions of the concept but what they have in common is that they merge BMI with sustainability aspects (Geissdoerfer et al., 2018). For example, Boons & Lüdeke-Freund (2013) define SBMI as "the adaption of the business model to overcome barriers within the company and its environment to market sustainable process, product, or service innovations". As is can be seen, this definition is focused on the incumbent firm. Other definitions such as Loorbach & Wijsman's (2013), Bocken et al.,'s (2014), and Geissdoerfer et al.,'s (2016) have a more comprehensive approach that includes the notion of environment and society as stakeholders. Another approach by Roome & Louche (2016) and Schaltegger et al., (2016) considers SBMI as a process on how firms change their current BMs to achieve sustainable development. These descriptions are more descriptive as they put emphasis on the process of change rather than what is meant by SBMI. Loorbach & Wijsman's (2013) definition can be also considered within these kind of definitions. Moreover, the definition by Yang et al., (2017) addresses the concept as a goal or output that can be achieved by identifying uncaptured value in current BMs and use this value opportunities to modify the BM to achieve higher sustainable value.

The most recent definition, given by Shakeel et al., (2020) builds on Schaltegger et al., (2016), Loorbach & Wijsman's (2013), and Roome & Louche (2016) and argues that SBMI is a subset and overlapping concept that gathers elements from BM (the way a firm's strategy is put into practice), SBM (integration of sustainability perspective) and BMI (see Figure 11). The authors state that SBMI "… deals with the modification of a business model to a more sustainable business model. This comprises either the creation of an exclusively new business model or changes the existing business model to innovatively address sustainability issues for its stakeholders for creating a long term sustainable competitive advantage. The change involves modification to its components" (Shakeel et al., 2020).

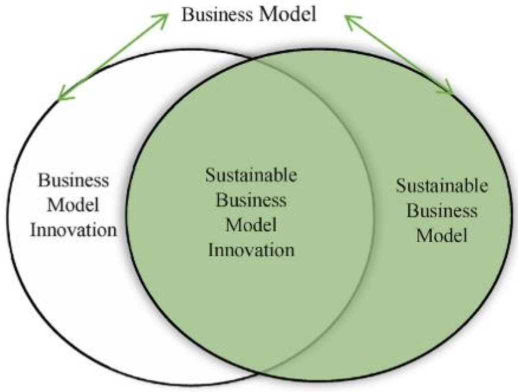

Figure 11: Fundamentals of SBMI (Shakeel et al., 2020)

Based on these merged ideas, the authors state that the core of SBMI is sustainable value innovation and propose the following concepts: of Sustainable Value Proposition Innovation (SVPI), Sustainable Value Creation and Delivery Innovation (SVC&DI), and Sustainable Value Capture Innovation (SVCI). SVPI involves an organisation's promise to its customers by leveraging into new opportunities and creating long term relationships with them and society. SVC&DI is related to a company's capability to manage value chain networks by managing resources, capabilities, activities, and partnerships. Finally, the authors define SVCI as the ability of a firm to capture economic, social, and environmental value by designing sustainable revenue models and cost structures Shakeel et al., (2020). Figure 12 shows a diagram with the core components of SBMI.

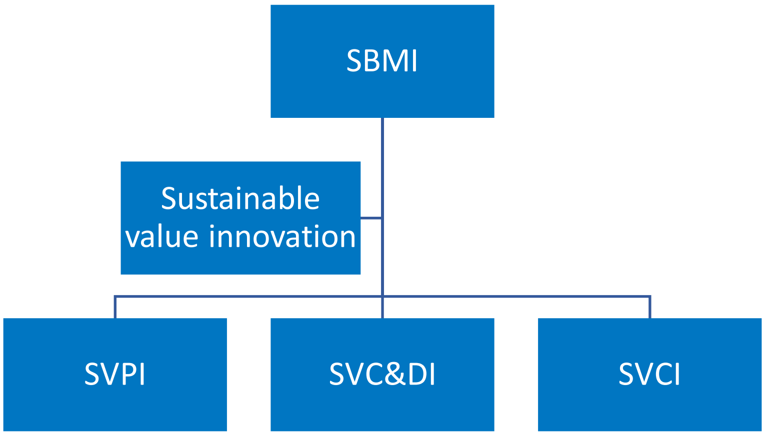

Figure 12: SBMI components, adapted from (Shakeel et al., 2020)

It can be noticed that all definitions integrate both BMI and sustainability to some extent. Therefore, it can be argued that for considering SBMI as such, a firm must aim to: (1) have positive and/or reduced negative impact on the environment, society, incumbent organization, and stakeholders in the long-term or, (2) adopt solutions that nurture sustainability within the value proposition, value creation, and value capture or the value network. (Geissdoerfer et al., 2018). An extended version of the definitions of SBMI can be found in Table 16 (see Appendix I).

Regarding the rationales for carrying out SBMI, Schaltegger et al., (2012) argue that companies have mainly six motivations that come from an economic perspective: cost reduction, sales and profit margin, risk reduction, reputation and brand value, attractiveness as an employer, and innovative capabilities. As it can be seen, innovating towards sustainability not only means contributing to the environment, it also may bring financial benefits for companies. Therefore, performing SBMI can be perceived as an opportunity for companies to contribute to society, the environment, and at the same time, remain competitive and profitable. In practice, when companies carry out SBMI, they influence their organizational performance in such a way that the new SBM acts as a driver to put in practice and communicate the strategy not only within the organization, but also throughout its business ecosystem (Carayannis et al., 2015).

The main research gaps among SBMI were identified by Geissdoerfer et al., (2018) and were grouped in three categories. The first involves the conceptualization of SBMI and its lack of knowledge on how to implement it within firms. The second gap is related to the tools that are used by organizations to design BMs. These tools are usually focused on the products or have a general view on eco-innovation that not fully addresses the triple bottom-line. Recent scholars such as Bocken et al., (2013), Evans et al., (2014), Geissdoerfer et al., (2016), Joyce & Paquin (2016), and Yang et al., (2017) have merged these approaches and used BMI to help companies to achieve sustainability. Nevertheless, according to Geissdoerfer et al., (2018), these tools are limited as they only address one aspect of the BMI process for achieving sustainability. The third research gap is related to the challenges BMI must face and the causes for its low implementation. These challenges comprise; balancing the benefits of all the aspects of the three bottom-line; change the mind-set within organizations to introduce new BMs; reconfigure resources and processes for BMI; stakeholder engagement; the multidimensionality and complexity of integrating technological innovations and BMI. Shakeel et al., (2020) also identify three research gaps. The first gap has to do with the conceptualisation of SBMI that is based only on frameworkds but lacks of development and use of guidelines (metrics) based on a green strategy towards sustainable innovation. The second gap is related to the interdependent nature of sustainability, innovation, and value, that has not been addressed yet by SBMI. The third gap regards to feedback loops that come from the external environment, for example, how the demands that stakeholders may have and the scarcity of certain materials can affect the performance of a company on the triple-bottom line.

The scope of the thesis project is focused on the third gap of integrating innovation and BMI towards sustainability.

2.5. Technological Innovations towards BMI

Innovations influence a firm's value proposition because they affect the very nature of the products and services offered. Moreover, innovations can also generate changes within companies' operational and commercial processes (Bashir & Verma, 2016; Bucherer et al., 2012; Zott et al., 2011). Based on this, technological innovations can be considered a driver that can modify companies' BMs. According to Chesbrough (2010), modifying BMs becomes a mandatory task for companies as they must adapt to the dynamics of the industry to remain competitive. This also goes in line with Bucherer et al., (2012) that argue that products and services can be easily copied, while a novel BM may not because it requires to fit the long-term strategy, corporate culture, and the core competences of the company. Nevertheless, the authors also argue that not only start-ups, but also mature firms must keep in mind that BMs are not static and therefore, BMI must be a practice within their routines. On the other hand, BMs help innovations by being a means to unleash their value through its commercialisation. From that perspective, it can be argued that BMs connect the inputs and outputs of a company to its customers (Teece, 2010). One example is the case study developed by Chesbrough & Rosenbloom (2002) in which Xerox was able to innovate on its BMs to successfully commercialise technologies that were rejected by other companies. This example may be useful to summarise two main statements proposed by Zott et al., (2011). The first is that firms commercialize their innovations through their BMs, the second is that BMs by themselves can be a subject of innovation.

As it can be seen, technological innovations and BMs complement each other. Innovations are key for companies' success but must be coupled with a proper business model that allows to generate, deliver, and capture the value of the incumbent innovation. An innovation by itself does not guarantee financial success because technology per se has no inherent value if cannot be commercialised, therefore, companies need to design appropriate BMs for releasing and diffusing the potential of the technology. Despite the relevance of this synergy, BMs are constantly mentioned but at the same time overlooked due to the interdisciplinary nature of the concept. One consequence in practice of this is the failure in the commercialization of new innovations because managers do not give the necessary attention when designing BMs (Teece, 2010; Zott et al., 2011).

Regarding the main streams of research within technological innovations as drivers for BMI, they are mainly focused on the so called *digital transformation*, which comprises the implementation of digital technologies and its effects within companies (Bourreau et al., 2012). Authors such as Zec et al., (2014), Haaker et al., (2017), Alberti & Varon Garrido (2017), and Newell et al., (2019) explore the opportunities that digital technologies may offer to organizations. One case study in which the effects of a radical innovation can be clearly seen is within the music industry. Here, digitization transformed the way music is created, distributed, and consumed (Bourreau et al., 2012). Nevertheless, this trend in research has somehow overlooked the impact that hardware radical innovations can have on BMs and thus on BMI. Such is the example of the electric car. This technology was developed in the 19th century, but it started to be considered as an alternative for internal combustion cars during the 1990s. For the case of this technology, BMI can be seen in decisions such as; selling or renting the batteries; selling or renting the vehicles; charging users a monthly fee or charging them for the energy they consume (Bourreau et al., 2012). Another example of BMI in hardware innovations is the use of the so-called *razor-blade* revenue model within jet engines for commercial aviation. In this case, companies as GE and Rolls Royce sell the engines to airlines at relatively low prices but their main income comes from spare parts and maintenance contracts (Teece, 2010). It can be seen in this case that BMI comes from two sources. The first is the innovation itself (engines), while the second is a service (maintenance contracts).

As technological innovations are drivers for BMI, they also can be for the subset SMBI. Leendertse et al., (2021) confirmed two hypotheses that relate the physical nature of a technology and its effect on climate performance (referred as the ability to reduce CO_2 or its equivalents CO_{2eq} emissions). The first hypothesis states that start-ups with hardware innovations have a higher potential climate performance than start-ups with software technologies. The second hypothesis states that start-ups with a more novel technology have a higher potential climate performance. Additionally, the authors found the existence of a paradox between financial and sustainability goals among sustainable start-ups. The paradox arises because environmental performance comes at the expense of business performance, but at the same time, business performance is required for start-up to commercialise their products and services and thus, contribute towards sustainability.

With their findings, the authors argue that start-ups can escape the paradox to a certain extent by using hardware novel technologies and at the same time, maximising sustainable performance. An explanation for this is that investors that have motivations towards sustainability allocate their resources in start-ups with the highest impact in environmental performance. Another explanation has to do with the increase in demand for new sustainable products and services that society is demanding (Leendertse et al., 2021). As it can be noticed, both explanations are related to the novelty and nature of the technology provided by the start-up.

2.6. Business Models within the Biobased Chemical Industry

Biotechnology comprises a family of technologies that manipulate enzymes and microorganisms to create knowledge, products, and services. Genentech, founded in the 1970s, is considered to be the first company to use these technologies (Festel et al., 2012; Patzelt et al., 2012; Simone & Proietti, 2012). Biotechnology started to be used within the pharmaceutical industry, but it has expanded to other sectors such as healthcare agriculture, veterinary applications, waste management, bioinformatics, and chemicals (Simone & Proietti, 2012). The latter application receives the name of *biobased chemical industry*, *industrial biotechnology* or *white biotechnology* and is considered an alternative for the decreasing fossil resources as it uses agricultural renewable sources as feedstock which gives these companies high social acceptance and therefore, room for growing and innovating (Festel et al., 2012). The global market of this sub-sector is estimated in US$640 Bn as of 2020 and it is expected to have a compound annual growth rate (CAGR) of 15,14% during 2021-2026 (Mordor Intelligence, 2022).

Biotechnology is characterized for being capital intensive as well as highly intensive in research as around 45% of the employees are focused on research and development activities (R&D) that usually involve developing enzymes and genetically modified organisms (Festel et al., 2012). These activities are crucial for the companies because this is the means for them to generate competitive advantages over their competitors (Simone & Proietti, 2012). Another characteristic of these technologies is that incumbent firms usually generate strategic alliances with other companies to gain and share capabilities. Moreover, young biotechnology firms look forward to develop alliances with relevant partners of the industry to gain capabilities but also to gain legitimacy within the industry (Patzelt et al., 2012).

The first BMs used for these technologies were designed to operate within the pharmaceutical industry for developing drugs. Schweizer (2006) classified them in four categories which are: integrated, layer player, market maker, and orchestrator model. The first one relates to companies that focus on one of the steps of the value chain which leads to the so-called Contract Research Organizations (CRO) and Contract Manufacturing Organizations (CMO). The second involves using new innovations to improve current processes. The third model relates to firms that focus on one or more steps of the value chain and outsource processes that are out of their core capabilities through strategic alliances and collaboration. Finally, the fourth model comprises integrating in-house the whole value chain for drug production.

Regarding BMs within industrial biotechnology, companies are mainly focused on being either producers or service providers. Producers develop their own technologies or buy/license them to other companies and are focused on producing through the whole value chain from raw materials to product distribution. This BM is used by Small Medium Enterprises (SMEs) that are diversified and multinational enterprises. On the other hand, service companies are moving towards being producers mainly due to growing opportunities. Nevertheless, changing the BM has a disadvantage as it requires high capital to build production sites. Moreover, this can be risky if there is overcapacity within the market, as occurred with European biodiesel producers (Festel et al., 2012).

In addition to these BMs, there are also emerging ones that are focused on process development in which firms develop Intellectual Property (IP) and license technology. Here, companies develop a portfolio of technologies and products that may be either licensed or sold to a third party. This model requires networking and cooperation with companies and institutions to successfully sell the IP. This model is being used by SMEs to move from a service to an IP oriented firm (Festel et al., 2012).

Current chemical companies have also incurred in the adoption of biotechnology to produce biobased products. Such is the example of Dupont, BASF, and Braskem. Dupont (USA), aimed in the 1990s to develop a biobased version of 1,3-propanediol (PDO) from corn using yeast to manufacture a new plastic to compete with the traditional ones. The company developed the product *Sorona* that came to the market in 2007. Sorona's development set the design of a new BM to incorporate sustainability in which value comes from developing new markets such as clothing manufacturers and ways to gain control of the supply chain. Moreover, the company also started to be active in carrying out marketing activities and identifying new potential raw materials. Additionally, Dupont was able to charge premiums leveraging on the environmental concerns of the customers (Iles & Martin, 2013).

In the case of BASF (Germany), the company developed *Ecoflex* that was biodegradable, although, with a petrochemical origin, to compete with polyethylene (PE). When the company wanted to introduce the product in the USA, it realised that the customer did not see the product as *green enough* compared to other products from the competition. Because of this, the company aimed to use biobased materials to replace Ecoflex's origin. To do so, in 2003, the company made an agreement with Metabolix, a MIT spin-off, to develop Polyhydroxyalkanoate (PHA) from starch. The agreement expired in 2004 but BASF continued developing the product in-house until 2005, when the firm decided to buy Ecoflex's raw materials from its competitor NatureWorks. Nevertheless, the initiative's lack of managerial commitment resulted in just relying on the existing distribution channels for PE. In consequence, BASF just used its dynamic capabilities to address regulatory changes that would open new market opportunities and to be responsive to competitors that were marketing bioplastics as biodegradable and biobased. During this process, BASF was able to modify its incumbent BM and rebrand as "the chemical company" to commercialize the biobased version of Ecoflex. Nevertheless, the company did not invest many resources on designing a proper BM to expand within the biobased products, BASF decided to be on a narrow place within the bioplastics value chain (Iles & Martin, 2013).

Finally, Braskem (Brazil) changed the petrochemical origin of its (PE) by using sugarcane as feedstock and the fermentation process. The company adopted a different approach than Dupont and BASF by designing a BM focused on growing market segments from Asia and Europe willing to use biopolymers to be framed "green". In addition to this, Braskem was able to offer the same product at a higher price (15-30% higher) with market acceptance because the product did not require adaptation from the current users of PE. After introducing biobased PE and market research, Braskem planned to become the world leader in bioplastics production, mainly focusing on commodities that do not require downstream processes and in some customers that required special products like Monopoly games (Iles & Martin, 2013).

Despite the three companies have changed the fossil origin of their products and modified, to some extent, their incumbent BMs, none of them developed a BM that included sustainability. To do this properly, the companies should have included value propositions that not only focused on the operational and financial aspects of the firm, but also have included the balance among financial, environmental and social value (Iles & Martin, 2013).

Regarding the new trends on BMs within the biobased chemical industry they are mainly four that are based on the producer model. The first is the vertically integrated BM that comprises the entire process of biomanufacturing from feedstock sourcing, genetic engineering, manufacturing, and sales. One example of this BM is the one used in biopharmaceuticals. The second model involves centralised production. In this case, manufacturing takes places in a few but large facilities that scale product manufacturing with relatively low margins. As an example, this BM is used by international breweries. The third model is the so-called horizontally stratified value chain. Here, activities such as research and manufacturing are carried out by different companies that are specialized along the value chain. This BM is mainly used by SMEs that focus on specialty chemicals. Finally, the fourth model is the distributed production value chain in which manufacturing is carried out in small facilities that take geographical advantage of raw materials and deliver products to supply local or niche markets. As an example, this BM is used by micro-breweries. In summary, in the first two BMs, one company is in control of all production steps. Meanwhile for the latter two, companies are part of the value chain and the incumbent BMs may vary depending on the type of company and is position within the value chain (Tait & Wield, 2021).

The first two BMs models can be considered that go together because they can overlap as vertically integrated companies are based on centralised production facilities and the opposite also occurs. An example of this situation can be found within the industrial biotechnology sector whereby biofuel producers from the US use both BMs. The main process used by these firms is fermentation of biofuels by microorganisms. It is expected that genetic engineering on these microorganisms will enhance the production and quality of the products. Moreover, it is also expected that incremental changes within these companies' BMs may occur. On the other hand, for horizontally stratified and distributed production BMs, technologies such as gene editing and fermentation will have effects on these BMs that may be either incremental or significant within the value chain. For example, SMEs that specialise in genetic engineering of microorganisms for fermentation processes have disrupted the market as there are no existing BMs they can adopt according to the *design and build* approach these companies are adopting. Therefore, the firms will need to decide between finding a BM to enter the current value chain or collaborate with other companies to design a totally new value chain. Another example lies on firms that manufacture specialty chemicals. These kinds of firms have BMs related to fossil raw materials and are aiming to use gene editing technologies to develop their products. In this case it can be noticed that gene editing will not disrupt the current BMs because these companies will remain producing the same products and it is expected that changes within their BMs will be most likely to be incremental (Tait & Wield, 2021).

One particular situation occurs on large scale chemical producers that use petrochemicals as feedstock. Should these companies decide to change their production towards biobased technologies, they will face a major disruption on their current BMs that will require major changes within their technological and human capabilities. Therefore, it is unlikely that these companies will adopt biobased technologies such as state of the art fermenters and biodigesters which still need to address challenges related to efficiency and reliability in large scale production. One implication of this particular case is that there are no policies whatsoever focused on transforming these kind of companies into biobased ones. Based on this, the way to successfully implement these technologies is by introducing them into existing biobased companies because they already have the capabilities and knowledge to exploit these kind technologies. Thus, the disruptive impact of new generations of biodigesters and fermenters technologies may be reduced. Nevertheless, these new generations of technologies may disrupt the market of biobased companies as they may enable new market segments in which companies have not experience. Here, special care must be taken by the companies when addressing a new market segment because an erratic introduction may have detrimental effects on the company's reputation (Tait & Wield, 2021).

According to Tait & Wield (2021), the combined use of fermentation technologies and genetic engineering of microorganisms may bring new opportunities for the biobased industry as new market niches related to high value specialty chemicals may be addressed. Furthermore, the type of companies that will adopt BMs to achieve these markets will be SMEs with the potential of rapid growing.

As it can be seen, the articles do not have a comprehensive approach when analysing the presented BMs for this industry (producer, service provider, and process developer) as the authors focus either on the revenue model or on the internal operational aspects of the companies. Furthermore, this lack of analysis also overlooks the very core of a BM, which is the value proposition of a company. Also, aspects related to value delivery are barely addressed. Moreover, despite BMI being present within the biobased chemical industry, the authors also do not analyse it properly either. This lack of rigor may be related to Suurna (2011) who argues that studies on BMs within the biotechnology sector are somehow paradoxical because despite being an increasing attention on them, the concept still lacks of a clear theoretical background which hinders the study on how BMs can capture the value of new innovations within this field.

2.7. Fermentation

Fermentation is a biological process that occurs in living cells including but not limited to animals, bacteria, yeast, and fungi. In this process, energy-rich molecules such as sugars are reduced to simpler ones by the action of enzymes and chemical reactions to obtain energy. Fermentation can occur either in an aerobic or anaerobic environment, this means under the presence or absence of oxygen, respectively (Biology Online, 2022). As an example, Figure 13 depicts three metabolic paths of glucose fermentation that begin with the degradation of glucose into pyruvate. In the first case (left) fermentation occurs under aerobic conditions and pyruvate is transformed into CO_2 and H_2O. In the second case (centre), fermentation occurs under anaerobic conditions and pyruvate is transformed into lactate. Finally, in the third case (right), alcoholic fermentation is carried out under anaerobic conditions and pyruvate is transformed into CO_2 and ethanol.

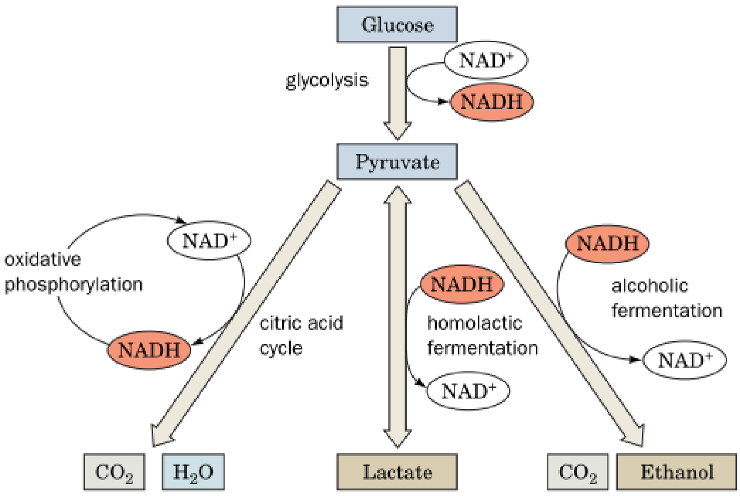

Figure 13: Fermentation of glucose (Voet et al., 2016)

Fermentation is under the umbrella of the so-called *biotransformation* that englobes several biological processes in which different *substrates* (inputs) are converted into products (outputs) by means of microorganisms. These processes can be tailored and optimized through genetically engineering microorganisms to obtain the desired products and improve yields (Tiso Till et al., 2014). As an example of microorganism tailoring, Figure 14 shows part of the metabolic pathway of glucose bioconversion into 2PE by genetically modified yeast. 2PE has a floral scent and is broadly used within the cosmetic and food industries. Biobased production of 2PE by yeast offers a sustainable and reliable production means compared to chemical synthesis because the latter process requires non-environmentally friendly products to purify the molecule (Hassing et al., 2019). Moreover, there are regulatory restrictions in the US and EU that limit the origin 2PE for food uses to only natural sources without fossil origin (Hassing et al., 2019).

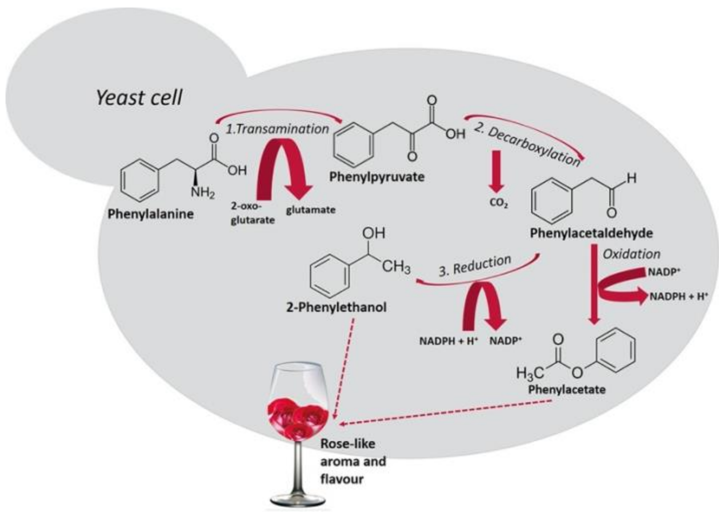

Figure 14: Metabolic pathway of bioconversion of glucose into 2PE (Vilela, 2020)

When produced at an industrial scale, *downstream processes* such as purification of the molecule and debris removal must be carried out. Figure 15 shows a simplified scheme of 2-PE industrial bioconversion.

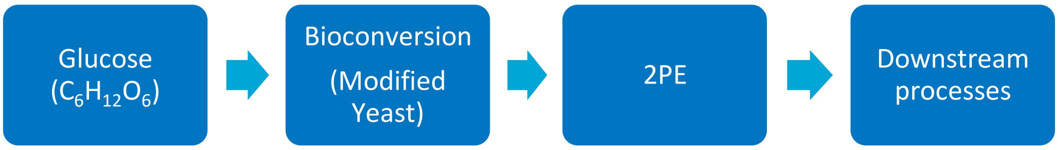

Figure 15: Simplified industrial bioconversion of glucose into 2PE (adapted from (Hassing et al., 2019)

Industrial production of chemical compounds occurs in a *fermenter* which is a vessel whereby microorganisms carry out bioconversions. A fermenter usually consists of a vessel with multiple inlets that allows substrates and other necessary supplies to enter the vessel. Additionally, the fermenter is agitated by a motorized agitator that increases the oxygen transfer (in case of aerobic fermentation) and homogenizes the *culture* that is known as the *broth* (everything that goes into the fermenter). Moreover, elements such as thermal jackets, and baffles are present on fermenters to heat the vessel at the right temperature and to improve the mixing of the broth to optimize the microorganisms' growth, respectively (Money, 2016). Figure 16 shows a basic layout of a fermenter.

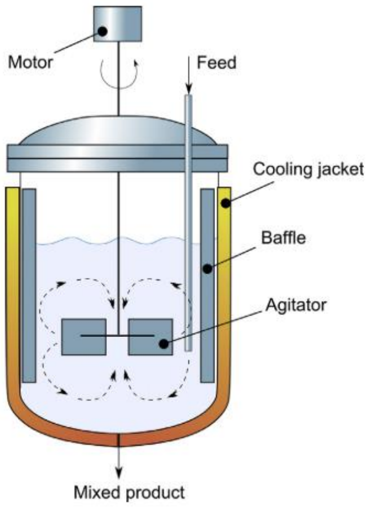

Figure 16: Basic layout of a fermenter (Money, 2016)

There are four main differences between the traditional chemical synthesis and the biobased. First, the traditional chemical industry uses raw materials from fossil origin, whilst the biobased uses renewable biobased sources such as sugars. Second, the chemical industry's processes require high temperatures and pressure to synthesise molecules. Conversely, the biobased takes place at milder temperature and pressure ranges, making this process safer than the chemical ones. Third, the chemical industry requires special treatments for its by-products such as sand and activated carbon filtration, whilst biobased by-products are usually treated under heat sterilization (Doran, 2013; Sivarajasekar & Balasubramani, 2018). Finally, the chemical industry generates a considerable amount of GHS emissions to synthesise compounds. On the contrary, the biobased has the potential to be carbon neutral (Doran, 2013; Yu et al., 2019). Figure 17 shows a comparison of the traditional chemical industry and the biobased.

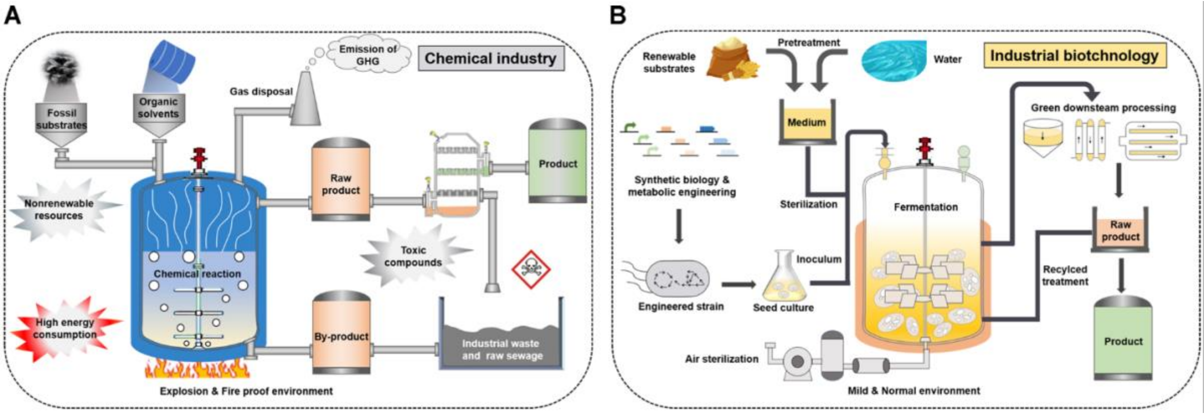

Figure 17: Comparison of fossil chemical industry (A) and biobased chemical industry (B) (Yu et al., 2019)

2.8. Theoretical Framework

Based on the literature review, a proposed conceptual model for this thesis is built on five theories that comprise:

1) Osterwalder & Pigneur (2010) and Teece's (2010) definition of BM
2) Technological innovation as a driver for BMI based on Zott et al.,'s (2011) statements
3) The definitions that consider that BMI can come within a spectrum of changes that may come as a response to changes within the market (Abelkafi et al., 2013; R Amit & Zott, 2012; Casadesus-Masanell & Zhu, 2013; Khanagha et al., 2014)
4) Leendertse et al., (2021) that relate the physical nature of a technology and its effect on climate performance and consequently, on sustainability
5) Shakeel et al., (2020) who state that changes towards SBMI can occur by having gradual changes or a radically new value proposition, value creation & delivery, and value capture

The first theory states that BMs are a tool for designing and describing the value creation, delivery, and capture that an organisation offers. The second theory elaborates on the influence that technological innovations have on a venture's value proposition and its operational and commercial processes. The third theory argues on BMI as an outcome that comes as modifications on an incumbent BM's activities that redefine the logics in which a company creates and capture value for its stakeholders. Moreover, the theory argues that these modifications may come in a spectrum that involves from incremental changes to replacing entirely an incumbent BM. With these theories it can be argued that a technological innovation acts as a mediator variable between an incumbent BM to its transformation towards BMI. Figure 18 shows a scheme that illustrates the moderating effect of technological innovation on a BM towards BMI.

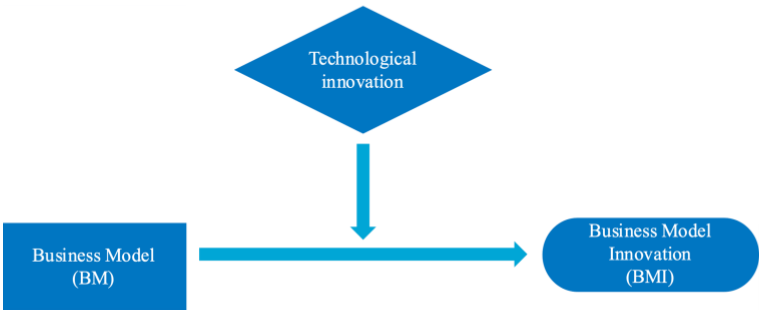

Figure 18: Technological innovation as a moderator for BMI

Building on the fourth theory relates the physical nature of a technology and its effect on climate performance, the conceptual model for BMs can be narrowed to the subset of SBMs and thus, move from an incumbent BM that evolves towards SBMI by the moderating effect of technological innovations. Finally, the fifth theory argues that changes towards SBMI can occur by having gradual changes or a radically new value proposition, value creation & delivery, and value capture that can be seen on the SVPI, SVC&DI, and SVCI, respectively. Figure 19 shows a scheme of the proposed conceptual model that illustrates the moderating effect of technological innovation on a BM towards SBMI.

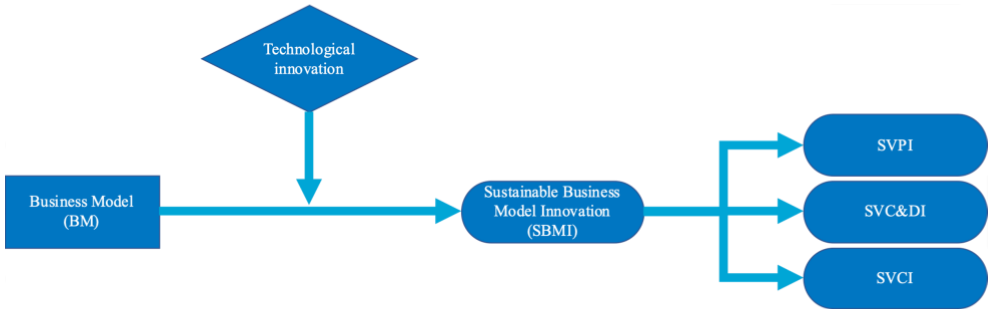

Figure 19: Proposed conceptual model "Technological innovation as a moderator for SBMI"

Applying the conceptual model on the biobased chemical industry, FAST can act as a driver for moving towards SBMI by generating sustainable value innovation that can be seen on its core elements SVPI, SVC&DI and SVCI in different extents. Figure 20 shows the conceptual framework applied on the biobased chemical industry whereby FAST acts as moderator for SBMI.

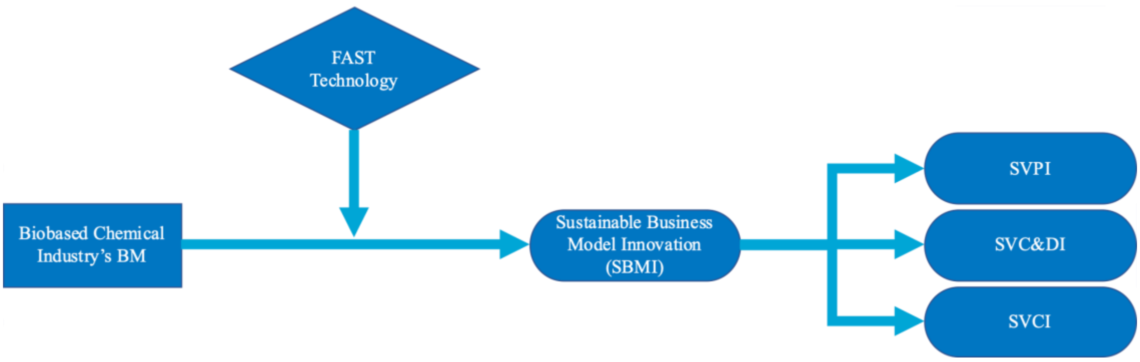

Figure 20: Conceptual model applied on FAST

Chapter 3: Research Methodology

The following chapter elaborates on the methodology for the research project. First, the research design is described in overall to explain how the main research objective is achieved. Second, a description of the main research methods that are used during the project is carried out. Third, the selection of the case is explained. Finally, data collection methods and data analysis are explained, respectively.

3.1. Research Design

The main objective of the research is to determine under what conditions FAST technology contributes towards sustainable business innovation. Given the fact that the technology is breakthrough and has the potential to be disruptive (in terms of market development) it is considered as the unit of analysis of the research project. The analysis of FAST is addressed under the scope of an exploratory single deep case study analysis because this approach provides a comprehensive empirical approach that gathers information from several perspectives by more than one data collection method in which data may be both quantitative and qualitative (Sekaran & Bougie, 2016).

3.2. Research Methods

To have a comprehensive overview of the case, the methods for data collection involve a literature review, a questionnaire, and the Delphi method which are briefly described. The sources of data are both primary and secondary. Primary data that in this case is qualitative, is collected by means of questionnaires and the Delphi method, whilst secondary data is both qualitative and quantitative, is obtained from the literature review and desk research, respectively.

A literature review is done to describe the conceptual framework in which the thesis project is developed and to build a conceptual model. Additionally, the review provides insight on the context in which the technology is being deployed. The main topics included within the literature review comprise the definitions and research areas on BMs, BMI, and BMfS. Another topic includes the influence of technological innovations on BMI and how this can be tailored towards SBMI. Furthermore, the BMs that are used in biotechnology specifically for the chemical sector and the process which is used by FAST are described.

Another method used are questionnaires. A questionnaire is a written set of questions in which respondents have defined alternatives. This method is normally used for quantitative data collection and can be applied electronically or personally. On the personal questionnaires, a researcher can collect the responses within a short period of time. Moreover, if participants have questions, they may be clarified in the moment. Another advantage of questionnaires is that the researcher may introduce the research topic and its goals so that the participants is encouraged to provide honest answers. Nevertheless, this method has disadvantages that should be considered, for example, bias may be introduced when explaining the questions or the research to different participants. Additionally, this type of questionnaires may be time demanding (Sekaran & Bougie, 2016).

Other tool used is the Delphi method. This is used to find an agreement on a certain topic or to forecast possible scenarios. Here, a set of experts on the matter answer a questionnaire usually in one or two rounds. During the first round the participants are asked several questions regarding the topic of interest. Then, their answers are collected, summarised, and sent for a second-round questionnaire. In this stage, the participants are required to assess the same matter but now considering the other experts' opinions. By doing this, the researcher carries out an iterative process that aims to find a consensus on the researched matter. The advantage of this technique is that the identity of the participants is not revealed, which prevents a dominant opinion some experts may have upon others. Moreover, participants are able to express their ideas without reservations and also revise their statements (Sekaran & Bougie, 2016). Regarding the disadvantages, the method may be tedious as it takes a considerable amount of time due to the rounds and data processing. Furthermore, it also requires finding suitable experts whose opinions and criteria have their own biases (QuestionPro, 2022).

3.3. Case Selection

The FAST technology is owned by DAB, a Dutch company from the biotechnology sector (DAB, n.d.-b). Data related to the technology, the company, and the market is collected from members of the company via the questionnaires, the Delphi method, and data generated by them. The nature of this data is both qualitative and quantitative.

3.4. Data Collection and Analysis

The following sub-section elaborates on how the research methods are adapted and applied to the case study.

A questionnaire in which participants are asked to select and rank indicators is carried out. The indicators are based on the article by Van Schoubroeck et al., (2019) that proposes which indicators in each aspect of sustainability (environment, society, and economy) may be used within the biobased chemical industry. The questionnaire is a closed one in which participants are asked to select, according to their own criteria, the top 5 most relevant indicators within each aspect and then assign 100 points among them using a fixed sum scale, which is an ordinal scale (Sekaran & Bougie, 2016). The participants do this by discarding the least relevant indicators in several rounds until the top 5 most relevant remain, in the case of the *environmental* and *society* aspects, the participants are asked to discard 5 indicators on each round. Whilst in the case of *economy*, participants are asked to discard 4 indicators per round. The order of the indicators is randomised so that the bias of the participants is reduced. The questionnaire for the indicators on every aspect, the scores, and their respective definition can be found in Appendix V.

To answer this questionnaire, the selection criteria of the participants considers that they must have background in bioprocesses, process design, management, or finances. Based on this, 14 members of DAB comply with these criteria. Finally, 12 participants from DAB answered the questionnaire, being this the sample. After this, the participants are clustered in three groups, *Management* (3 members), *Process* (3 members), and *Fermentation* (6 members), that correspond to the departments of the organisation whereby they work. This segmentation is done to see whether there are differences among the indicators selected in overall by all the participants and on each department.

The weight of each indicator in overall (global analysis) and within each category (local analysis) is calculated by using Equation 1:

Equation 1: Weight of an indicator

$$W_i = f_i * \sum_{k=1}^{f_i} In_k^i$$

Whereby

W_i = Total weight of indicator i

W_i= Frequency of indicator i

$\sum_{k=1}^{f_i} In_k^i$ = Summation of the points given to indicator i

The rationale to use a nominal scale lies in making the decision process for the participant easier when choosing from different alternatives. This is also helpful for the researcher because information can be processed and analysed easily (Sekaran & Bougie, 2016).

Besides, the Delphi method is used to generate a consensus of a general overview of the biobased chemical industry, the company, and FAST. In the first round, a written questionnaire with open questions is sent to the participants. Then, the answers are summarised and sent to the participants as a second round. In the second round, the participants are asked for their vision on the summary and whether they would like to add anything else. Finally, the answers are summarised. The rationale for using open questions is that participants have more freedom to answer so that the discussion on the topic may be enriched with different points of view (Sekaran & Bougie, 2016). The questionnaire for the first round of Delphi can be found in Appendix VI. In this case, the number of participants was reduced to 6 members of DAB because carrying out two rounds of questionnaires is more time demanding. Moreover, 2 members of the three departments of the company (*Management*, *Process*, and *Fermentation*) are chosen to have an even consensus. The selection criteria is based on gathering participants with different backgrounds such as bioprocesses, process design, finances, and professional experience to obtain a more comprehensive consensus.

Moreover, DAB provided data related to the company's background, its technology, and developments during the Delphi rounds by its members. Furthermore, the company also provided technical data based on process simulations for FAST and the petrochemical route for the production of 2PE. This latter source of data comprises key performance indicators (KPIs) related to production, utilities and consumption, waste, and CO_{2eq} emissions that are based on the KPI obtained from the questionnaire on sustainability indicators.

Regarding the formalities and confidentiality of the research, the participants are asked to participate voluntarily before carrying out the questionnaires. After receiving their consent, participants are asked to fill and sign an informed consent form that follows TU Delft's ethical guidelines on research with individuals. The informed consent template can be found in Appendix VII.

After filling the informed consent form, participants receive an explanation of the questionnaires. The explanation for the questionnaire on sustainability indicators is given personally and the questionnaires for Delphi rounds are given via e-mail, respectively. Then, the questionnaires are received, the information of each participant is de-identified and anonymised. For the sustainability indicators a random number is assigned to the participant and the only information that is kept is the department whereby works. On the other hand, the answers provided by the participants on the Delphi rounds are de-identified. The only information that is kept is the level of education, previous experience, expertise, and department of the participant. Therefore, the background of the participants is known but neither their answers nor their identities.

Chapter 4: Case Study

The following chapter elaborates on the case study and the context in which is immerse. It describes the general context of policies and regulations for climate change and the biobased economy. Additionally, a description of the company and FAST are provided.

4.1. Global Context

To address climate change, the IPCC set a limit of 2 ºC on the global temperature increase by 2050, goal that is stated on the Paris Agreement by its adhering members (IPCC, 2019; United Nations, 2015). To achieve this, the UN proposed in 2015 the Millennium Development Goals (MDG), in which ensuring environmental sustainability is included (United Nations, n.d.). To narrow down these objectives, the sustainability challenges were formalized in 17 Sustainable Development Goals (SDG) that are part of the *Agenda 2030*. These goals aim to end poverty, inequality, and climate change and apply to all countries in which businesses are considered to play an important role in the realization of the goals (Global Compact Network Netherlands, n.d.). The SDG goals can be seen in Figure 21.

Figure 21: Sustainable development goals (Global Compact Network Netherlands, n.d.)

The entity in charge of encouraging enterprises and supporting the goal achievement is UN Global Compact, which is known for being the biggest worldwide sustainability-oriented initiative. In the Netherlands the entity in charge is Global Compact Network Netherlands that works along with organisations that include but are not limited to NGO's, knowledge institutions, and communities (Global Compact Network Netherlands, n.d.).

4.2. Biobased Economy

Due to the pollution and GHG emissions caused by the chemical industry, new policies have been developed and focus on promoting sustainable development for transitioning from an economy based fossil raw materials towards the so-called Biobased Economy (BBE), which is based on renewable biological resources and its conversion into biobased products (European Commission, 2012; Tait & Wield, 2021; Yu et al., 2019). Biobased products come from renewable sources and can contribute to reduce CO_2, have lower overall toxicity, and be biodegradable. The features of these products have the potential to contribute to a more sustainable economy and at the same time, reduce the dependency on petrochemicals (European Commission, n.d.). Due to this, the EU declared biobased products as a priority with potential for future growth, reindustrialisation, and tackling social challenges. Moreover, the adoption of these products can help EU's to comply with its energy and climate change policies (Horizon 2020, n.d.). From the economic point of view, according to the EU, biobased products and biofuels comprise approximately €57 billion in annual revenue and involve 300.000 jobs. Additionally, as of 2012, the biobased share of chemical sales will rise to 12.3% by 2015 and to 22% by 2020 with a CAGR of 20% (European Commission, n.d.).

Due to the importance and benefits of the BBE, the EU has proposed its development in three main areas: transform current the fossil-based processes into biotechnology ones; establish reliable, sustainable supply chains of biomass, by-products and waste streams and a wide network of bio-refineries throughout Europe; and support market development for biobased products and processes (Horizon 2020, n.d.). To guide the development streams, the EU has proposed several policies that involve policies such as: the *EU's industrial policy* which aims to increase the contribution of the EU industry to its GDP from 15% to 20% by 2020. Here, biobased products are a priority; the *Bioeconomy Strategy* that aims to shift the EU economy towards the use of renewable resources; the *flagship initiative for a resource-efficient Europe* strategy supports the shift towards a low-carbon economy to achieve sustainable growth; and the *Circular Economy Package* to help EU enterprises and consumers to make the transition to a more circular economy (European Commission, n.d.).

Regarding the Netherlands, the Dutch government issued the *Climate Act* in 2019 to tackle climate change. This act established the goals to reduce GHG emissions by 49% in 2030 and 95% by 2050, compared to the levels of 1990. The policy and the measures to achieve the goals are in the *Climate Plan*, the *National Energy and Climate Plan* (NECP) and the *National Climate Agreement* contain the policy and measures to achieve these climate goals (Government of the Netherlands, n.d.). This policy goes in line with the Dutch strategy of implementing the biobased economy as a means for economic development, whose objective is to produce biobased materials and use residues for biofuels, electricity, and heat in biorefineries as a key technological development. To accomplish this, the Netherlands created the RVO, a national agency, that is responsible for implementing policies for the bioeconomy. This sets a milestone as the Netherlands along with Germany, Estonia, Finland, and Hungary are the only countries within the OECD that created governmental agencies to promote the biobased economy. The main drivers for these policies (in order) are economic development, strategic development and environment (Biomass Research, 2016).

4.3. Delft Advanced Biorenewables

Delft Advanced Biorenewables (DAB) is an industrial biotechnology academic spin-off from TU Delft that was established in 2012. DAB aims is to transform bio-manufacturing into a cost-effective process that accelerates the transition towards the biobased economy by replacing petrochemicals raw materials with renewable ones via its proprietary fermentation technology that intensifies production of biobased chemicals which allows to produce more at lower costs (Crunchbase, 2022; DAB, 2021b). DAB's headquarters and laboratory services facility are located at the Biotech Campus Delft since 2019. The company also has a demo reactor to demonstrate its large scale production in a pilot plant located at the Bio Base Europe Pilot Plant (BBEPP) in Ghent, Belgium since 2021 (DAB, n.d.-a, 2021a; Innovation Quarter, 2019b). Currently, DAB is aiming to deploy its technology within the market and thus, start with its commercialisation phase.

Regarding its milestones, DAB was awarded with €2 million Series A funding from FORWARD.one and InnovationQuarter in 2019. This allowed the company to move to the Biotech Campus Delft and acquire resources to continue with its developments and commercialisation of its technology (DAB, 2019; Innovation Quarter, 2019b). Moreover, in 2020, DAB was awarded with a subsidy of the DEI+ programme from the RVO, which is focused on demonstrating technologies than can enhance CO_2 reduction at industrial level. In this project, DAB carried out a pilot DAB to validate its performance at a scale of 10 m^3. The project was developed along with Wageningen Food and Biobased Research (WFBR), which provided knowledge on fermentation and strain engineering (HollandBIO, 2020; Wageningen University & Research, n.d.). Additionally, in 2021 the company doubled its pre-series A fundraise. With this funding DAB was able to set its demo plant at BBEPP in Ghent to test the synthesis of different chemical compounds, increase its IP, expand its laboratory services facility, and staff. The company is also planning to go under another series-A financing round during 2022 (DAB, 2021b).

DAB has proven the effectiveness and legitimacy of its technology through time, which can be seen in investments by new shareholders such as Invest-NL and Nemho, which are investors focused on sustainable ventures and a centre for innovation and technology for material companies, respectively (DAB, 2021b).

4.4. FAST Technology

Reducing CO_2 by replacing the fossil origin of raw materials is possible by industrial biotechnology which involves fermentation. Nevertheless, the majority of these process are still expensive when scaled if compared with the traditional fossil route, which hinders the commercialisation of these family of technologies and its outcomes (HollandBIO, 2020). Besides this financial aspect, challenges related to low productivity and product titration of these processes, make them energy intensive as require an intense downstream processing. To tackle this, innovations in strain development and optimisation as well as innovations in bioreactors and processes are needed (Wageningen University & Research, n.d.).

DAB addressed this problem by developing the patented *Fermentation Acceleration by Separation Technology* (FAST) that was based on joint research carried out at TU Delft (DAB, n.d.-b; Oudshoorn et al., 2019). The features of the technology involve: continuous product extraction of the compounds on a single vessel; reduction on product toxicity for the used microorganisms; reduction of capital expenditure (CAPEX) and operational expenditure (OPEX) between 20-50%. These features increase the productivity of the process which enable FAST to become competitive with traditional chemical processes that use materials from petrochemical origin (Biology Online, 2022; DAB, n.d.-b, 2021b; HollandBIO, 2020; Innovation Quarter, 2019a; Pappas & Oudshoorn, 2022). Given all these advantages, the FAST technology is considered a breakthrough and has the potential to be disruptive (in terms of market development) within the industry. In addition to this, FAST can be seen as a platform because the reactors can be specifically designed to optimise the production of certain biobased chemicals with microorganisms. Additionally, the technology can be scaled as a unique unit or can be retrofitted on current facilities (HollandBIO, 2020; Innovation Quarter, 2019a). Figure 22 shows a diagram with the potential molecules that FAST may synthetise. The diagram shows the price of the molecule as a function of its toxicity to the microorganisms that produce it. A higher toxicity of the products difficult the synthesis of compounds because the microorganisms die at lower concentrations of it. FAST is able to overcome this by removing the products at a faster rate than other technologies and thus, conserving the microorganisms and the rate of production.

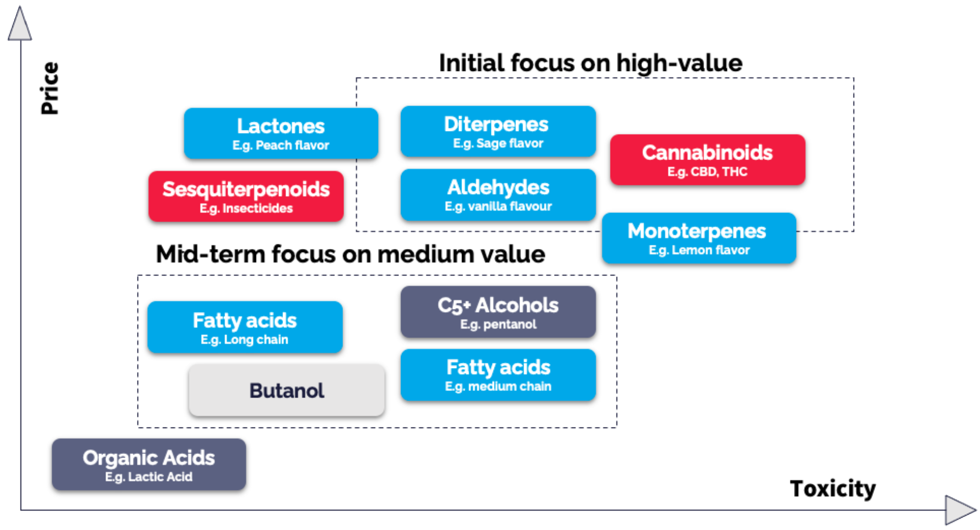

Figure 22:Potential molecules for FAST (Courtesy of DAB)

Figure 23 shows a comparison between a traditional fermentation process and one with the FAST technology. It can be seen that FAST is able to carry out multiple processes in just one unit (ERA-NET Bioenergy, n.d.).

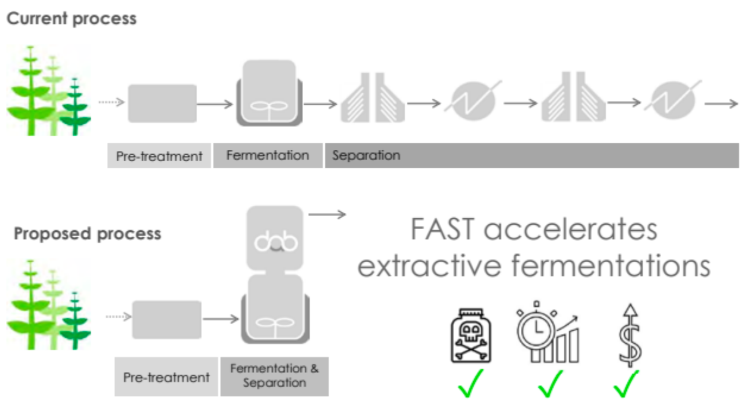

Figure 23: Comparison of current fermentation process and FAST's (ERA-NET Bioenergy, n.d.)

The FAST technology works by separating the product from the fermentation section with an extractant creating a second phase, the separation section, that has a higher concentration of the produced molecule in the bioconversion process (Oudshoorn et al., 2019). Figure 24 shows a diagram of the FAST reactor.

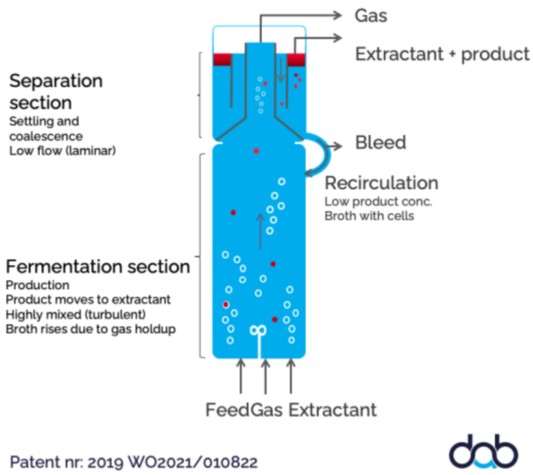

Figure 24: FAST reactor (Courtesy of DAB)

Regarding the performance, FAST can synthetise the desired chemical compound for a longer period of time showing an increased performance compared to the (fed)batch overlay process, which is a competitor technology. Figure 25 shows a comparison of the FAST technology and the batch overlay performance on BuOH production.

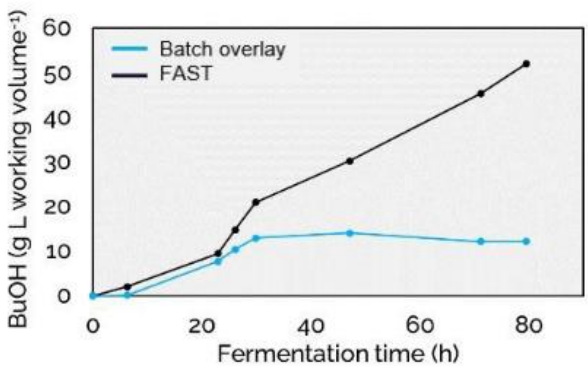

Figure 25: Comparison of FAST technology and batch overlay performance on BuOH production (Pappas & Oudshoorn, 2022)

Regarding IP matters, DAB made a patent application at the European Patent Office and several countries such as Mexico, Japan, United States, Chine, Republic of Korea, Australia, European Patent Office, Canada (Oudshoorn et al., 2019; WIPO IP PORTAL, n.d.).

4.5. 2-Phenylethanol Market

2PE is a molecule that has a floral scent and is broadly used in cosmetics and food. The worldwide market of this product exceeded USD 255 [MM] in 2021 and it is expected grow at a CAGR over 5.5% between 2022-2028 and reach a volume over USD 370 [MM]. The most important markets for the compound are North America, Europe, and Asia Pacific. 2PE can be obtained from petrochemical routes or natural processes such as plant extraction and biobased production (fermentation). The natural processes become the only option for food use as regulations within the US and EU restrict 2PE from fossil origin for this application. The market price of 2PE for the flavour market that comprises beverages and food is 200 [$\frac{USD}{kg}$] (Global Market Insights, 2022; Hassing et al., 2019).

Chapter 5: Results

The following chapter presents the data collected during the questionnaire application on sustainability indicators, the Delphi rounds, and the data generated by DAB to compare FAST with the petrochemical route to produce 2PE. Additionally, two business models proposed for DAB using the data collected are presented.

5.1. Questionnaire on Sustainability Indicators

In this applied questionnaire, 12 participants from the company are asked to rank the top 5 indicators from each aspect of sustainability that may be used within the biobased chemical industry as proposed by Van Schoubroeck et al., (2019). The participants are also clustered among the three departments of the organisation: *Management*, *Process*, and *Fermentation*. Table 3 shows the number of participants from each department of the company.

Table 3: Clusters of participants for questionnaire on sustainability indicators

Department	Number of Participants
Management	3
Process	3
Fermentation	6
Total	**12**

The ranking of the indicators is calculated on an overall ranking that considers all the participants, and on local one with participants from each department.

Within the global analysis of the *environmental* category *GHG emissions*, *Raw material efficiency*, *Water consumption*, *Water generation*, and *Energy efficiency* are ranked as the most important indicators. For the case of the local analysis, *GHG emissions*, *Raw material efficiency*, *Water consumption*, and *Energy efficiency* are present within the three departments of the company. Meanwhile, *Natural land transformation* and *Abiotic fossil depletion* are only present within *Management* and *Process*, respectively. Table 4, shows the rankings on the *environmental* category.

Table 4: Ranking of environmental indicators

Overall	Management	Process	Fermentation
GHG emissions	GHG emissions	Water consumption	Waste generation
Raw material efficiency	Raw material efficiency	GHG emissions	GHG emissions
Water consumption	Water consumption	Raw material efficiency	Raw material efficiency
Waste generation	Natural land transformation	Abiotic fossil depletion	Water consumption
Energy efficiency	Energy efficiency	Energy efficiency	Energy efficiency

Regarding the global analysis of the *social* category *Human toxicity*, *Fatal work injuries*, *Job creation*, *Product transparency*, and *Acceptance of Biobased materials* are ranked as the most important indicators. For the local analysis on this category, the only indicator present in the three departments is *Fatal work* injuries. *Job creation* and *Acceptance of biobased materials* are present in *Management* and *Fermentation*. Whilst *Workplace accidents and illnesses* is present in *Management* and *Process*. On the other hand, *Human toxicity* is in *Process* and *Fermentation*. The indicators that are only within one department are *Income levels*

(Management), *Child labour* and *Working hours* (*Process*), and *Product transparency* (*Fermentation*). Table 5, shows the rankings on the *social* category.

Table 5: Ranking of social indicators

Overall	Management	Process	Fermentation
Human toxicity	Job creation	Fatal work injuries	Human toxicity
Fatal work injuries	Acceptance of biobased material	Human toxicity	Product transparency
Job creation	Workplace accidents and illnesses	Child labor	Acceptance of biobased materials
Product transparency	Income levels	Working hours	Job creation
Acceptance of biobased materials	Fatal work injuries	Workplace accidents and illnesses	Fatal work injuries

About the global analysis of the *economy* category *Process innovation*, *Product efficiency*, *Market Potential*, *Capital productivity*, and *Energy cost* are ranked as the most important indicators. For the local analysis on this category, *Market Potential*, *Product efficiency*, and *Process innovation* are present within the three departments of the company. *Energy cost* and *Raw materials cost* are present in *Management* and *Fermentation*. Meanwhile *Capital productivity* is present in *Management* and *Process* departments. The only indicator that is just in one category is *Labour productivity* in *Process*. It is important to notice that the *Management* department has six indicators rather than five. This is because *Capital productivity* and *Raw material cost* have the same score. Table 6, shows the rankings on the *economy* category.

Table 6: Ranking of economy indicators

Overall	Management	Process	Fermentation
Process innovation	Market potential	Capital productivity	Process innovation
Product efficiency	Product efficiency	Product efficiency	Product efficiency
Market potential	Energy cost	Process innovation	Market potential
Capital productivity	Process innovation	Market potential	Energy cost
Energy cost	Capital productivity	Labor productivity	Raw materials cost
-	Raw materials cost	-	-

The data processed can be found in Appendix V.

5.2. Delphi Rounds

In this questionnaire, 6 participants from the company are asked to answer a first round of open questions to generate a consensus of a general overview of the biobased chemical industry, the company, and FAST. Table 7 shows the area of expertise of the participants.

Table 7: Expertise of the participants

Participant #	Area of Expertise
1	Bioprocess technology
2	Fermentation, molecular biology
3	Bioprocess technology
4	Finances
5	Microbiology, molecular biology
6	Process design, projects

The opinions and perspectives gathered on the first round are summarised (see Appendix VIII), after that, the summary is sent to the participants as second round. In this stage, participants are asked to provide feedback on the summary and further information if they consider relevant. A second and final summary, the *consensus,* is done with this last round of answers (see Appendix VIII). A summary of the *consensus* is presented as follows:

Biobased chemical industry:

There is agreement that the transition towards the biobased economy has been slow and not many transitions are occurring currently, which is perceived as a lost opportunity.

The participants considered that biotechnology companies are innovating currently on process development, strain development, and products in protein and meat replacement. Regarding the stakeholders within biobased products, manufacturers (technology owners), retailers, governments, strain producers, CMOs (contract manufacturing operators), customers, final users, process developers, farmers, traders, and staff are mentioned.

Value proposition:

According to the participants, DAB's solution is unique as it focuses on hardware (the current trend is to develop strains) brings a cheaper CAPEX&OPEX and more efficient scalable fermentation process by converting a batch process into a continuous/semi-continuous one that generates less waste and requires less use of water and solvents. Additionally, the FAST technology has the potential to enable new biochemicals to enter the market. The participants also mentioned the use of renewable energies to power the process.

Value creation and delivery:

DAB is currently working on the 2PE molecule (rose fragrance). The participants argued that the current and potential market segments for the molecule are fragrances, cosmetics, anti-microbials, molecular intermediate (precursor), and flavours. Regarding the customers, strain developers and chemical producers that use fermentation are identified. The means DAB approaches to these customers by conferences, shared connections (LinkedIn), direct contact (from both parties), websites, social media, cold calling, traders, other companies, and advisors.

Regarding DAB's capabilities, the participants mentioned that the company has one lab services facility unit (Delft) and one demo large scale pilot unit (Ghent).

The social benefits the technology can bring are job creation with better quality conditions and provision of more sustainable products to people. On the other hand, the environmental benefits comprise reduction on GHG emissions, toxic waste, and utilities usage. Additionally, it was also stated that the technology will potentially allow the replacement of hydrocarbons and, that the company has the potential to replace plant extraction processes which may potentially reduce de-forestation.

Partners such as investors, strain development, start-ups related to biobased chemicals, CMOs, shareholders, process development companies, downstream processing companies (DSP), potential buyers of 2PE, BPF, BBEPP (CRO), and companies to which DAB develops fermentation processes are mentioned. It was mentioned that strain developers trust more in the technology because has proven to be effective.

The participants consider that strategic partners may be strain developers with technologies that allow strain development on a shorter timeframe; current manufacturers that may use FAST as an add-on to their current "traditional" fermenters in which DAB may access to their business network; and strain owners that can develop products together with DAB.

Value capture:

The participants stated that changes within the revenues and costs will occur due to the increase in efficiency and reduction in CAPEX and OPEX the technology offers. This means that the products will become competitive with the fossil-based ones, but at the same time a premium may be charged for the "natural" or "biobased" origin of the product.

The answers given by each participant on round 1 and round 2 can be found in Appendix IX and Appendix X, respectively.

5.3. Comparison of Technologies

A comparison of the chemical route and the FAST process for 2PE production is done in terms of raw materials, energy, water consumption, and CO_{2eq} emissions. The analysis is based on a fixed production of 360 $[\frac{ton}{year}]$ of 2PE whereby the volume of the reactor for FAST is 100 $[m^3]$, whilst for the chemical route is 8 $[m^3]$.

The chemical route for synthesis of 2PE was simulated by DAB. This process uses mainly chloroform, peroxybenzoic acid, styrene, methanol, sodium carbonate, and Palladium as raw materials. The process consists of five stages in which the materials go into a first reactor. Then, the obtained compound goes under a first distillation and after under second reactor. In the next stage, the output is filtered and goes under a second distillation to obtain 2PE. Figure 26 shows a summarised version of the process with the main inputs and outputs. The full process can be found in Appendix XI.

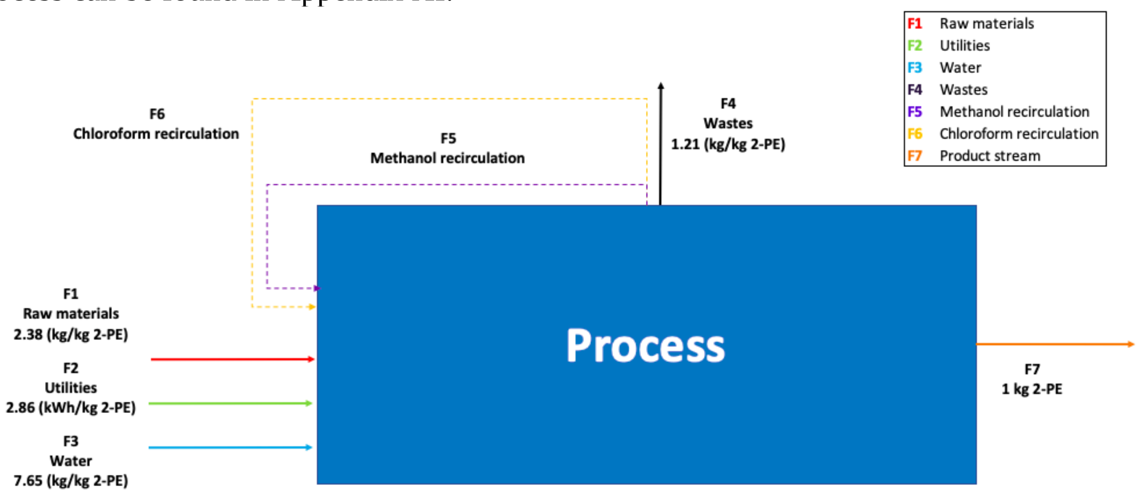

Figure 26: Simplified chemical route for 2PE (courtesy of DAB)

The CO_{2eq} emissions for raw materials, wastes, and utilities as well as the water consumption are shown in Table 8. The energy source that is considered is coal, whose emission factor is 0.82 $[\frac{kg\ CO_2}{kWh}]$ (World Nuclear Association, 2021).

Table 8: CO_{2eq} emissions and water consumption for chemical route synthesis of 2PE (courtesy of DAB)

Main raw materials	**Amount** $[\frac{kg\ raw\ material}{kg\ 2-PE}]$	**Factor** $[\frac{kg\ CO_2}{kg\ raw\ material}]$	**Emission Factor** $[\frac{kg\ CO_2}{kg\ 2-PE}]$
Chloroform	0.09	1.50	0.14
Peroxybenzoic acid	1.15	1.50	1.72
Styrene	1.11	3.68	4.10
Methanol	0.02	0.30	0.005
Sodium carbonate	0.01	1.12	0.01
Palladium	0.0000013	30,000	0.04
Total	**2.38**		**6.01**
Main wastes	**Amount** $[\frac{kg\ raw\ material}{kg\ 2-PE}]$	**Factor** $[\frac{kg\ CO_2}{kg\ raw\ material}]$	**Emission Factor** $[\frac{kg\ CO_2}{kg\ 2-PE}]$
Waste (1)	1.17	2.5	2.9
Waste (2)	0.04	0.1	0.002
Total	**1.21**		**2.95**
Utilities	**Amount** $[\frac{kWh}{kg\ 2-PE}]$	**Factor** $[\frac{kg\ CO_2}{kWh}]$	**Emission Factor** $[\frac{kg\ CO_2}{kg\ 2-PE}]$
Electricity	2.74	0.82	2.24
Natural gas	3.45	0.18	0.62
Total	**6.19**		**2.86**
	Amount $[\frac{kg}{kg\ 2-PE}]$		
Water input	**7.65**		
Overall			**11.82**

The FAST route for synthesis of 2PE was also simulated by DAB. This process uses mainly glucose, castor oil, ammonium sulphate, monopotassium phosphate, salts, and trace components. The process consists of three stages in which the raw materials go into the FAST fermenter. Then, they go into a centrifugation/filtration process to finally be distilled and thus obtain 2PE. Figure 27 summarises the process with the main inputs and outputs. The full process can be found in Appendix XI.

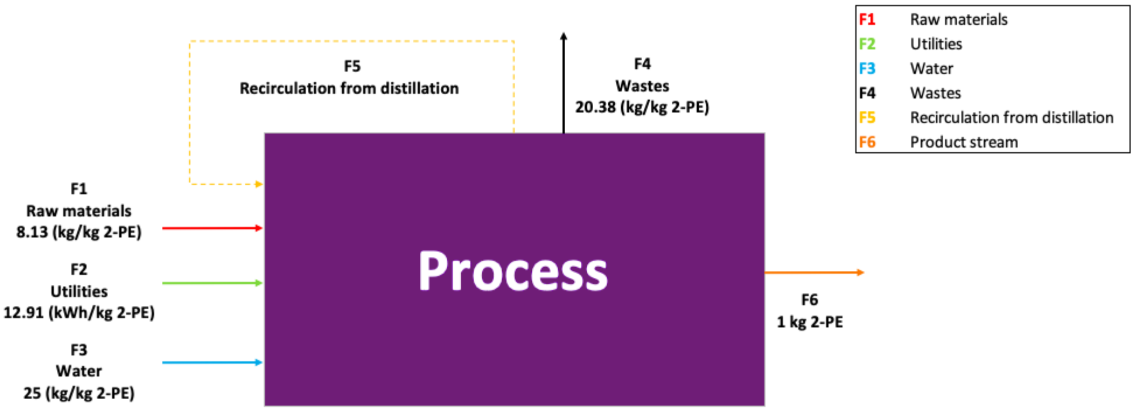

Figure 27: Simplified FAST route for 2PE (courtesy of DAB)

The CO_{2eq} emissions for raw materials, wastes, and utilities as well as the water consumption are shown in Table 9. The energy source that is considered is coal, whose emission factor is 0.82 $[\frac{kg\ CO_2}{kWh}]$ (World Nuclear Association, 2021).

Table 9: CO_2 emissions and water consumption for FAST route synthesis of 2PE (courtesy of DAB)

Main raw materials	**Amount** $[\frac{kg\ raw\ material}{kg\ 2-PE}]$	**Factor** $[\frac{kg\ CO_2}{kg\ raw\ material}]$	**Emission Factor** $[\frac{kg\ CO_2}{kg\ 2-PE}]$
Glucose	7.35	-0.6	-4.41
Castor Oil	0.54	0	0
Ammonium sulphate	0.14	0.5	0.07
Monopotassium phosphate	0.09	1	0.09
Salts& trace components	0.014	0.3	0.00
Total	**8.13**		**-4.25**
Main wastes	**Amount** $[\frac{kg\ raw\ material}{kg\ 2-PE}]$	**Factor** $[\frac{kg\ CO_2}{kg\ raw\ material}]$	**Emission Factor** $[\frac{kg\ CO_2}{kg\ 2-PE}]$
Off-gas	4.97	1	4.97
Wastewater	14.31	0.01	0.14
Biomass	1.09	0.01	0.01
Total	**20.38**		**5.12**
Utilities	**Amount** $[\frac{kWh}{kg\ 2-PE}]$	**Factor** $[\frac{kg\ CO_2}{kWh}]$	**Emission Factor** $[\frac{kg\ CO_2}{kg\ 2-PE}]$
Electricity	10.79	0.82	8.85
Natural gas	2.12	0.18	0.38
Total	**12.91**		**9.23**

	Amount $[\frac{kg}{kg\ 2-PE}]$		
Water input	**25**		
Overall			**10.11**

Table 10 shows a comparison of the overall CO_{2eq} emissions and water consumption of the chemical and FAST route for 2PE synthesis per category. It can be seen in *raw materials* FAST has a negative emission of CO_2 of -4.25 $[\frac{kg\ CO_2}{kg\ 2-PE}]$, whereas the chemical route emits 6.01 $[\frac{kg\ CO_2}{kg\ 2-PE}]$. In terms of *waste*, FAST produces more CO_2 than the chemical route, 5.12 and 2.95 $[\frac{kg\ CO_2}{kg\ 2-PE}]$, respectively. The case for *utilities* is similar, FAST produces more CO_2 than the chemical route, 9.23 and 2.87 $[\frac{kg\ CO_2}{kg\ 2-PE}]$, respectively. In overall, if coal is considered as the energy source, both technologies have similar CO_{2eq} emissions with 10.11 and 11.83 $[\frac{kg\ CO_2}{kg\ 2-PE}]$ for FAST and the chemical route, respectively. Considering water consumption, FAST consumes more water than the chemical with route with 25 and 7.65 $[\frac{kg}{kg\ 2-PE}]$, respectively. From the data, it can be said that FAST consumes more water and emits more CO_{2eq} in almost all the categories than the chemical route except for *raw materials*, in which the emissions are negative and compensate the total emissions giving FAST a lower overall value. Despite the values from table, it is important to clarify that most of the CO_2 from *waste* has a biogenic origin as it comes from biorenewable *raw materials*. Therefore, emissions of *waste* are only 0.87 $[\frac{kg\ CO_2}{kg\ 2-PE}]$ for the case of FAST.

Table 10: Comparison of overall CO_{2eq} emissions and water consumption of chemical and FAST route for 2PE synthesis

	Chemical	**FAST**
Raw Materials $[\frac{kg\ CO_2}{kg\ 2-PE}]$	6.01	-4.25
Waste $[\frac{kg\ CO_2}{kg\ 2-PE}]$	2.95	5.12
Utilities $[\frac{kg\ CO_2}{kg\ 2-PE}]$	2.86	9.23
Total $[\frac{kg\ CO_2}{kg\ 2-PE}]$	**11.82**	**10.11**
Water $[\frac{kg}{kg\ 2-PE}]$	**7.65**	**25**

The total CO_{2eq} emissions vary depending on the energy source to power the process. Figure 28 shows the level of emissions on *utilities* for FAST and the chemical route at different sources of power (World Nuclear Association, 2021). It can be seen from the figure that coal and biomass-co-firing have the highest emissions for FAST and the chemical route. As FAST is a more energy intensive process, the CO_{2eq} emissions are considerably higher. Nevertheless, if renewable energy sources are used, the emissions for both technologies are reduced and become similar. This inflexion point occurs when solar PV- utility source is used and the CO_2 emissions are 0.75 and 0.90 $[\frac{kg\ CO_2}{kg\ 2-PE}]$ for the chemical route and FAST, respectively. If the source with the least emissions is used, wind onshore, the emissions on *utilities* are 0.65 for the chemical route and 0.50 $[\frac{\mathrm{kg}\ CO_2}{\mathrm{kg\ 2{-}PE}}]$ for FAST, making FAST emitting less CO_2 within this category. This shift occurs because FAST has a less intensive use of natural gas than the chemical route.

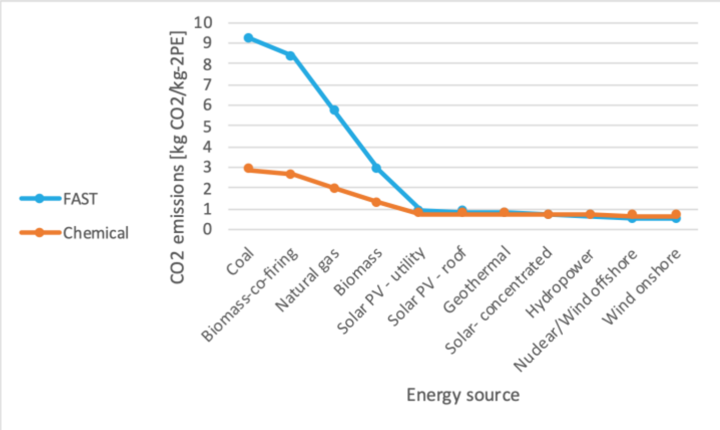

Figure 28: CO_2 emissions on utilities of chemical route and FAST

Regarding the total CO_{2eq} emissions, Figure 29 shows the overall level of emissions FAST and the chemical route at different sources of power (World Nuclear Association, 2021). It can be seen from the figure that coal and biomass-co-firing have the highest emissions for FAST and the chemical route showing similar values. Nevertheless, if renewable energy sources are used, the emissions for both technologies are reduced and the difference in emissions between the chemical route and FAST increases. The difference reaches a plateau of 82% in overall CO_{2eq} reduction if solar PV- utility is used, whereby the chemical route emits 9.71 and the FAST route 1.78 $[\frac{\mathrm{kg}\ CO_2}{\mathrm{kg\ 2{-}PE}}]$. If the source with the least emissions is used; wind onshore, the overall emissions are 9.61 for the chemical route and 1.38 $[\frac{\mathrm{kg}\ CO_2}{\mathrm{kg\ 2{-}PE}}]$ for FAST, making FAST to reduce its CO_{2eq} emissions by 86% compared to the chemical route. This occurs for two reasons: first, FAST has a less intensive use of natural gas than the chemical route; and second, by using the renewable sources the contribution of CO_2 from electricity becomes marginal. The emission factors can be found in Appendix XI.

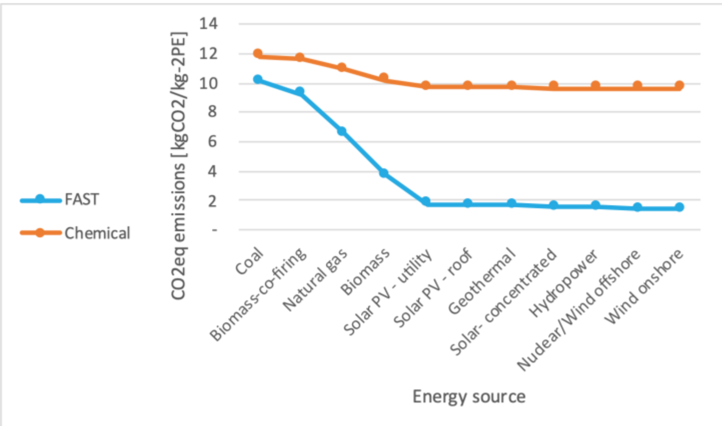

Figure 29: Overall CO_{2eq} emissions of chemical route and FAST

Table 11 shows the overall CO_{2eq} emissions of FAST and the chemical route by energy source. It also shows the reduction in emissions of FAST over the chemical route's ones. It can be seen that the plateau in emissions reduction occurs when solar PV- utility is used as energy source.

Table 11: CO_{2eq} overall emissions for chemical route and FAST

Source	**Chemical** $[\frac{kg\ CO_2}{kg\ 2-PE}]$	**FAST** $[\frac{kg\ CO_2}{kg\ 2-PE}]$	**Reduction** [%]
Coal	11.83	10.11	15
Biomass-co-firing	11.61	9.24	20
Natural gas	10.92	6.65	40
Biomass	10.21	3.74	63
Solar PV- utility	9.71	1.78	82
Solar PV- roof	9.69	1.70	82
Geothermal	9.68	1.67	83
Solar-concentrated	9.65	1.55	84
Hydropower	9.65	1.52	84
Nuclear/Wind offshore	9.61	1.39	86
Wind onshore	9.61	1.38	86

Table 12 shows a comparison of the CO_{2eq} emissions for both technologies using wind onshore energy. In this case the emission factor of the energy source is 0.011 $[\frac{kg\ CO_2}{kWh}]$ (World Nuclear Association, 2021). It can be seen the reduction of in CO_{2eq} for FAST compared to the chemical route.

Table 12: Comparison of overall CO2eq emissions and water consumption of chemical and FAST route for 2PE synthesis using wind onshore energy

	Chemical	**FAST**
Raw Materials $[\frac{kg\ CO_2}{kg\ 2-PE}]$	6.01	-4.25
Waste $[\frac{kg\ CO_2}{kg\ 2-PE}]$	2.95	5.12
Utilities $[\frac{kg\ CO_2}{kg\ 2-PE}]$	0.65	0.50
Total $[\frac{kg\ CO_2}{kg\ 2-PE}]$	**9.61**	**1.38**
Water $[\frac{kg}{kg\ 2-PE}]$	**7.65**	**25**

5.4. Sustainable Business Models

Using the ranked sustainability indicators (5.1), the data gathered during the Delphi rounds (5.2), and the data of FAST's process (5.3), a business model considering DAB as a producer of 2PE using FAST is outlined using Joyce & Paquin's (2016) TLBMC. This canvas is chosen because it is based on the LCA, which allows a quantitative analysis of the impacts, and also offers a more comprehensive analysis on the interrelations of the triple-bottom line compared to canvases such as the *Value Triangle* or the *Ecocanvas* that is only applicable for designing a circular business model (Biloslavo et al., 2018; Daou et al., 2020).

Economy layer

In this case, the sustainability indicators that are considered are: (1) "Process innovation", (2) "Product efficiency", (3) "Market potential", (4) "Capital productivity", and (5) "Energy cost". The components of the layer are mentioned as follows:

1) **Value proposition:** Efficient and cheaper bioproduction of chemicals. Indicators: (1) (2)

2) **Customer segments:** Chemical distributors, food companies, cosmetic companies, and chemical companies. Indicators: (3)

3) **Channels:** Conferences, LinkedIn, cold-call, traders, advisors.

4) **Customer relationships:** Direct contact, with customers, direct contact with distributors.

5) **Revenues:** Sales of 2PE.

6) **Key resources:** People, know-how, laboratory, patents, demo plant, facility.

7) **Key activities:** R&D, marketing, patenting, sales, running the facility. Indicators: (1)

8) **Key partnerships:** Strain owners, green energy companies, investors, biotechnology start-ups, CMOs, BBEPP, process development companies, DSP companies, suppliers.

9) **Cost structure: Fixed:** Salaries, patent fees, sales, marketing, R&D. **Variable:** Production. Indicators: (2) (4) (5)

Figure 30 shows the component on the economy canvas.

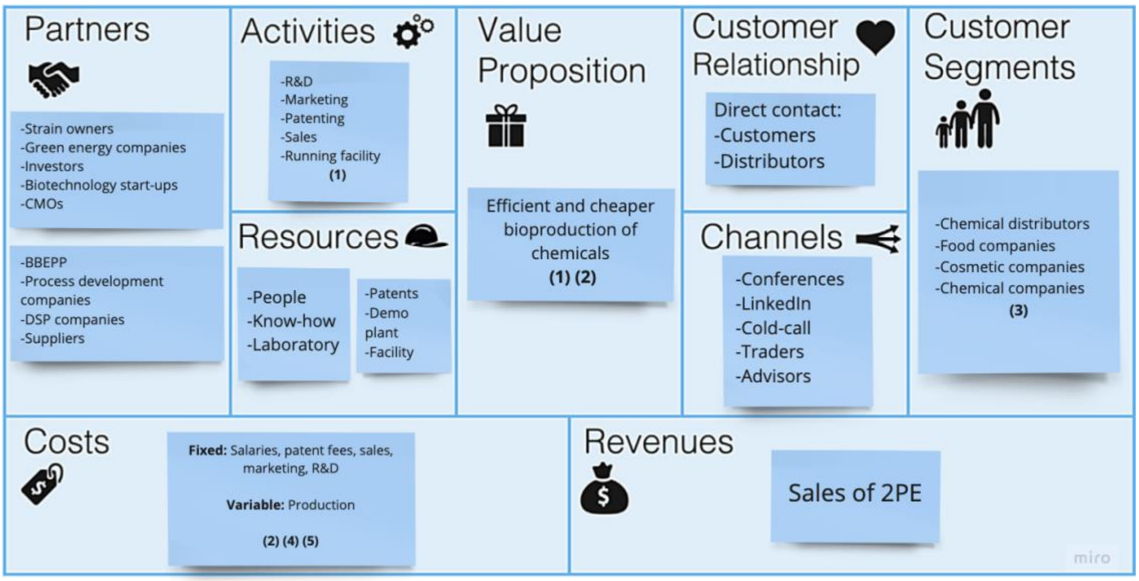

Figure 30: Economy canvas for DAB as a producer of 2PE

Social layer

In this case, the sustainability indicators that are considered are: (6) “Human toxicity”, (7) “Fatal work injuries”, (8) “Job creation”, (9) “Product transparency”, and (10) “Acceptance of biobased materials”. The components of the layer are mentioned as follows:

1) **Social value:** Provide access to sustainable biobased chemical products. Indicators: (9)

2) **Employee:** Safer working place, less workload, less heavy work. Indicators: (6) (7) (8)

3) **Governance:** Hierarchical organisation for manufacturing efficiently.

4) **Communities:** Start-ups, suppliers. Indicators: (6) (8)

5) **Societal culture:** Culture of promoting environmental awareness.

6) **Scale of outreach:** Europe, USA, Mexico, Canada, China, Japan, South Korea, Australia.

7) **End-users:** Users of food, fragrances, or chemical compounds. They are addressed by offering a sustainable product at lower price and the potential access to new chemicals. Indicators: (9) (10)

8) **Social impacts:** Odour generation, land usage that could be used for building households or agriculture for food. Use of food as a raw material for manufacturing chemicals.

9) **Social benefits:** Job creation, cleaner environment. Indicators: (6) (8)

Figure 31 shows the component on the social canvas.

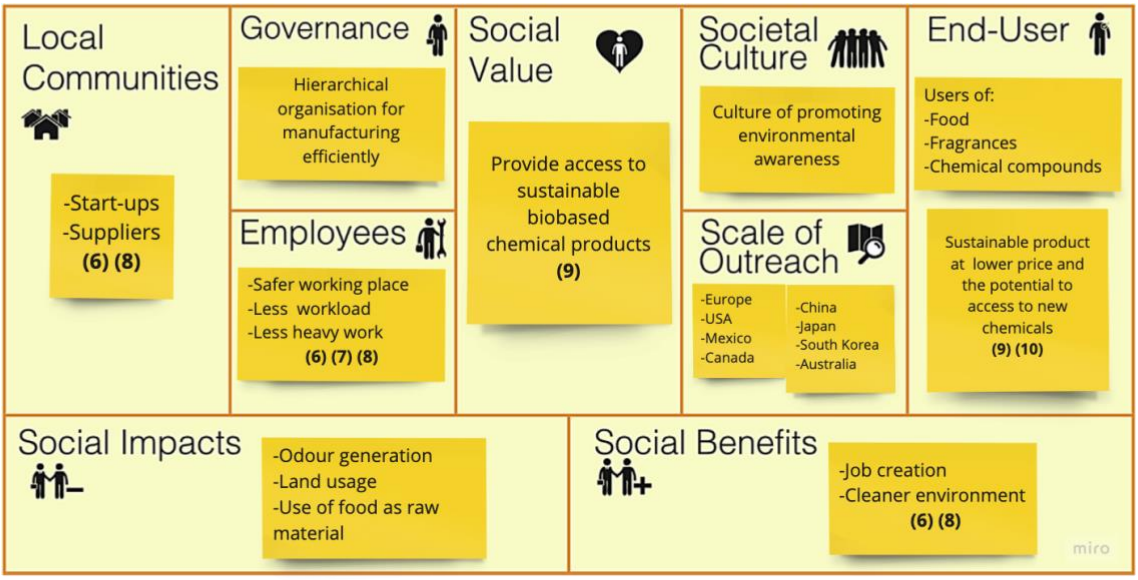

Figure 31: Social canvas for DAB as a producer of 2PE

Environmental layer

In this case, the sustainability indicators that are considered are: (11) “GHG emissions”, (12) “Raw material efficiency”, (13) “Water consumption”, (14) “Waste generation”, and (15) “Energy efficiency”. The components of the layer are mentioned as follows:

1) **Functional value:** 1 [kg] of 2PE.

2) **Materials:** Glucose, castor oil. CO_2 emissions: -4.25 $[\frac{\text{kg } CO_2}{\text{kg 2-PE}}]$, Raw materials: 8.13 $[\frac{\text{kg}}{\text{kg 2-PE}}]$. Indicators: (11) (12)

3) **Production:** This component considers CO_2 emissions and mass flows of the waste generation. Waste is composed by off-gas, wastewater, and biomass. CO_2: 5.12 $[\frac{\text{kg } CO_2}{\text{kg 2-PE}}]$, Mass flow: 20.38 $[\frac{\text{kg}}{\text{kg 2-PE}}]$ (Off-gas: 4.97, Wastewater: 14.31, Biomass: 1.09). The wastewater (broth) must be sterilized and disposed (*Draft Law on Genetically Modified Organisms*, 2016). Water consumption, CO_2 of supplies and materials are considered on other components. Indicators: (11) (14)

4) **Supplies and outsourcing:** Utilities. Using wind onshore energy: CO_2: 0.50 $[\frac{\text{kg } CO_2}{\text{kg 2-PE}}]$, Power: 12.91 $[\frac{\text{kWh}}{\text{kg 2-PE}}]$ (10.79 from electricity, 2.12 from natural gas). Water: 25 $[\frac{\text{kg}}{\text{kg 2-PE}}]$. Indicators: (11) (13) (15)

5) **Distribution:** Unknown. Indicators: (11)

6) **Use phase:** Unknown. Indicators: (11)

7) **End-of-life:** Unknown. Indicators: (11) (14)

8) **Environmental impacts:** Net CO_2 emissions: 1.38 $[\frac{\text{kg } CO_2}{\text{kg 2-PE}}]$, Water: 25 $[\frac{\text{kg}}{\text{kg 2-PE}}]$, Waste: 20.38 $[\frac{\text{kg}}{\text{kg 2-PE}}]$, Power using wind onshore: 12.91 $[\frac{\text{kWh}}{\text{kg 2-PE}}]$ (10.79 from electricity, 2.12 from natural gas). Indicators: (11) (13) (14) (15)

9) **Environmental benefits:** Biogenic raw materials. CO_2 -4.25 $[\frac{\text{kg } CO_2}{\text{kg 2-PE}}]$. Indicators: (11)

Figure 32 shows the component on the environmental canvas.

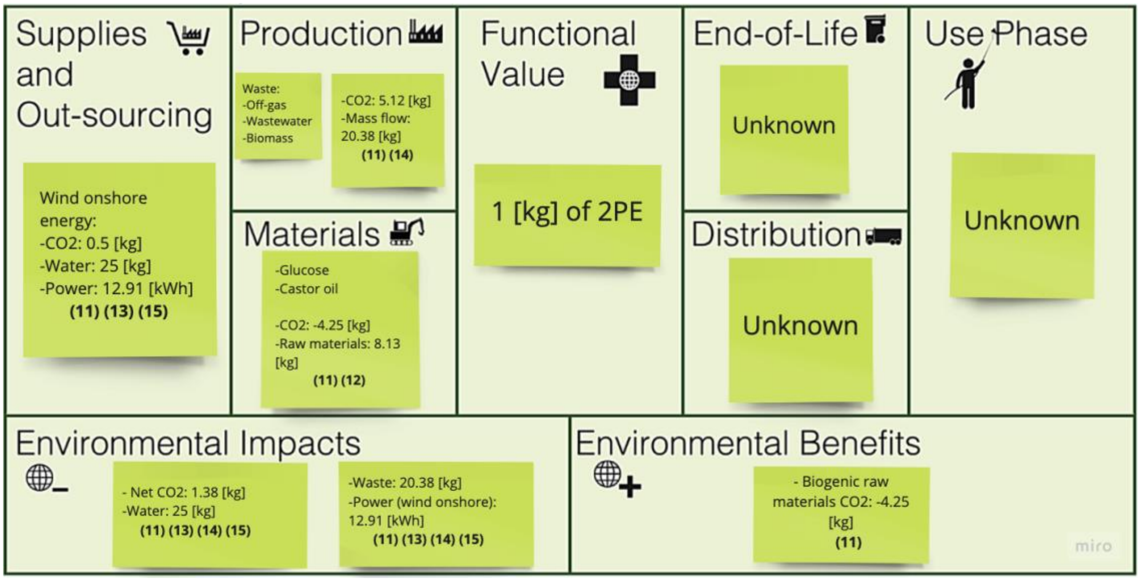

Figure 32: Environmental canvas for DAB as a producer of 2PE

Using the ranked sustainability indicators (5.1), the data gathered during the Delphi rounds (5.2), and the data of FAST's process (5.3), a business model considering DAB as a licensor of FAST to produce of 2PE can be found in Appendix XII.

Chapter 6: Discussion

The following chapter elaborates on the results obtained from the explorative single case study through the questionnaire on sustainability indicators and the Delphi rounds. Additionally, the outlined BMs for DAB as a producer and licensor for 2PE are analysed. Furthermore, recommendations and a comparison for both models are presented within this chapter.

6.1. Sustainability indicators

The differences in the selection of the top 5 most relevant sustainability indicators on each category among each department of DAB may be related to the function that the respective department has at the company. Additionally, other factors such as educational background and working experience of the participants may influence the decision process. Ranking the indicators is only limited to be descriptive and finding the rationales for the selection of the factors is therefore out of scope for this thesis project. It is also important to mention that by ranking the indicators, the participants are not overlooking the remaining factors. Instead, they are only selecting the most relevant ones according to their criteria.

The category with the most common chosen indicators is the *environmental* with four matches (*GHG emissions*, *Raw material efficiency*, *Water consumption*, and *Energy efficiency*), followed by *economy* with three matches (*Market Potential*, *Product efficiency*, and *Process innovation*). The *social* category only has one common match (*Fatal work* injuries). This can be interpreted that in general terms DAB members are mostly aligned in the *economy* and *environmental* aspects of sustainability. Nevertheless, for the *social* aspects, alignment among the members may be more difficult as this aspect of sustainability is more personal because involves individual systems of beliefs that influence the selection of the indicators.

Although the selected indicators were selected by experts within the biobased chemical industry during Delphi rounds, the constructs require more face validation to identity and assess their respective and appropriate measuring instruments. Moreover, more Delphi rounds with other experts are needed to triangulate the indicators and therefore, have more internal and external validation (Yin, 2018). Still, they are a practical tool to assess sustainability because they are specific for the biobased chemical industry.

6.2. Delphi Rounds

In this case the participants have similar visions regarding the biobased chemical industry, FAST, and the way on how the technology may be commercialised. However, differences in educational background and working experience of the participants may have contributed to have perspectives that complement each other. The differences in the visions are mainly related to which key partners were mentioned by the participants. Within this aspect, it is relevant to mention that although DAB is an academic spin-off that is still working with TU Delft and at the same time with WUR, none of the participants mentioned these institutions as key partners. This may be due to the fact that the participants take these partnerships for granted.

Besides the partnerships, there is general consensus on the potential positive effects FAST can have on sustainability and the biobased chemical industry. These effects relate to the fact that FAST offers a cheaper and efficient process that is able have less CO_2 emissions and pollution that current processes. Furthermore, the participants also agreed that FAST has the potential to be competitive with the chemical industry in the current production of chemicals and also has the potential to introduce new biochemicals within the market.

With these features of FAST, it can be argued that the proposed theoretical framework from 2.8 in which FAST acts a moderator between the current biobased chemical industry BMs and SBMI, is confirmed as FAST is able to generate SVPI and SVC&DI. First, FAST offers a new value proposition in which the production biochemicals is cheaper and more efficient (SVPI). Second, the technology may generate disruption by entering markets in which biotechnology processes are not cost effective to compete with traditional processes such as the chemical routes. Furthermore, FAST also has the potential to introduce new biobased chemicals to the industry such as cannabinoids, which may bring new opportunities for the development of new chemical compounds and at the same time, be beneficial for society (SVC&DI).

6.3. Business Model as DAB as a Producer with Recommendations

The business models from 5.4 that are outlined only considered the data gathered and generated from 5.1, 5.2, and 5.3. Nevertheless, it is still possible to make recommendations within their components for having a more comprehensive proposal. These recommendations for DAB's BM as producer for 2PE are presented as follows.

Economy layer

To have a more comprehensive *value proposition* and therefore a SVPI, "sustainability" must be included within the statement. On the *customer relations* block, contracts to keep and expand the sales with both the current customers and retailers may be considered. By doing this the company can ensure its current and future sales of 2PE to have a sustained growth. Considering *key resources*, it may be recommended to consider explicitly the resources from subsidies and venture capitals. These latter resources usually entail financial resources and a network that may be useful for boundary spanning activities (Schilling, 2020). Within *key partnerships*, TU Delft, WUR, and venture capitals can be mentioned explicitly to leverage from them when attracting new investors or potential customers. Additionally, institutions such as NGO's and governments can be included because they may also leverage the awareness of the technology for investors and potential customers. Furthermore, enrolling into standard organisations such as ISO or ASTM can increase the reputation of the company and at the same time turn it into a relevant stakeholder within the biobased industry in both public opinion and standards generation. Moreover, including joint ventures with chemical companies can also accelerate the diffusion of the FAST technology. Finally, within *cost structure*, maintenance of the facility can be highlighted because this operation is usually overlooked. However, it is relevant for the company because it can ensure a reliable production and operation of FAST, which needs to gain legitimacy within the market. The categories that remain the same within this layer are *revenues*, *activities*, *channels*, and *customer segments*.

In this case, the sustainability indicators that are considered are: (1) "Process innovation", (2) "Product efficiency", (3) "Market potential", (4) "Capital productivity", and (5) "Energy cost". The components of the layer are mentioned as follows:

1) **Value proposition:** Sustainable, efficient, and cheaper bioproduction of chemicals. Indicators: (1) (2). Innovativeness can be seen in this component.

2) **Customer segments:** Chemical distributors, food companies, cosmetic companies, and chemical companies. Indicators: (3). Innovativeness can be seen in this component.

3) **Channels:** Conferences, LinkedIn, cold-call, traders, advisors.

4) **Customer relationships:** Direct contact, with customers, direct contact with distributors.

5) **Revenues:** Sales of 2PE.

6) **Key resources:** People, know-how, laboratory, subsidies, venture capitals, patents, demo plant, facility. Innovativeness can be seen in this component.

7) **Key activities:** R&D, marketing, patenting, sales, running the facility. Indicators: (1)

8) **Key partnerships:** Strain owners, green energy companies, investors, biotechnology start-ups, BBEPP, process development companies, DSP companies, suppliers, CMOs, NGOs, governments, venture capitals, TU Delft, WUR standard organisations, joint ventures with chemical companies. Innovativeness can be seen in this component.

9) **Cost structure: Fixed:** Salaries, patent fees, sales, marketing, R&D. **Variable:** Production, maintenance. Indicators: (2) (4) (5)

Figure 33 shows the component on the economy canvas.

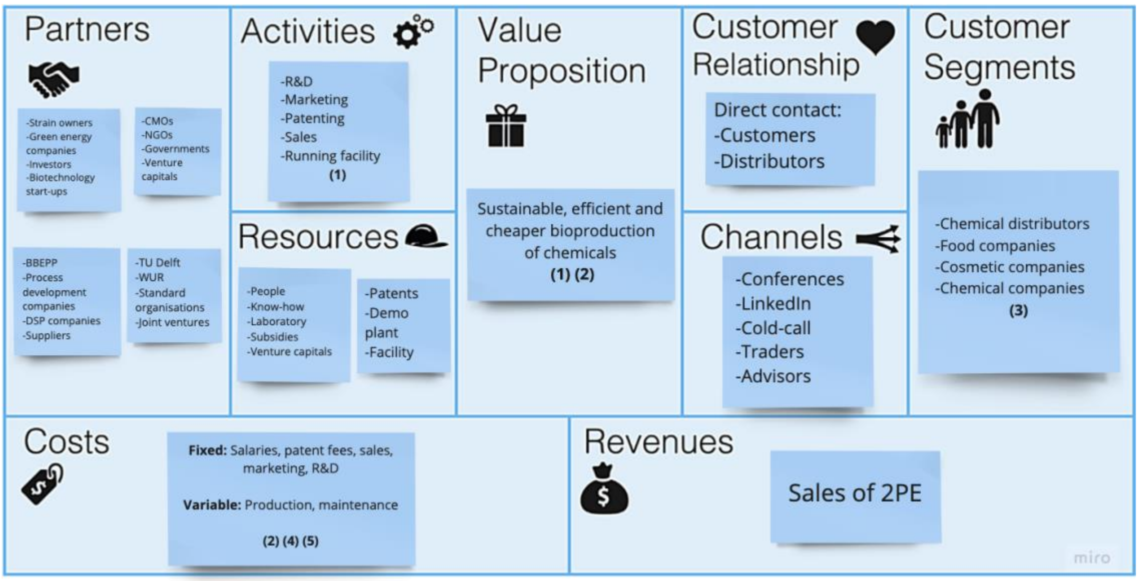

Figure 33: Recommended economy canvas for DAB as a producer of 2PE

<u>Social layer</u>

Within this layer the categories of *social value*, *employees*, *social impacts*, and *end-user* remain the same. For *local communities* it may be recommended to explicitly include universities such as TU Delft and WUR (mentioned on the economy layer). Regarding *social benefits*, the use of FAST allows the substitution of fossil raw materials. On *societal culture*, it may be recommended to promote CSR, environmental awareness, and positive change. This latter recommendation is used to generate change and strengthen the performance of an organisation (Positive Change Europe, 2021). Considering *governance*, this block may be oriented towards a one with transparent decision-making processes. Additionally, as the company is R&D intense, it can become an ambidextrous organisation in both knowledge management and organisational structure. By doing this, the company can balance its knowledge exploration (R&D) and exploitation (production) activities by means of having two different organisational structures. This means, an organic structure for R&D and a mechanistic one for production (Newell et al., 2019; Schilling, 2020). Finally, on *scale of outreach*, FAST can also be deployed in other countries such as India, Brazil, and South Africa whereby sugar feedstock is abundant and demand for 2PE is high.

In this case, the sustainability indicators that are considered are: (6) “Human toxicity”, (7) “Fatal work injuries”, (8) “Job creation”, (9) “Product transparency”, and (10) “Acceptance of biobased materials”. The components of the layer are mentioned as follows:

1) **Social value:** Provide access to sustainable biobased chemical products. Indicators: (9)

2) **Employee:** Safer working place, less workload, less heavy work. Indicators: (6) (7) (8)

3) **Governance:** Ambidextrous organisation (organic and hierarchical), transparency in decision making.

4) **Communities:** Start-ups, suppliers, universities. Indicators: (6) (8)

5) **Societal culture:** Culture of promoting environmental awareness and positive change, corporate social responsibility.

6) **Scale of outreach:** Europe, USA, Mexico, Canada, India, Brazil, China, Japan, South Korea, Australia, South Africa, Thailand.

7) **End-users:** Users of food, fragrances, or chemical compounds. Users are addressed by offering a sustainable product at lower price and the potential access to new chemicals. Indicators: (9) (10)

8) **Social impacts:** Odour generation, land usage that could be used for building households or agriculture for food. Use of food as a raw material for manufacturing chemicals.

9) **Social benefits:** Job creation, cleaner environment. Substitution of fossil raw materials. Indicators: (6) (8)

Figure 34 shows the component on the social canvas.

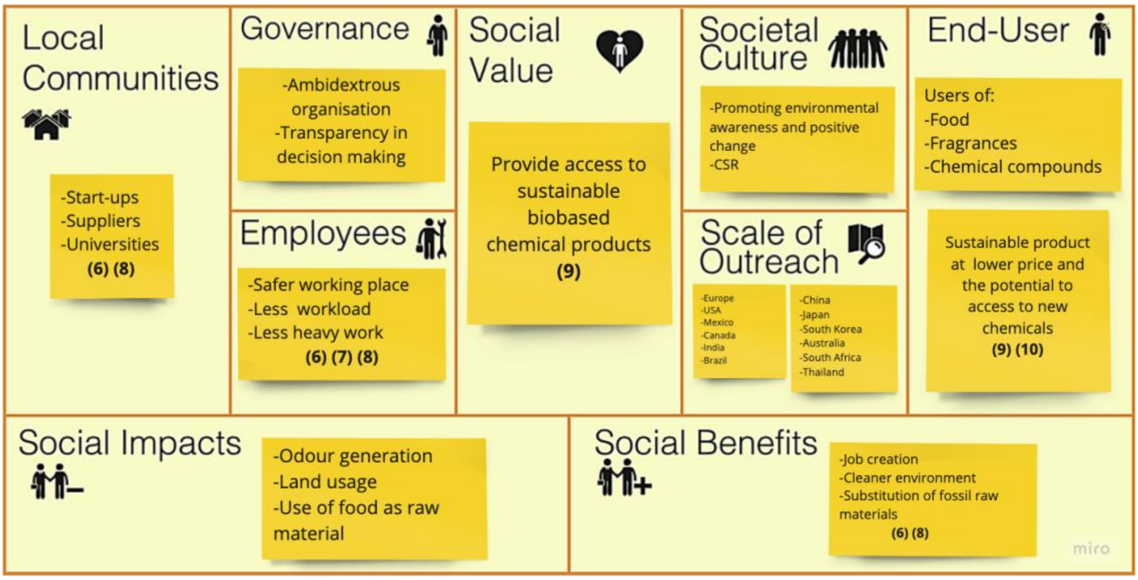

Figure 34: Recommended social canvas for DAB as a producer of 2PE

<u>Environmental layer</u>

Within this layer there are no changes compared to the previous version. However, it is relevant to notice that *end-of-life*, *distribution*, and *use phase* have an unknown CO_{2eq} impact. This implies uncertainty within the calculation of the overall environmental impact of the process. Therefore, it cannot be stated whether the whole process has more or less environmental impact than the one estimated on the process simulations.

It is also relevant to highlight a few aspects that have implications for the company. First, as the process is energy intensive it becomes mandatory the use of renewable energy sources to reduce the CO_{2eq} emissions and thus have a sustainable process. Otherwise, the overall emissions are similar to the ones of the chemical route. Second, replacing the current chemicals that are being used by organic ones with the same functionality also contributes to reduce the CO_2 footprint and the toxicity for the environment.

In this case, the sustainability indicators that are considered are: (11) “GHG emissions”, (12) “Raw material efficiency”, (13) “Water consumption”, (14) “Waste generation”, and (15) “Energy efficiency”. The components of the layer are mentioned as follows:

1) **Functional value:** 1 [kg] of 2PE.

2) **Materials:** Glucose, castor oil. CO_2 emissions: -4.25 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Raw materials: 8.13 $[\frac{\text{kg}}{\text{kg 2−PE}}]$. Indicators: (11) (12)

3) **Production:** This component considers CO_2 emissions and mass flows of the waste generation. Waste is composed by off-gas, wastewater, and biomass. CO_2: 5.12 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Mass flow: 20.38 $[\frac{\text{kg}}{\text{kg 2−PE}}]$ (Off-gas: 4.97, Wastewater: 14.31, Biomass: 1.09). The wastewater (broth) must be sterilized and disposed (*Draft Law on*

Genetically Modified Organisms, 2016). Water consumption, CO_2 of supplies and materials are considered on other components. Indicators: (11) (14)

4) **Supplies and outsourcing:** Utilities. Using wind onshore energy: CO_2: 0.50 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Power: 12.91 $[\frac{\text{kWh}}{\text{kg 2−PE}}]$ (10.79 from electricity, 2.12 from natural gas). Water: 25 $[\frac{\text{kg}}{\text{kg 2−PE}}]$. Indicators: (11) (13) (15)

5) **Distribution:** Unknown. Indicators: (11)

6) **Use phase:** Unknown. Indicators: (11)

7) **End-of-life:** Unknown. Indicators: (11) (14)

8) **Environmental impacts:** Net CO_2 emissions: 1.38 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Water: 25 $[\frac{\text{kg}}{\text{kg 2−PE}}]$, Waste: 20.38 $[\frac{\text{kg}}{\text{kg 2−PE}}]$, Power using wind onshore: 12.91 $[\frac{\text{kWh}}{\text{kg 2−PE}}]$ (10.79 from electricity, 2.12 from natural gas). Indicators: (11) (13) (14) (15)

9) **Environmental benefits:** Biogenic raw materials. CO_2 -4.25 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$. Indicators: (11)

Figure 35 shows the component on the environmental canvas.

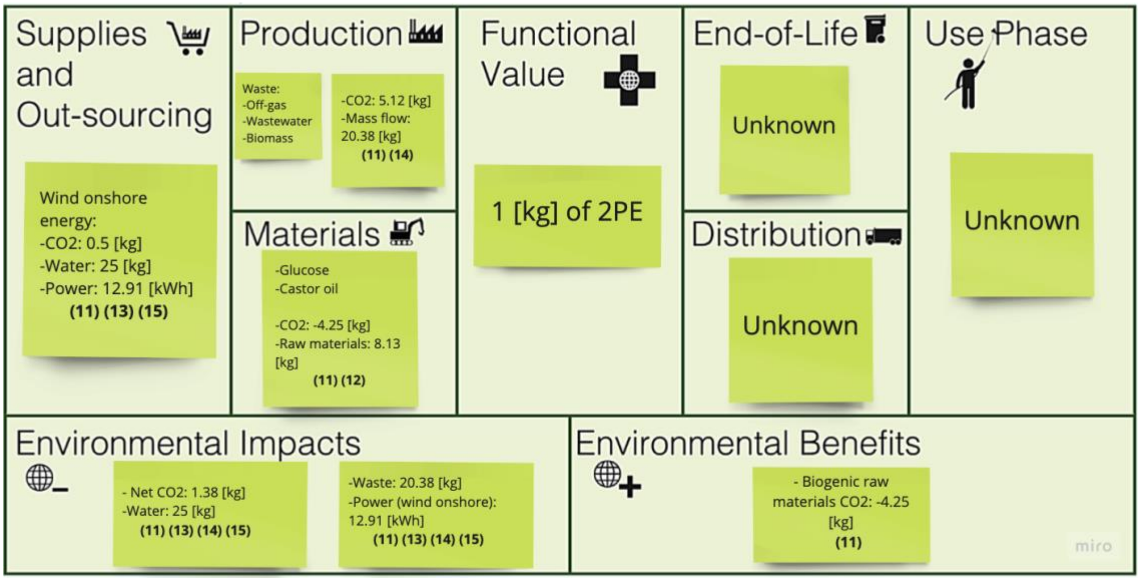

Figure 35: Recommended environmental canvas for DAB as a producer of 2PE

It can be seen from the horizontal analysis that the BM components are consistent within each layer. Moreover, from a vertical analysis they do not present any conflict among the layers (Joyce & Paquin, 2016).

6.4. Business Model as DAB as a Licensor with Recommendations

As it was done on the previous section, the recommendations for DAB's BM as licensor for 2PE are presented as follows.

Economy layer

To have a more comprehensive *value proposition* and therefore a SVPI, "sustainability" must be included within the statement. Regarding *customer segments*, the potential licensees for FAST comprise chemical companies and biotechnology companies. On *customer relations*, the idea is to keep the relation with the licensees by means of contracts. For *key resources*, it may be recommended to consider explicitly the resources from subsidies and venture capitals. These latter resources usually entail financial resources and a network that may be useful for boundary spanning activities (Schilling, 2020). An additional resource which involves the financial resources and also the knowledge the licensees gather while operating the facilities is included. The *key activities* still comprise R&D marketing, and patenting but also auditing the licensees and sales on behalf of the licensees are included. Within *key partnerships*, TU Delft, WUR, and venture capitals can be mentioned explicitly to leverage from them when attracting new investors or potential customers. Additionally, institutions such as NGO's and governments can be included because they may also leverage the awareness of the technology for investors and potential customers. Furthermore, enrolling into standard organisations such as ISO or ASTM can increase the reputation of the company and at the same time turn it into a relevant stakeholder within the biobased industry in both public opinion and standards generation. Moreover, including joint ventures with chemical companies can also accelerate the diffusion of the FAST technology. New partners that are included within this BM involve the licensees and audit companies to oversee them. Within *cost structure*, salaries, patenting, sales and marketing are the most relevant. The *revenues* becomes more sophisticated than that of the producer's models. In this case, an initial down payment for licensing the technology and a royalty for the sales of 2PE is charged to the licensees. Also, an additional royalty for commercialisation of 2PE can be charged. This latter royalty offers an extra revenue source for the company and, at the same time, reduces the financial risk for potential licensees because DAB can reduce uncertainty by having a sales force that has knowledge and a network within the industry. Finally, the category that remains the same within this layer is *channels*.

In this case, the sustainability indicators that are considered are: (1) "Process innovation", (2) "Product efficiency", (3) "Market potential", (4) "Capital productivity", and (5) "Energy cost". The components of the layer are mentioned as follows:

1) **Value proposition:** Sustainable, efficient, and cheaper bioproduction of chemicals. Indicators: (1) (2). Innovativeness can be seen in this component.

2) **Customer segments:** Chemical companies, biotechnology companies. Indicators: (3). Innovativeness can be seen in this component.

3) **Channels:** Conferences, LinkedIn, cold-call, traders, advisors.

4) **Customer relationships:** Direct contact with licensees.

5) **Revenues:** Down payment for licencing FAST, royalty for the sales of 2PE, royalty for commercialisation of 2PE.

6) **Key resources:** People, know-how, laboratory, subsidies, venture capitals, patents, demo plant, knowledge & resources from licensees. Innovativeness can be seen in this component.

7) **Key activities:** R&D, marketing, patenting, sales, audit licensees. Indicators: (1)

8) **Key partnerships:** Strain owners, green energy companies, investors, biotechnology start-ups, licensees, process development companies, BBEPP, DSP companies, suppliers, TU Delft, WUR. NGOs, governments, standard organisations, venture capitals, auditory companies. Innovativeness can be seen in this component.

9) **Cost structure: Fixed:** Salaries, patent fees, R&D, sales, marketing. Indicators: (2) (4) (5)

Figure 36 shows the component on the economy canvas.

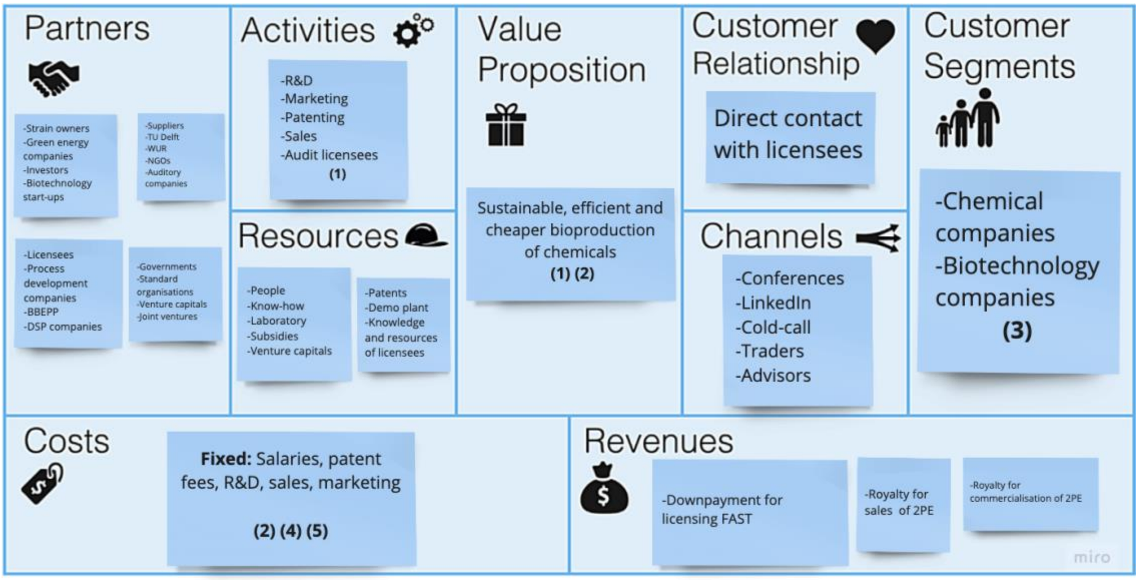

Figure 36: Recommended economy canvas for DAB as a licensor for 2PE production

<u>Social layer</u>

Within this layer the categories of *social value*, *employees*, *social impacts*, and *end-user* remain the same. For *local communities* it may be recommended to explicitly include universities such as TU Delft and WUR (mentioned on the economy layer). Regarding *social benefits*, the use of FAST allows the substitution of fossil raw materials. On *societal culture*, it may be recommended to promote CSR, environmental awareness, and positive change. This latter recommendation is used to generate change and strengthen the performance of an organisation (Positive Change Europe, 2021). Considering *governance*, this block may be oriented towards a one with transparent decision-making processes. Additionally, as the company is R&D intense, it can become an ambidextrous organisation in both knowledge management and organisational structure. By doing this, the company can balance its knowledge exploration (R&D) and exploitation (commercial) activities by means of having two different organisational structures. This means, an organic structure for R&D and a mechanistic one for sales and auditing the licensees (Newell et al., 2019; Schilling, 2020). Finally, on *scale of outreach*, the FAST technology can also be deployed simultaneously through the licensees in more countries such as India, Brazil, and South Africa whereby sugar feedstock is abundant and demand for 2PE is high.

In this case, the sustainability indicators that are considered are: (6) “Human toxicity”, (7) “Fatal work injuries”, (8) “Job creation”, (9) “Product transparency”, and (10) “Acceptance of biobased materials”. The components of the layer are mentioned as follows:

1) **Social value:** Provide access to sustainable biobased chemical products. Indicators: (9)

2) **Employee:** Safer working place, less workload, less heavy work. Indicators: (6) (7) (8)

3) **Governance:** Ambidextrous organisation (organic and hierarchical), transparency in decision making.

4) **Communities:** Start-ups, suppliers, universities. Indicators: (6) (8)

5) **Societal culture:** Promoting environmental awareness and positive change to licensees, corporate social responsibility.

6) **Scale of outreach:** Europe, USA, Mexico, Canada, India, Brazil, China, Japan, South Korea, Australia, South Africa, Thailand.

7) **End-users:** Users of food, fragrances, or chemical compounds. They are addressed by offering a sustainable product at lower price and the potential access to new chemicals. Indicators: (9) (10)

8) **Social impacts:** Odour generation, land usage that could be used for building households or agriculture for food. Use of food as a raw material for manufacturing chemicals.

9) **Social benefits:** Job creation, cleaner environment. Substitution of fossil raw materials. Indicators: (6) (8)

Figure 37 shows the component on the social canvas.

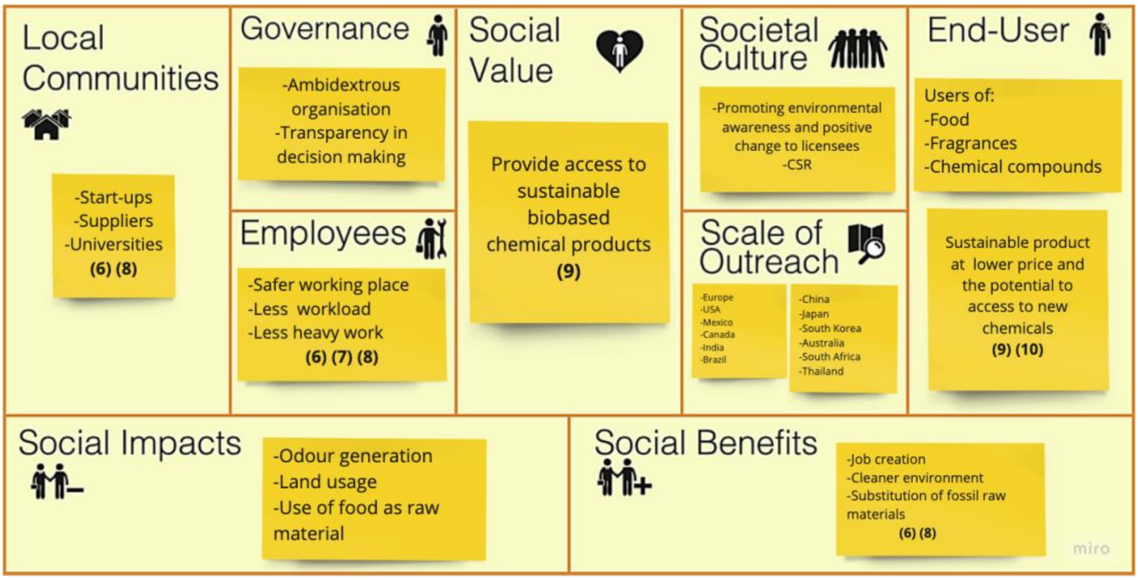

Figure 37: Recommended social canvas for DAB as a licensor for 2PE production

<u>Environmental layer</u>

Within this layer there are no changes compared to the previous version. However, it is relevant to notice that *end-of-life*, *distribution*, and *use phase* have an unknown CO_{2eq} impact. This implies uncertainty within the calculation of the overall environmental impact of the process. Therefore, it cannot be stated whether the whole process has more or less environmental impact than the one estimated on the process simulations.

It is also relevant to highlight a few aspects that have implications for the company. First, as the process is energy intensive it becomes necessary to state on the contracts to the licensees that the use of renewable energy sources to reduce the CO_{2eq} emissions becomes mandatory for having a sustainable process. Otherwise, the overall emissions are similar to the ones of the chemical route. Second, replacing the current chemicals that are being used by organic ones with the same functionality also contributes to reduce the CO_2 footprint and the toxicity for the environment. If these measures are not enforced, the reputation of DAB may be affected as the public opinion may consider that the company is only using biotechnology as a mere means for marketing, which may be interpreted as greenwashing.

In this case, the sustainability indicators that are considered are: (11) "GHG emissions", (12) "Raw material efficiency", (13) "Water consumption", (14) "Waste generation", and (15) "Energy efficiency". Is important to mention that in this case, as DAB is a licensor of the FAST technology, the emissions account per installed facility. The components of the layer are mentioned as follows:

1) **Functional value:** 1 [kg] of 2PE.

2) **Materials:** Glucose, castor oil. CO_2 emissions: -4.25 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Raw materials: 8.13 $[\frac{\text{kg}}{\text{kg 2−PE}}]$. Indicators: (11) (12)

3) **Production:** This component considers CO_2 emissions and mass flows of the waste generation. Waste is composed by off-gas, wastewater, and biomass. CO_2: 5.12

$[\frac{kg\ CO_2}{kg\ 2-PE}]$, Mass flow: 20.38 $[\frac{kg}{kg\ 2-PE}]$ (Off-gas: 4.97, Wastewater: 14.31, Biomass: 1.09). The wastewater (broth) must be sterilized and disposed (*Draft Law on Genetically Modified Organisms*, 2016). Water consumption, CO_2 of supplies and materials are considered on other components. Indicators: (11) (14)

4) **Supplies and outsourcing:** Utilities. Using wind onshore energy: CO_2: 0.50 $[\frac{kg\ CO_2}{kg\ 2-PE}]$, Power: 12.91 $[\frac{kWh}{kg\ 2-PE}]$ (10.79 from electricity, 2.12 from natural gas). Water: 25 $[\frac{kg}{kg\ 2-PE}]$. Indicators: (11) (13) (15)

5) **Distribution:** Unknown. Indicators: (11)

6) **Use phase:** Unknown. Indicators: (11)

7) **End-of-life:** Unknown. Indicators: (11) (14)

8) **Environmental impacts:** Net CO_2 emissions: 1.38 $[\frac{kg\ CO_2}{kg\ 2-PE}]$, Water: 25 $[\frac{kg}{kg\ 2-PE}]$, Waste: 20.38 $[\frac{kg}{kg\ 2-PE}]$, Power using wind onshore: 12.91 $[\frac{kWh}{kg\ 2-PE}]$ (10.79 from electricity, 2.12 from natural gas). Indicators: (11) (13) (14) (15)

9) **Environmental benefits:** Biogenic raw materials. CO_2 -4.25 $[\frac{kg\ CO_2}{kg\ 2-PE}]$. Indicators: (11)

Figure 38 shows the component on the environmental canvas.

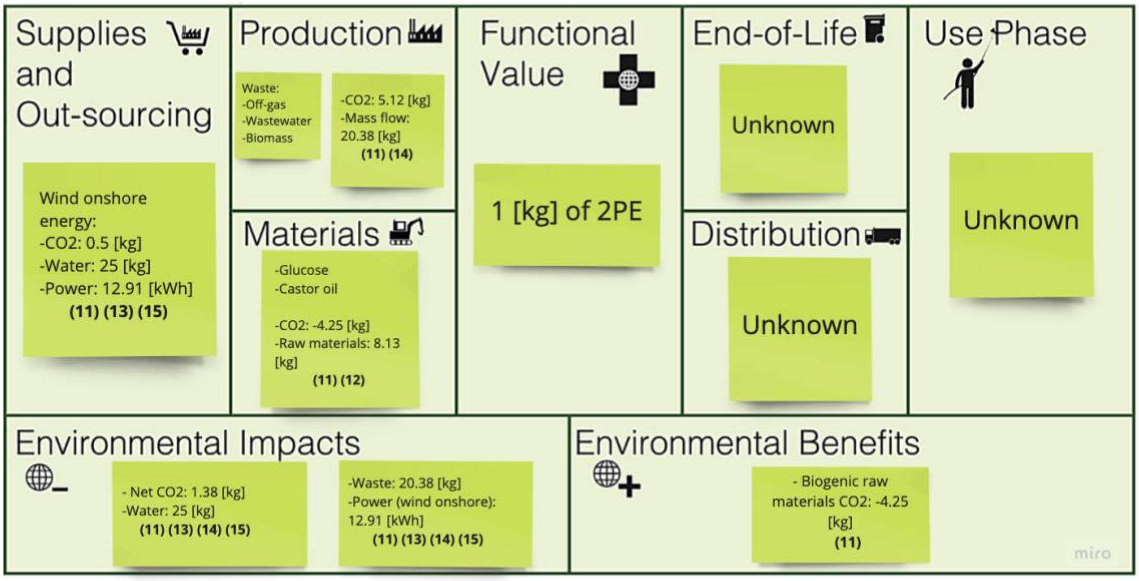

Figure 38: Recommended environmental canvas for DAB as a licensor for 2PE production

It can be seen from the horizontal analysis that the BM components are consistent within each layer. Moreover, from a vertical analysis they do not present any conflict among the layers (Joyce & Paquin, 2016).

6.5. Comparison of the Business Models

In the economy layer the main differences between these BMs are within the *customer segments*, key *activities*, key *partnerships*, *cost structure* and *revenues*. The producer model considers chemical distributors, food companies, cosmetic companies, and chemical companies as direct customers whereby 2PE is sold directly to them. On the other hand, the licensor model considers chemical and biotechnology companies as the customers. In this case, the FAST technology is licensed to them, and they are in charge of producing 2PE. Within *key activities*, manufacturing represents the main difference between these two BMs. Additionally, sales for the case of licensor, is focused on ensuring revenues for the licensees. Within *key partnerships*, the licensor model adds audit companies to enforce the complying of the licence contract by the licensees. Additionally, licensees become a relevant partner for the company. Regarding the *cost structure*, the main difference lays in that the producer model has production costs, whilst the licensor does not. Finally, both models also have differences in the *revenue streams*. For the producer model, the revenues are come from the direct sale of 2PE. On the other hand, for the licensor model, the revenues come from the down payment and the royalties for both the sales and commercialisation of 2PE. It is also important to highlight that the revenue streams in the producer model will be higher than that of the licensor model. However, on the producer model the financial risk and investment for DAB also increases.

Regarding the social layer, both models show similarities. On the producer model, the *social impact* is done directly by DAB, whilst in the licensor model, the impact is done by the licensees, but for both cases the effects are the same. It is important to mention that in both cases DAB should adopt an ambidextrous organisation, which is crucial for balancing its respective exploration and exploitation capabilities.

In the environmental layer both models have the same components. On the producer model, the environmental impact is done directly by DAB, whilst in the licensor model, the impact accounts per licensee. It is important to mention that using renewable energy sources and organic supplies becomes mandatory for having a sustainable production.

It can be noticed on both BMs that FAST is a driver for SBMI in *value proposition* and *value creation & delivery*. The *value proposition* is innovative as it offers a bioproduction of chemicals (in this case 2PE) that is more efficient, cheaper, and sustainable. On *value creation* two innovation aspects can be recognized, the first one is on *key resources* as the patent is for a breakthrough technology, FAST, that allows to work on a different operational range than traditional fermenters. The second is on key *partnerships* because DAB is working with strain developers for designing organisms that can synthetise 2PE through bioconversion by using a different approach on genetic engineering choices that enhances product output rather than product titration, which is the common approach. This is innovative as 2PE production via fermentation with the current processes is not feasible due to their lack of efficiency. Finally, in *value delivery* innovation can be seen on the *customer segment* as FAST can enter the 2PE market and be competitive with the plant extraction process and the chemical route. This is the main contribution of the thesis projects as it shows how FAST is a driver for SBMI and goes beyond the common practices of companies within this industry that only focus on replacing the petrochemical origin of their raw materials.

Regarding the theoretical contribution of this thesis project, differently from other literature, it not only focuses on the revenue model or operational aspects of the business models outlined.

It goes beyond and makes a comprehensive analysis of all the components of the two business models for 2PE production within the biobased chemical industry. Furthermore, this thesis also shows how a business model from the biotechnology sector is able to capture the value of a breakthrough technology such as FAST in a sustainable way, and thus, reducing the research gap between business model innovation, sustainability, and technology.

Chapter 7: Conclusion

The main research question and the sub-research questions are answered in this chapter. Furthermore, the main limitations of the research are described, and future research is proposed. Finally, recommendations for DAB based on the research are presented.

7.1. Answers to the Research Questions

- **Main research question:** *How can the FAST technology be a driver for sustainable business model innovation of biobased chemical companies?*

This thesis project has proven that FAST drives sustainable business model innovation within the biobased chemical industry. Sustainable business model innovation is found in both *value proposition* and *value creation & delivery* of the two sustainable business models generated by complementing FAST with the use of organic raw materials and solvents, and renewable energies as power source. Specifically, FAST sustainable innovativeness can be seen in the elements of *value proposition*, *key resources*, *key partnerships*, and *customer segments* of these novel sustainable business models. FAST drives sustainable business model innovation within these four elements by being a breakthrough innovation (*key resources*) that includes a sustainable and efficient production of biochemicals within its *value proposition.* Moreover, innovation is also driven within *key partnerships* as FAST requires strain designers to adopt a different approach when engineering new microorganisms. Here, the technology has an effect outside its business model, modifying the value chain. Furthermore, FAST can reach new *customer segments* and be competitive with current production processes of chemicals as it was shown for the case of 2PE. This sustainable innovativeness differs from the practices other companies within the industry have implemented which are focused on changing the fossil origin of raw materials but do not consider the creation of new value propositions/business models to balance the financial, environmental, and social aspects of sustainability.

- **Sub Question 1**: *What is Sustainable Business Model Innovation?*

From section 2.4 of the literature review, the concept of Sustainable Business Model Innovation is relatively recent and corresponds to a sub-set of the research field of Sustainable Business Models that combines sustainability aspects with Business Model Innovation. The concept has several definitions, but they have common elements that relate to changing an incumbent business model or creating a new one with the aim of achieving sustainability through sustainable value creation. This value creation can be seen to different extents in the components of sustainable business model innovation which are: Sustainable Value Proposition Innovation, Sustainable Value Creation and Delivery Innovation, and Sustainable Value Capture Innovation. In practice for considering sustainable business model innovation as such, organisations must aim to have a positive or reduced negative impact on the environment and society and also integrate solutions that foster sustainability within the business models. Sustainable business model innovation can be understood as an opportunity for companies to contribute to society, the environment, and at the same time, remain competitive and profitable.

- **Sub Question 2**: *What are the traditional business models of biobased chemical companies?*

From section 2.6 of the literature review, business models within biobased chemical companies are focused on being producers or services providers. On one hand, producers develop their own technologies or buy/license them for being in value chain from to raw materials to the distribution of products. This model is mainly used by diversified small medium enterprises and multinationals. On the other hand, the other business model is service provider: However, companies are changing towards being a producer due to the growing opportunities. Nevertheless, these opportunities also involve financial risks. Additionally, there are emerging business models whereby companies focus on process development for having intellectual property and thus to license the technology. In this business model, companies have a portfolio of technologies that can be sold or licensed to another firm.

New trends within this industry comprise mainly four business models that are based on the producer model. The first one is based on vertically integrated production. The second model relates to centralised production. Here manufacturing is done in few large facilities that scale product manufacturing. The third model is horizontally stratified value chain. Here, activities are carried out by different companies that are specialized along the value chain. The fourth model is distributed production value chain. In this case manufacturing is done in small facilities that use local raw materials and deliver products to supply local or niche markets. It can be seen that for the first two models, the production is carried out by one organisation. Whilst for the other two, several companies are involved in the value chain.

- **Sub Question 3:** *How can traditional business models of biobased chemical companies transform themselves towards more sustainable business models using the FAST technology?*

From section 2.6 of the literature review, technologies such as new developments in fermentation will affect the current business models of biobased companies and can generate incremental or radical effects within the value chain. For making a successful implementation of these new technologies, it may be recommended to introduce them into existing biobased companies due to the fact that they already have developed the capabilities and the knowledge to operate these technologies. By doing this, companies can leverage from the disruptive impact these new fermenters offer as they can enable the development of new markets and chemicals.

From section 4.4 of the case study, the FAST technology is a platform whose features increase the sustainable productivity and reduce the costs (CAPEX and OPEX) of the fermentation process which enable the technology to become competitive with chemical processes that use fossil raw materials. Therefore, FAST has the potential to disrupt the market in terms of market development within the industry. Moreover, the technology also has the potential to bring new molecules to the market such as cannabinoids, which may bring new opportunities for developing new compounds.

If FAST is adopted by biobased companies. Their current business models will become more sustainable because the technology will bring changes within their value proposition and value creation & delivery by generating sustainable value proposition innovation and sustainable value creation & delivery innovation.

- **Sub Question 4:** *How can the FAST technology be used to design sustainable business models within DAB?*

By using section 5.4 of the results, the framework from section 2.8 of the literature review in which FAST is a moderator for sustainable business model innovation within the biobased chemical industry is confirmed as the technology is capable to generate sustainable value proposition innovation and sustainable value creation & delivery innovation. For the new value proposition, FAST offers a sustainable, efficient and cheaper bioproduction of chemicals. Whilst for new value creation & delivery, the technology is able to generate disruption because in can enter markets in which biotechnology processes are not competitive with the chemical routes. Additionally, FAST can bring new molecules to the market which means new opportunities for product developments that can be beneficial for society.

7.2. Limitations and Future Research

During the research, some limitations were found and are discussed briefly.

First, the article on sustainable indicators only describes them, it does not go into further analysis on the rationales of the decisions making process. Moreover, the definition of some of the indicators is ambiguous. Due to this, the indicators need more external validation. After that, they may be proposed on a policy, standards, or on a law. Nevertheless, they can be used a reference for companies who aim to incorporate sustainability within its strategy. Second, during the research, the questionnaire on sustainability indicators was only descriptive. Therefore, its limitation is that it does not explore the rationales for choosing the indicators. It may be recommended to carry out interviews to find out the why the participants selected certain indicators and not others. Another limitation is that the questionnaire was applied only on 12 employees of DAB and therefore, the ranking of the indicators is limited to their perspectives and has low representativeness as more individuals should be asked to answer the questionnaire. Third, the 6 participants during the Delphi rounds were members of DAB. Consequently, a bias towards the positive attributes of the FAST technology is inherent. To reduce bias and incorporate different visions, Delphi rounds may be carried out with external parties such as scholars, partners of the company, potential customers, and investors within the chemical and biobased industry to reduce the bias and increase the representativeness of the consensus. It may be also considered to change the Delphi method and use interviews because they allow to obtain a more comprehensive perspective from the participants, although they are more time consuming. Fourth, the FAST and the chemical route were simulated by DAB. Data on the FAST process was reliable as DAB knows how its technology works. Nevertheless, there is uncertainty and bias towards the chemical route because it was designed by DAB members based on several assumptions. Therefore, the comparison with the chemical route has limitations and may not be taken for granted. However, it may be used as a reference. Fifth, it was not possible to compare FAST with traditional fermentation processes because the commercial production of 2PE is only feasible by means of the chemical route or plant extraction. A future research may compare the degree of sustainability between plant extraction process and FAST to assess what can be done on both technologies to have a sustainable production and how that may be used to compete with the chemical route for 2PE synthesis. Sixth, data regarding the LCA analysis is limited. It was found that there are no universal databases as every organisation can have different emission factors for the same compound. Moreover, some companies carry out LCA analyses, but they are not disclosed and are often questioned in terms of transparency. For this, it is recommended to carry out a research focused only on estimating the CO_2 emission factors of FAST. Seventh, the triple layered business model canvas was used to have a quantitative approach and a more comprehensive assessment of the impact on sustainability of the FAST technology. Nevertheless, it presents some limitations for its use. The canvas is still new and requires more validation within different industries. Additionally, the inter-layer analysis may be difficult due to the number of extra blocks that are added to the model. Furthermore, depending on the scope of the LCA analysis, some of the blocks may not be filled. Eight, as the research only focused on a single case study, it may be recommended to explore how other technologies within the biobased chemical industry can also be drivers for sustainability. Finally, a future research may go one step further and study to what extent and how the circular strategies can be incorporated on proposed sustainable business models to transform them into circular business models.

The theoretical contribution of this thesis project is a comprehensive analysis of two business models from the biotechnology sector and shows how they are able to capture the value of a novel sustainable innovation. By doing this, the research gap among business model innovation, sustainability, and technology is reduced. Future research may also study different technologies to assess how business model differ and how they capture the value of their respective innovations.

7.3. Recommendations for DAB

After carrying out the research, the following recommendations are presented for DAB. First, the company still needs to carry out industrial trials at BBEPP to gain cognitive legitimacy within the industry. Second, the same research can be performed for different molecules (production processes) to assess to what extent FAST allows their sustainable bioproduction. Third, the company can carry out group sessions to generate discussion for aligning its social sustainability indicators or to at minimum, understand the rationales behind the differences among the participants. Fourth, once the FAST technology is fully developed, DAB may carry out its own LCA analyses to obtain reliable data by using a transparent methodology that goes in line with the suggested governance of transparency in decision making. Fifth, DAB can develop a portfolio of molecules with different profit margins that involves from bulk chemicals and to high end ones such a cannabinoids or natural vanilla flavour. This portfolio must be based on a strategy that enables the company to become profitable and at the same time known within the industry. Finally, regarding the business models, DAB can start as a licensor to reduce financial risk and gain legitimacy within the market. After that, once the company becomes profitable, it may decide to be a producer for certain markets according to its molecule portfolio strategy. It is important to highlight that both business models are compatible but require the organisation to be ambidextrous.

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List of Appendices

Appendix I

BMs definitions.

Table 13: BMs definitions (adapted from (Bashir et al., 2020; Geissdoerfer et al., 2018; Massa et al., 2017; Zott et al., 2011)*)*

#	Author	Definition	Components
1	(Timmers, 1998)	"an architecture of the product, service and information flows, including a description of the various business actors and their roles; a description of the potential benefits for the various business actors; a description of the sources of revenues" (p. 2).	The actors and their roles, potential benefits for the business actors, sources of revenue
2	(Raphael Amit & Zott, 2001)	"the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities" (p. 511)	Product, information, resources, capabilities, output, value creation, business opportunities, transaction content, transaction governance, and transactions structure
3	(Chesbrough & Rosenbloom, 2002)	"the heuristic logic that connects technical potential with the realization of economic value" (p. 529)	Market, value proposition, value chain, cost and profit, value network, competitive strategy, revenue/ pricing, competitors, output (offering), and value creation
4	(Magretta, 2002)	"stories that explain how enterprises work. A good business model answers Peter Drucker's age old questions: Who is the customer? And what does the customer value? It also answers the fundamental questions every manager must ask: How do we make money in this business? What is the underlying economic logic that explains how we can deliver value to customers at an appropriate cost?" (p. 87).	Economic logic, customers, profit, cost, and value proposition
5	(Morris et al., 2005)	A business model is a "concise representation of how an interrelated set of decision variables in the areas of venture strategy, architecture, and economics are addressed to create sustainable competitive advantage in defined markets" (p. 727).	Customer (target market/scope), value proposition, capabilities, cost, offering, strategy, value creation, economic logic, time, scope and size ambition, pricing and revenue sources
6	(Osterwalder et al., 2005)	"A business model is a conceptual tool that contains a set of elements and their relationships and allows expressing the business logic of a specific firm. It is a de scription of the value a company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, to generate profitable and sustainable revenue streams." (p. 10)	Value proposition, key relationships, key partners, customer relationships, channels, key activities, key resources, revenue streams, cost structure

7	(Osterwalder & Pigneur, 2010)	“A business model describes the rationale of how an organisation creates, delivers, and captures value.”(p. 14).	Value proposition, key relationships, key partners, customer relationships, channels, key activities, key resources, revenue streams, cost structure
8	(Teece, 2010)	“A business model articulates the logic, the data and other evidence that support a value proposition for the customer, and a viable structure of revenues and costs for the enterprise delivering that value” (p. 179).	The benefit delivered, the benefit delivery, the value capture
9	(Zott & Amit, 2010)	“we conceptualize a firm's business model as a system of interdependent activities that transcends the focal firm and spans its boundaries. The activity system enables the firm, in concert with its partners, to create value and also to appropriate a share of that value” (p. 216).	Value creation, activity system on content, governance, and structure
10	(Gassmann et al., 2013)	”business models describe how the magic of a business works based on its individual bits and pieces.”	Customer, value proposition, value chain, revenue model
11	(Saebi & Foss, 2015)	” we define business models as the content, structure, and governance of transactions within the company and between the company and its external partners that support the company in the creation, delivery and capture of value.” (p. 204).	Content, structure, and governance of transactions. Partners, value creation, value delivery, and value capture
12	(Geissdoerfer et al., 2016)	“we describe business models as simplified representations of the elements and interactions between these elements that an organisational unit chooses in order to create, deliver, capture, and exchange value.” (p. 1218).	Value creation, value delivery, value capture, and value exchange
13	(Wirtz et al., 2016)	“A business model is a simplified and aggregated representation of the relevant activities of a company” (p.41).	Strategy, resources, network, customer, market offer, revenue, costs manufacturing and procurement
14	(Geissdoerfer et al., 2018)	“simplified representations of the value proposition, value creation and delivery, and value capture elements and the interactions between these elements within an organisational unit.” (p. 402).	Value creation, value delivery, value capture, and value exchange

Table 14: BMI definitions (adapted from (Foss & Saebi, 2017; Geissdoerfer et al., 2018)*)*

#	**Author**	**Definition**
1	(Mitchell & Bruckner Coles, 2004)	“By business model innovation, we mean business model replacements that provide product or service offerings to customers and end users that were not previously available. We also refer to the process of developing these novel replacements as business model innovation.“ (p. 17).
2	(Osterwalder et al., 2005)	“Specifying a set of business model elements and building blocks, as well as their relationships to one another […] a business model designer […] can experiment with these blocks and create completely new business models, limited only by imagination and the pieces supplied.” (p. 24).
3	(Chesbrough, 2007)	Business model innovation is to “advance [the] business model […] from very basic (and not very valuable) models to far more advanced (and more valuable) models.” (p.15).
4	(Romero & Molina, 2009)	“business models as definers of the value creation priorities in an organisation should be continuously reviewed in response to actual and possible changes in the perceived market conditions and evolve the enterprise strategy as the business environment and customers' needs change.” (p. 3).
5	(R Amit & Zott, 2012)	“Innovate business model by redefining (a) content (adding new activities), (b) structure (linking activities differently), and (c) governance (changing parties that do the activities)”.
6	(Abelkafi et al., 2013)	“A business model innovation happens when the company modifies or improves at least one of the value dimensions.”
7	(Casadesus-Masanell & Zhu, 2013)	“At root, business model innovation refers to the search for new logics of the firm and new ways to create and capture value for its stakeholders; it focuses primarily on finding new ways to generate revenues and define value propositions for customers, suppliers, and partners.”
8	(Khanagha et al., 2014)	“Business model innovation activities can range from incremental changes in individual components of business models, extension of the existing business model, introduction of parallel business models, right through to disruption of the business model, which may potentially entail replacing the existing model with a fundamentally different one.”
9	(Geissdoerfer et al., 2016)	“Business model innovation describes either a process of transformation from one business model to another within incumbent companies or after mergers and acquisitions, or the creation of entirely new business models in start-ups.” (p. 1220)

Table 15: BMfS definitions (adapted from (Abdelkafi & Täuscher, 2016; Geissdoerfer et al., 2018)*)*

#	Author	Definition
1	(Stubbs & Cocklin, 2008)	"a model where sustainability concepts shape the driving force of the firm and its decision making [so that] the dominant neoclassical model of the firm is transformed, rather than supplemented, by social and environmental priorities." (p. 103)
2	(Garetti & Taisch, 2012)	Sustainable business models "have a global market perspective, taking into account the development of new industrialised countries as well as the need for more sustainable products and services." (p. 88)
3	(Schaltegger et al., 2012)	Sustainable business models "create customer and social value by integrating social, environmental, and business activities" (p. 112)
4	(Nancy Bocken et al., 2013)	"Sustainable business models seek to go beyond delivering economic value and include a consideration of other forms of value for a broader range of stakeholders." (p. 484)
5	(Boons & Lüdeke-Freund, 2013)	"A sustainable business model is different from a conventional one through four propositions, "1. The value proposition provides measurable ecological and/or social value in concert with economic value […] 2. The supply chain involves suppliers who take responsibility towards their own as well as the focal company's stakeholders […] 3. The customer interface motivates customers to take responsibility for their consumption as well as for the focal company's stakeholders. […] 4. The financial model reflects an appropriate distribution of economic costs and benefits among actors involved in the business model and accounts for the company's ecological and social impacts" (p. 13)
6	(N. Bocken et al., 2014)	"a sustainable business model aligns interests of all stakeholder groups, and explicitly considers the environment and society as key stakeholders." (p. 44)
7	(Abdelkafi & Täuscher, 2016)	Sustainable business models, "incorporate sustainability as an integral part of the company's value proposition and value creation logic. As such, BMfS [Business models for Sustainability] provide value to the customer and to the natural environment and/or society." (p. 75)
8	(Geissdoerfer et al., 2016)	"we define a sustainable business model as a simplified representation of the elements, the interrelation between these elements, and the interactions with its stakeholders that an organisational unit uses to create, deliver, capture, and exchange sustainable value for, and in collaboration with, a broad range of stakeholders." (p. 1219)
9	(Evans et al., 2017)	Sustainable business models are described with five propositions, "1. Sustainable value incorporates economic, social and environmental benefits conceptualised as value forms. 2. Sustainable business models require a system of sustainable value flows among multiple stakeholders including the natural environment and society as primary stakeholders. 3. Sustainable business models require a value network with a new purpose, design and governance. 4. Sustainable business models require a systemic

		consideration of stakeholder interests and responsibilities for mutual value creation. 5.Internalizing externalities through product-service systems enables innovation towards sustainable business models." (p. 5ff)
10	(Geissdoerfer et al., 2018)	"business models that incorporate pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and hold a long-term perspective"

Table 16: SBMI definitions (Geissdoerfer et al., 2018)

#	Author	Definition
1	(Boons & Lüdeke-Freund, 2013)	"Sustainable business model innovation is understood as the adaption of the business model to overcome barriers within the company and its environment to market sustainable process, product, or service innovations" (p. 13).
2	(Loorbach & Wijsman, 2013)	Sustainable business model innovation describes businesses' "searching for ways to deal with unpredictable […] wider societal changes and sustainability issues." (p. 20).
3	(N. Bocken et al., 2014)	"Business model innovations for sustainability are defined as: Innovations that create significant positive and/or significantly reduced negative impacts for the environment and/or society, through changes in the way the organisation and its value-network create, deliver value and capture value (i.e. create economic value) or change their value propositions." (p. 44).
4	(Geissdoerfer et al., 2016)	"Sustainable business innovation processes specifically aim at incorporating sustainable value and a pro-active management of a broad range of stakeholders into the business model." (p.1220).
5	(Roome & Louche, 2016)	"Sustainable business model innovation describes the "processes through which […] new business models are developed by businesses and their managers […] how companies revise and transform their business model in order to contribute to sustainable development." (p. 12).
6	(Schaltegger et al., 2016)	"Sustainable business model innovation describes the creation of "modified and completely new business models [that] can help develop integrative and competitive solutions by either radically reducing negative and/or creating positive external effects for the natural environment and society" (p. 3)
7	(M. Yang et al., 2017)	"Sustainable business model innovation can be more easily achieved by identifying the value uncaptured in current business models, and then turning this new understanding of the current business into value opportunities that can lead to new business models with higher sustainable value." (p. 2)
8	(Shakeel et al., 2020)	"It deals with the modification of a business model to a more sustainable business model. This comprises either the creation of an exclusively new business model or changes the existing business model to innovatively address sustainability issues for its stakeholders for creating a long term sustainable competitive advantage. The change involves modification to its components."

Appendix II

Value Triangle (VT)

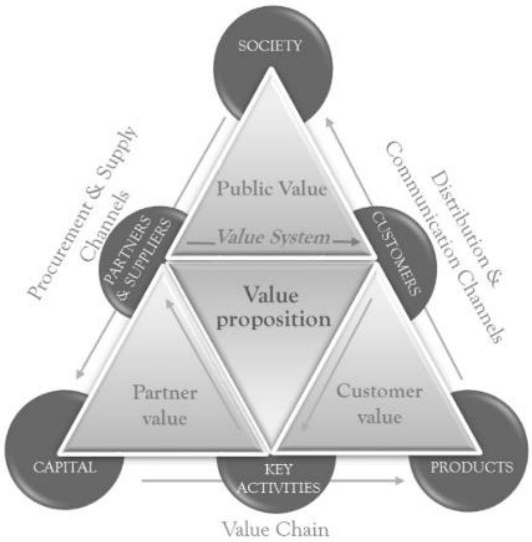

Figure 39: Value Triangle Model (VT) (Biloslavo et al., 2018)

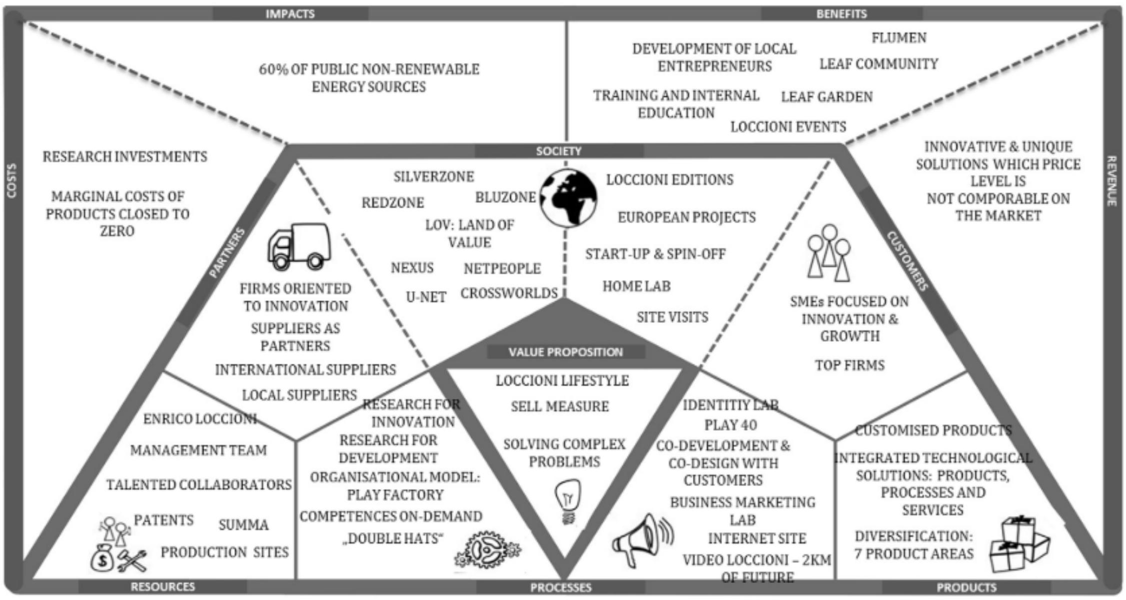

Figure 40: VT Applied on Case Study (Biloslavo et al., 2018)

Appendix III

Sustainable Business Model Canvas (SBMC)

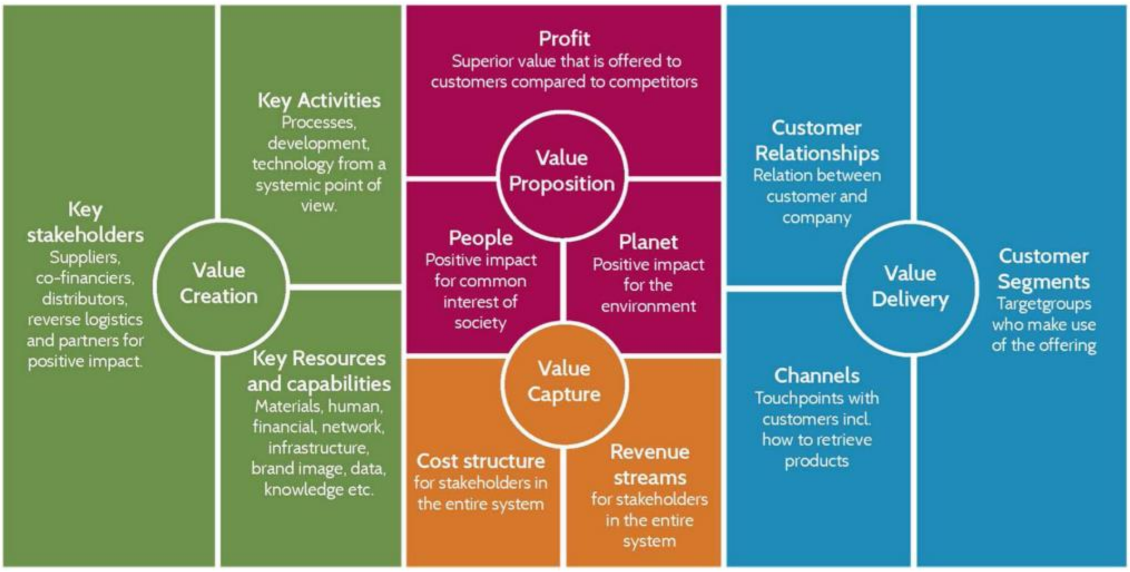

Figure 41: Sustainable Business Model Canvas (Bocken et al., 2018)

Appendix IV

Ecocanvas

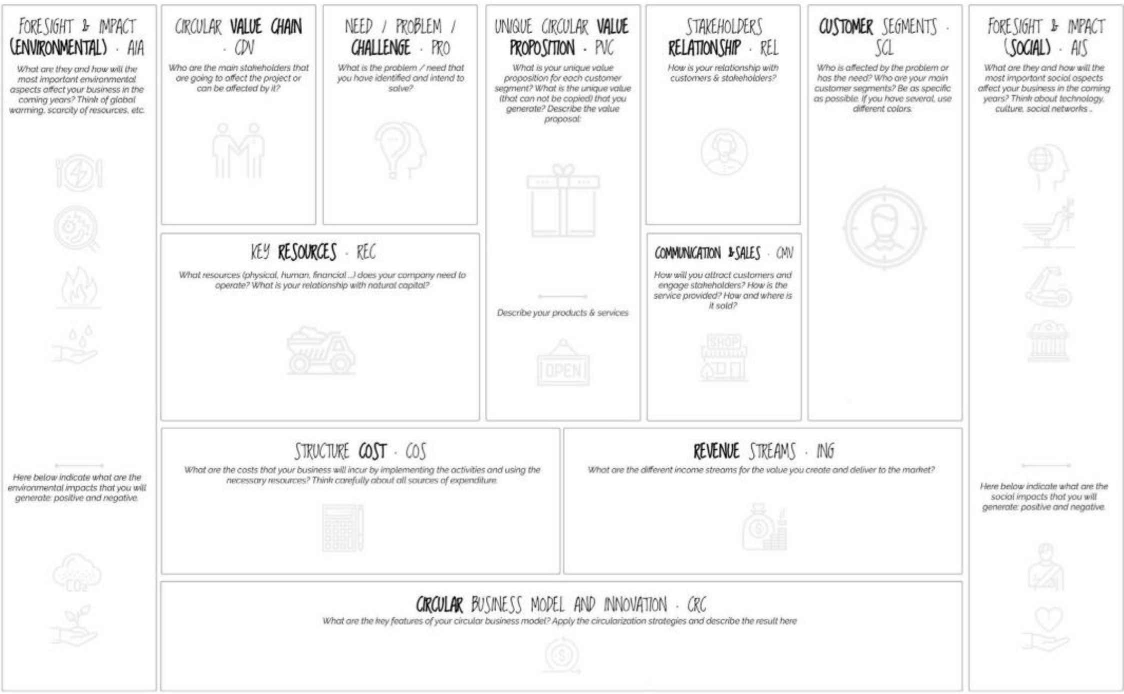

Figure 42: Ecocanvas BM framework (Daou et al., 2020)

Figure 43: Ecocanvas Applied on case study (Daou et al., 2020)

Appendix V

Questionnaire on sustainability indicators

Table 17: Questionnaire for the environmental aspect (Van Schoubroeck et al., 2019)

				Environmental						
1	Natural land transformati	1			1			1		
2	End of life options	2			2			2		
3	Particular matter formatic	3			3			3		
4	Ionising radiation	4			4			4		
5	Management practices	5			5			5		
6	Acidification	6			6					
7	Raw material efficiency	7			7				**Total**	**0**
8	Ecotoxicity	8			8				**Remaining**	**100**
9	Agricultural land occupati	9			9					
10	Organic carbon depletion	10			10					
11	Abiotic mineral depletion	11					**Remaining**	**5**		
12	GHG emissions	12								
13	Soil erosion	13								
14	Energy efficiency	14								
15	Photo-oxidant formation	15								
16	Abiotic fossil depletion				**Remaining**	**5**				
17	Eutrophication									
18	Stratospheric ozone depletion									
19	Waste generation									
20	Water consumption	**Remaining**	**5**							

Table 18: Questionnaire for the social aspect (Van Schoubroeck et al., 2019)

				Social				
1	Product transparency	1			1			
2	Education and training	2			2			
3	Human toxicity	3			3			
4	Community support and ir	4			4			
5	Working hours	5			5			
6	Security measures	6						
7	Cultural heritage	7				**Total**	**0**	
8	Job creation	8				**Remaining**	**100**	
9	Workplace accidents and i	9						
10	Social security	10						
11	Income levels							
12	Child labor			**Remaining**	**5**			
13	Acceptance of biobased materials							
14	Fatal work injuries							
15	Discrimination		**Remaining**	**5**				

Table 19: Questionnaire for the economy aspect (Van Schoubroeck et al., 2019)

				Economy			
1	Product efficiency	1			1		
2	Waste disposal cost	2			2		
3	Energy cost	3			3		
4	Land productivity	4			4		
5	Labor productivity	5			5		
6	Process innovation	6					
7	Technical risks	7				**Total**	**0**
8	Product innovation	8				**Remaining**	**100**
9	Raw materials cost	9					
10	Transportation cost			**Remaining**	**4**		
11	Market potential						
12	Subsidies						
13	Capital productivity		**Remaining**	**4**			

Data processing of the questionnaire on sustainability indicators

Table 20: Data processing on environmental indicators

Overall	Score	Frequency	Weighted Score
Abiotic fossil depletion	60	4	240
Abiotic mineral depletion	10	1	10
Agricultural land occupation	10	1	10
Ecotoxicity	45	2	90
End of life options	55	3	165
Energy efficiency	140	7	980
Eutrophication	10	1	10
GHG emissions	250	10	2500
Ionising radiation	25	1	25
Natural land transformation	70	3	210
Particular matter formation	25	1	25
Photo-oxidant formation	10	1	10
Raw material efficiency	180	9	1620
Waste generation	150	8	1200
Water consumption	160	8	1280

GHG emissions	2500
Raw material efficiency	1620
Water consumption	1280
Waste generation	1200
Energy efficiency	980

Management	Score	Frequency	Weighted Score
Abiotic fossil depletion	10	1	10
Energy efficiency	40	2	80
GHG emissions	80	3	240
Natural land transformation	50	2	100
Raw material efficiency	65	3	195
Water consumption	40	3	120
Waste generation	15	1	15

GHG emissions	240
Raw material efficiency	195
Water consumption	120
Natural land transformation	100
Energy efficiency	80

Process	Score	Frequency	Weighted Score
Abiotic fossil depletion	35	2	70
End of life options	20	1	20
Energy efficiency	35	2	70
GHG emissions	60	3	180
Natural land transformation	20	1	20
Raw material efficiency	45	2	90
Water consumption	85	4	340

Water consumption	340
GHG emissions	180
Raw material efficiency	90
Abiotic fossil depletion	70
Energy efficiency	70

Fermentation	Score	Frequency	Weighted Score
Abiotic mineral depletion	25	2	50
Agricultural land occupation	10	1	10
Ecotoxicity	45	2	90
End of life options	35	2	70
Energy efficiency	65	3	195
Eutrophication	10	1	10
GHG emissions	110	4	440
Ionising radiation	25	1	25
Particular matter formation	25	1	25
Photo-oxidant formation	10	1	10
Raw material efficiency	70	4	280
Waste generation	100	5	500
Water consumption	70	3	210

Waste generation	500
GHG emissions	440
Raw material efficiency	280
Water consumption	210
Energy efficiency	195

Table 21: Data processing on social indicators

Overall	Score	Frequency	Weighted Score
Acceptance of biobased materials	15	6	828
Child labor	25	5	425
Discrimination	15	2	40
Education and training	30	2	92
Fatal work injuries	25	7	1085
Human toxicity	25	9	1665
Income levels	15	5	425
Job creation	15	7	1057
Product transparency	30	6	984
Security measures	15	1	15
Social security	15	1	15
Working hours	12,5	3	127,5
Workplace accidents and illnesses	12,5	6	591

Human toxicity	1665
Fatal work injuries	1085
Job creation	1057
Product transparency	984
Acceptance of biobased materials	828

Management	Score	Frequency	Weighted Score
Acceptance of biobased materials	26	2	82
Child labor	20	1	20
Discrimination	15	1	15
Education and training	16	1	16
Fatal work injuries	30	1	30
Human toxicity	20	1	20
Income levels	15	2	60
Job creation	15	3	213
Product transparency	26	1	26
Workplace accidents and illnesses	15	2	62

Job creation	213
Acceptance of biobased materials	82
Workplace accidents and illnesses	62
Income levels	60
Fatal work injuries	30

Process	Score	Frequency	Weighted Score
Child labor	25	2	90
Fatal work injuries	10	3	195
Human toxicity	15	3	180
Income levels	25	1	25
Job creation	15	1	15
Product transparency	35	1	35
Working hours	12,5	2	55
Workplace accidents and illnesses	12,5	2	55

Fatal work injuries	195
Human toxicity	180
Child labor	90
Working hours	55
Workplace accidents and illnesses	55

Fermentation	Score	Frequency	Weighted Score
Acceptance of biobased materials	20	4	388
Child labor	15	2	40
Discrimination	5	1	5
Education and training	30	1	30
Fatal work injuries	25	3	180
Human toxicity	25	5	525
Income levels	20	2	60
Job creation	20	3	195
Product transparency	35	4	412
Security measures	15	1	15
Social security	15	1	15
Working hours	15	1	15
Workplace accidents and illnesses	20	2	80

Human toxicity	525
Product transparency	412
Acceptance of biobased materials	388
Job creation	195
Fatal work injuries	180

Table 22: Data processing on economy indicators

Overall	Score	Frequency	Weighted Score
Capital productivity	130	6	780
Energy cost	110	7	770
Labor productivity	50	3	150
Land productivity	40	3	120
Market potential	205	8	1640
Process innovation	225	9	2025
Product efficiency	205	9	1845
Product innovation	45	3	135
Raw materials cost	95	6	570
Subsidies	10	1	10
Technical risks	45	2	90
Transportation cost	15	1	15
Waste disposal cost	25	2	50

Process innovation	2025
Product efficiency	1845
Market potential	1640
Capital productivity	780
Energy Cost	770

Management	Score	Frequency	Weighted Score
Capital productivity	30	2	60
Energy cost	45	2	90
Market potential	75	3	225
Process innovation	40	2	80
Product efficiency	60	2	120
Product innovation	10	1	10
Raw materials cost	30	2	60
Subsidies	10	1	10

Market potential	225
Product efficiency	120
Energy cost	90
Process innovation	80
Capital productivity	60
Raw materials cost	60

Process	Score	Frequency	Weighted Score
Capital productivity	75	3	225
Energy cost	5	1	5
Labor productivity	35	2	70
Land productivity	20	1	20
Market potential	40	2	80
Process innovation	45	2	90
Product efficiency	65	3	195
Raw materials cost	15	1	15

Capital productivity	225
Product efficiency	195
Process innovation	90
Market potential	80
Labor productivity	70

Fermentation	Score	Frequency	Weighted Score
Capital productivity	25	1	25
Energy cost	60	4	240
Labor productivity	15	1	15
Land productivity	20	2	40
Market potential	90	3	270
Process innovation	140	5	700
Product efficiency	80	4	320
Product innovation	35	2	70
Raw materials cost	50	3	150
Technical risks	45	2	90
Transportation cost	15	1	15
Waste disposal cost	25	2	50

Process innovation	700
Product efficiency	320
Market potential	270
Energy cost	240
Raw materials cost	150

	INDICATOR	DESCRIPTION
ENVIRONMENT	Abiotic fossil depletion	Fossil resources required to produce a biobased chemical
	Abiotic mineral depletion	Mineral resources required to produce a biobased chemical
	Acidification	Emissions causing acidifying effects to the environment
	Agricultural land occupation	Amount of agricultural area occupied
	Ecotoxicity	Emissions of toxic substances to air, water and soil
	End of life options	Possibilities for recycling, composting, biodegrading, burning, … the end product
	Energy efficiency	Amount of energy from renewable and non-renewable resources needed per biobased chemical
	Eutrophication	Emissions (including phosphor and nitrogen) that cause eutrophication of marine water, fresh water and terrestrial environment
	GHG emissions	Greenhouse gas emissions and their contribution to climate change (including biogenic carbon and direct and indirect land use change)
	Ionising radiation	Level of exposure related to releases of radioactive material to the environment
	Management practices in crop production	The type of practices used for crop production
	Natural land transformation	Amount of transformed 'natural land' area (= no human distortion)
	Organic carbon depletion	Amount of organic carbon in the soil lost
	Particular matter formation	Presence of PM10 in the air
	Photo-oxidant formation	Formation of summer smog
	Raw material efficiency	Amount of raw materials needed per biobased chemical
	Soil erosion	Displacement of the upper layer of the soil
	Stratospheric ozone depletion	Emissions causing depletion of the ozone layer
	Waste generation	Amount and type of waste generated (e.g. by calculating 'atom economy')
ECONOMY	Capital productivity	Capital needed for the production per biobased chemical
	Energy cost	Cost of energy per biobased chemical
	Labor productivity	Direct and indirect labor needed for the production per biobased chemical
	Land productivity	Direct land needed for the production per biobased chemical
	Market potential	Market price and size per biobased chemical
	Process innovation	Effects on price and output of improvement of facilities, skills and technologies, etc.
	Product efficiency	Actual productivity divided by maximum productivity
	Product innovation	Effects on price and output of new products, new features, improvement of performance, etc.
	Raw materials cost	Cost of feedstock per biobased chemical
	Subsidies	Amount of subsidies per biobased chemical
	Technical risks	Risks associated directly with the supply chain activities, e.g. feedstock supply risk, infrastructure risk, etc.
	Transportation cost	Cost of transportation per biobased chemical
	Waste disposal cost	Cost of waste disposal per biobased chemical
SOCIETY	Acceptance of biobased chemicals	Perception of consumers towards the biobased chemical
	Child labor	Presence of child labor
	Community support and involvement	Support and involvement from the local community
	Cultural heritage	Respect towards local cultural heritage (including language, religion, etc.)
	Discrimination	A "fair chance" for everybody, e.g. equal payment male/female
	Education and training	Education and training initiatives and opportunities
	Fatal work injuries	Number of fatal work injuries
	Human toxicity	Effects of toxic substances on the human environment
	Income levels	Level of income of the workers
	Job creation	Number of jobs created
	Product transparency	Creation of an informed choice for the consumer without intent to mislead or conceal
	Security measures	Security measures taken at the workplace
	Social security	Compensation for retirement, disability, illness, injury, etc.
	Working hours	Number of hours worked
	Workplace accidents and illnesses	Number of workplace accidents and illnesses

Figure 44: Definitions of the indicators (Van Schoubroeck et al., 2019)

Appendix VI

Questionnaire Round 1 Delphi

Questions for Round 1 Delphi

Information of the participant

Education (most recent degree):
Previous experience:
Expertise:
Department

Warm up questions:

1. How have you experienced the transition towards the biobased economy?
2. Where along the value chain of biotechnology are companies mainly innovating? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)
3. Who are the main stakeholders when it comes to develop a biobased product?

Question regarding the company: (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

Value proposition:

4. What kind of solution do you bring to the biobased chemical industry?
5. What makes your solution unique to solve your customers' needs?
6. How may this solution evolve towards sustainability?

Value creation and delivery

7. What could be the potential market segments? (focus on 2PE molecule)
8. What are the current markets?
9. Through which channels you approach to them?
10. Where in the value chain of the biobased industry is DAB positioned? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)
11. Is DAB aiming to be present on another stage of the value chain?
12. How many prototypes/pilots of the technology has the company developed?
13. How has the technology changed over time?
14. In your opinion, how do you think the technology will create social benefits?
15. In your opinion, how do you think the technology will create environmental benefits?
16. In your opinion, how may producers and end users need to change the way they are currently doing business when the technology is within the market?
17. Who are the current DAB's partners? (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)
18. How have these relationships evolved overtime?
19. Who do you think will be an appropriate partner for the company? Why?

Value capture:

20. In your opinion, how may the introduction of this technology generate changes within the revenue model and costs for a producer?

Appendix VII

Informed consent form

Delft University of Technology
HUMAN RESEARCH ETHICS
INFORMED CONSENT

You are being invited to participate in a research study titled "The Role of FAST Technology as a Driver for Sustainable Business Models to Achieve Sustainability within the Biobased Chemical Industry: The Case Study of DAB". This study is being done by **anonymized** at **anonymized**.

The purpose of this research study is to understand the role of FAST technology as a driver for sustainable business model innovation within the biobased chemical industry and will take you approximately 30 minutes to complete. The data will be used for determining sustainability indicators that will be included in the design of a business model within the context of the researcher's Master thesis. You will be asked to respond a questionnaire in which you will select and rank indicators for sustainability that were proposed by experts to be used within the biobased industry. Additionally, you may be asked to respond to two rounds of questionnaires in which you will provide your perspective of the biobased chemical industry and the FAST technology, these questionnaires will take you approximately 30 minutes to complete each.

As with any computer and online activity the risk of a breach is always possible. To the best of the researcher's ability, your answers in this study will remain confidential. The researcher will minimize any risks by carrying out the questionnaires offline, de-identifying and anonymizing the participants responses by assigning random numbers to the questionnaires, and storing the data collected at **anonymized's** cloud.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. As the questionnaire will remain anonymous, data will remain available for academic and managerial purposes.

Hereby you can find the details of the researcher:

Name: **anonymized**

Position: **anonymized**

e-mail: **anonymized**

In the following section you will be asked to tick boxes regarding the research, potential risks of participating in the study, data publication, and storage.

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: complete 1 questionnaire filled by the participant	☐	☐
4. I understand that the study will end in 11/08/2022 on the estimated thesis defence of the researcher	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. I understand that taking part in the study involves the following risks: identity breach and Covid infection. I understand that these will be mitigated by de-identifying and anonymizing data collected and following DAB's procedures for Covid prevention.	☐	☐
6. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach: de-identifying and anonymizing data collected	☐	☐
7. I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.	☐	☐
8. I understand that the (identifiable) personal data I provide will be destroyed 5 working days after the thesis defence of the researcher, which is planned to be on 11/08/2022	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
9. I understand that after the research study the de-identified information I provide will be used for the masters' thesis of the researcher and DAB's managerial purposes	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
10. I agree that my responses, views or other input can be quoted anonymously in research outputs		
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
10. I give permission for the de-identified answers that I provide to be archived in TU Delft thesis repository so it can be used for future research and learning.	☐	☐
11. I understand that access to this repository is open	☐	☐

Signatures

____________________________ ___________________________ XX/XX/XXXX

Name of participant Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

___________________ ___________________ XX/XX/XXXX

Researcher name Signature Date

Appendix VIII

Summary of round 1 Delphi

The following summary gathers the opinions and perspectives of the participants during round 1 of Delphi.

Biobased chemical industry:

There is agreement among the participants that the transition towards the biobased economy has been slow and not many transitions are occurring currently. This may be considered as a lost opportunity for the environment.

The participants showed different perspectives on where they considered biotechnology companies are innovating. They stated that innovations are mainly on products in the area of protein and meat replacement, process development, and strain design. In the case of the pharmaceutical industry innovation occurs on the whole value chain. Regarding the stakeholders within biobased products, the participants mentioned manufacturers (technology owners), retailers, governments, strain producers, CMOs (contract manufacturing operators), customers, final users, process developers, farmers, traders.

Value proposition:

According to the participants, the technology was designed originally for wastewater treatment towards an enhanced fermentation process. Afterwards, the FAST technology was developed and started as a demo scale, which is not common because normally lab scale units are designed before a demo scale.

The participants stated that DAB's solution brings a cheaper (CAPEX and OPEX) and a more efficient scalable fermentation process by converting a batch process into a continuous/semi-continuous one that generates less waste and requires less use of water and solvents. Additionally, they also agreed that FAST technology has the potential to enable new biochemicals to enter the market. Moreover, they believe that it can enable the replacement of hydrocarbons and plant extraction as raw materials for biomass, that will reduce carbon footprint and land-use, respectively. Additionally, the participants believe that solution is unique within the industry because is focused on hardware which differs from the current trend, that according to them, focuses on strain development. Another perspective considered that the solution can make the value of chain of the industry more sustainable and also may be complemented with renewable energies to power it.

Value creation and delivery:

The participants argued that the potential market segments for 2PE molecule (rose fragrance), the current molecule in which DAB is working, are fragrances, cosmetics, anti-microbials, molecular intermediate (precursor), and flavours. For this particular molecule the participants stated that the FAST technology can enable a cost-effective production which is currently possible only by the petrochemical route or plant extraction. Regarding the customers, the participants named several means for approach them such as; conferences, shared connections

(LinkedIn), direct contact (from both parties), websites, social media, cold calling, traders, other companies, and advisors.

The participants agreed that DAB is a technology supplier, so its position within the value chain for biobased products is process development. Moreover, they stated that the company is currently offering CRM (contract research, process development) services to strain developers, although is limited. DAB will aim in the long-term to be part of product development, manufacturing, sales, distribution, and possibly own its own strain. Furthermore, the participants expect that the technology may outcompete current actors within the industry and then it will integrate to the current value chain.

Regarding Dab’s capabilities, the participants mentioned that the company has one lab services facility unit (Delft) and one demo large scale pilot unit (Ghent). It was also stated that the development of an industrial large-scale unit is planned as well as the development of processes with strain owners.

Regarding the social benefits that FAST technology can bring, the participants mentioned mostly job creation with better quality conditions. It was also mentioned by them that the technology will also enable a faster transition towards the biobased economy enabling the production of biobased products which will provide access to more sustainable products to people.

Regarding the environmental benefits, the participants mentioned that FAST will reduce GHG emissions, toxic waste, and utilities usage. Additionally, it was also stated that the technology will allow the replacement of hydrocarbons that will reduce the dependence on oil and, that the company has the potential to replace plant extraction processes which may potentially reduce de-forestation.

The participants mentioned several partners that involve investors, strain development, start-ups related to biobased chemicals, CMO, shareholders, process development companies, downstream processing companies (DSP), potential buyers of 2PE, BPF, BBEPP (CRO), and companies to which DAB develops fermentation processes. One remarkable milestone that was mentioned is that nowadays strain developers trust more in the company because the technology has proven to be effective.

The participants were asked about what strategic partners may be relevant for the company. They stated partners such as: strain developers with technologies that allow strain development on a shorter timeframe; current manufacturers that may use FAST as an add-on to their current “traditional” fermenters in which DAB may access to their business network; and strain owners that can develop products together with DAB.

Value capture:

The participants stated that changes within the revenues and costs will occur due to the increase in efficiency and cost reduction (CAPEX and OPEX) the technology offers. This implies that the products will become cheaper and will be able to compete with fossil-based technologies but also, the participants mentioned that a premium may be charged for the “natural” or “biobased” origin of the product. Therefore, profit margins will be higher.

Summary of round 2 Delphi, Consensus

The following summary gathers the feedback that participants gave to the summary of round 1 and their additional opinions and perspectives.

Biobased chemical industry:

There is agreement among the participants that the transition towards the biobased economy has been slow and not many transitions are occurring currently which is perceived as a lost opportunity for the environment.

The participants showed different perspectives on where they considered biotechnology companies are innovating. They stated that innovations are on process development, strain development, and on products in the specific area of protein and meat replacement. In the specific case of the pharmaceutical industry innovation occurs most likely on drug development. Regarding the stakeholders within biobased products, the participants mentioned manufacturers (technology owners), retailers, governments, strain producers, CMOs (contract manufacturing operators), customers, final users, process developers, farmers, traders, and staff.

Value proposition:

According to the participants, the technology is based on a reactor that is used in wastewater plants. Afterwards, the FAST technology was developed and started as a demo scale, which is not common because normally lab scale units are designed before a demo scale. This occurred because a professor that is also a founder of the company wanted to prove the functionality of the technology.

The participants stated that DAB's solution brings a cheaper (CAPEX and OPEX) and a more efficient scalable fermentation process by converting a batch process into a continuous/semi-continuous one that generates less waste and requires less use of water and solvents. Additionally, they also agreed that FAST technology has the potential to enable new biochemicals to enter the market. Moreover, they believe that it can enable the replacement of hydrocarbons and plant extraction as raw materials for biomass, that will potentially reduce carbon footprint and land-use, respectively. In summary, the participants agreed that the technology enables sustainability by both process efficiency and hydrocarbons substitution. They also mentioned that the solution may be complemented with renewable energies to power it. Additionally, the participants believe that the FAST technology is unique within the industry because is focused on hardware which differs from the current trend, that according to them, focuses on strain development. Another perspective considered that the solution can contribute to make the value of chain of the industry more sustainable.

Value creation and delivery:

The participants argued that the potential market segments for 2PE molecule (rose fragrance), the current molecule in which DAB is working, are fragrances, cosmetics, anti-microbials, molecular intermediate (precursor), and flavours. For this particular molecule the participants stated that the FAST technology can enable a cost-effective production which is currently possible only by the petrochemical route or plant extraction. Regarding the customers, the participants named strain developers and chemical producers that use fermentation. They also mentioned that getting strain owners to work with the DAB in the early stages of process development is challenging. Furthermore, they also stated the challenge of working with chemical producers mainly due to their low readiness in investing in the FAST technology. The way DAB approaches to these customers is by conferences, shared connections (LinkedIn), direct contact (from both parties), websites, social media, cold calling, traders, other companies, and advisors.

The participants agreed that DAB is a technology supplier, so its position within the value chain for biobased products is process development. Moreover, they stated that the company is currently offering CRM (contract research, process development) services to strain developers, although is limited. DAB will aim in the long-term to be part of product development, manufacturing, sales, distribution, and possibly own its own strain. Furthermore, the participants expect that the technology may outcompete current actors within the industry and then, integrate to the current value chain.

Regarding DAB's capabilities, the participants mentioned that the company has one lab services facility unit (Delft) and one demo large scale pilot unit (Ghent). It was also stated that the development of an industrial large-scale unit is planned as well as the development of processes with strain owners.

Regarding the social benefits the technology can bring, the participants mentioned mostly job creation with better quality conditions. It was also mentioned that the technology will enable a faster transition towards the biobased economy enabling the production of biobased products which will provide access to more sustainable products to people.

Regarding the environmental benefits, the participants mentioned that FAST will reduce GHG emissions, toxic waste, and utilities usage. Additionally, it was also stated that the technology will allow the replacement of hydrocarbons that will reduce the dependence on oil and, that the company has the potential to replace plant extraction processes which may potentially reduce de-forestation.

The participants mentioned several partners such as investors, strain development, start-ups related to biobased chemicals, CMOs, shareholders, process development companies, downstream processing companies (DSP), potential buyers of 2PE, BPF, BBEPP (CRO), and companies to which DAB develops fermentation processes. One remarkable milestone that was mentioned is that nowadays strain developers trust more in the company because the technology has proven to be effective.

The participants were asked about what strategic partners may be relevant for the company. They stated partners such as: strain developers with technologies that allow strain development on a shorter timeframe; current manufacturers that may use FAST as an add-on to their current "traditional" fermenters in which DAB may access to their business network; and strain owners that can develop products together with DAB.

Value capture:
The participants stated that changes within the revenues and costs will occur due to the increase in efficiency and cost reduction (CAPEX and OPEX) the technology offers. This implies that the products will become cheaper and will be able to compete with fossil-based technologies

but also, the participants mentioned that a premium may be charged for the “natural” or “biobased” origin of the product. Therefore, profit margins will be higher.

Appendix IX

Answers round 1 Delphi

The following section shows the answers given by the participants during round 1 of Delphi.

Questions for Round 1 Delphi

Participant #:	1
Expertise:	Bioprocess technology

Warm up questions:

1. How have you experienced the transition towards the biobased economy?

   Not yet many transitions available.

2. Where along the value chain of biotechnology are companies mainly innovating? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution):

   Mostly on strain development and food products

3. Who are the main stakeholders when it comes to develop a biobased product?

   Government & marketing development

Question regarding the company: (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

Value proposition:

4. What kind of solution do you bring to the biobased chemical industry?

   Enabling more (cost) efficient production of biobased chemicals

5. What makes your solution unique to solve your customers' needs?

   It is hardware and overall production process focused solution not just strain development focussed only.

6. How may this solution evolve towards sustainability?

   Solution intensifies fermentation processes lowering overall footprint of the production process

7. What could be the potential market segments? (focus on 2PE molecule)

   Fragrance market and natural chemical market

8. What are the current markets?

   Fragrances companies/wholesale market
9. Through which channels you approach to them?

   Conferences; preliminary talks

Value creation and delivery

10. Where in the value chain of the biobased industry is DAB positioned? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

    Predominantly product/process development

11. Is DAB aiming to be present on another stage of the value chain?

    Integration with (point source) feedstocks and downstream processing/manufacturing is highly likely

12. How many prototypes/pilots of the technology has the company developed?

    3 prototypes; 1 pilot unit; 1 demonstration unit; Used on ~4-6 fermentation processes

13. How has the technology changed over time?

    More control of L-L phase separation and optimization between the functional requirements of reactor segments/compartments.

14. In your opinion, how do you think the technology will create social benefits?

    It will significantly increase the amount of biobased chemicals that can be produced by fermentative route

15. In your opinion, how do you think the technology will create environmental benefits?

    Significant lowering of utility requirements of biobased fermentation processes. (per kg product produced)

16. In your opinion, how may producers and end users need to change the way they are currently doing business when the technology is within the market?

    They need to see how (at lower production costs) biobased products can be placed in the market

17. Who are the current DAB's partners? (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

BPF; BBEPP (CRO); ev biotech (strain); X, Y, Z clients (for which we do fermentation process development)

18. How have these relationships evolved overtime?

    No significant shift in relationship.

19. Who do you think will be an appropriate partner for the company? Why?

    Manufacturing company that produces fermentation products via overlay (as they will have significant benefits when implementation of FAST is successful for them).

Value capture:

20. In your opinion, how may the introduction of this technology generate changes within the revenue model and costs for a producer?

    The producer will experience lower overall production costs changing the choices in markets available (as some pricing for chemicals is at existing price levels only reaching limited market volume).

Questions for Round 1 Delphi

Participant #:	2
Expertise:	Fermentation and molecular biology

Warm up questions:

1. How have you experienced the transition towards the biobased economy?

   Only through reading articles. No real impact in my personal life

2. Where along the value chain of biotechnology are companies mainly innovating? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

   Not in raw materials. Product/process development is where most happens

3. Who are the main stakeholders when it comes to develop a biobased product?

   The company and the customer (perception)

Question regarding the company: (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

Value proposition:

4. What kind of solution do you bring to the biobased chemical industry?

   Cheaper and more efficient manufacturing for biobased products

5. What makes your solution unique to solve your customers' needs?

   Without our solution, their biobased products can't economically compete

6. How may this solution evolve towards sustainability?

   It enables more biobased products to compete and therefore more biobased products will be developed

7. What could be the potential market segments? (focus on 2PE molecule)

   Flavour and Fragrance

8. What are the current markets?

   Flavour and Fragrance, also molecular intermediate for other compounds

9. Through which channels you approach to them?

   Conferences and shared LinkedIn connections

Value creation and delivery

10. Where in the value chain of the biobased industry is DAB positioned? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

    Process development

11. Is DAB aiming to be present on another stage of the value chain?

    Yes>manufacturing in the near future. Possibly product development

12. How many prototypes/pilots of the technology has the company developed?

    2

13. How has the technology changed over time?

    Not much

14. In your opinion, how do you think the technology will create social benefits?

    Yes, more jobs and higher quality jobs

15. In your opinion, how do you think the technology will create environmental benefits?

    Yes, biobased solutions have less emissions and less toxic waste

16. In your opinion, how may producers and end users need to change the way they are currently doing business when the technology is within the market?

    End users don't change. Producers will have a wider variety of biobased molecules to choose from

17. Who are the current DAB's partners? (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

    Investors and strain development companies

18. How have these relationships evolved overtime?

    Strain developers trust us more now that we have proven our technology more

19. Who do you think will be an appropriate partner for the company? Why?

    Strain developers with new technology that allows you to develop a strain in a very short timeframe. Also fermentation manufacturers as they could use FAST as add-on to their current fermenters.

Value capture:

20. In your opinion, how may the introduction of this technology generate changes within the revenue model and costs for a producer?

    The costs for biobased products will become lower but you can still charge a premium for "natural" "biobased" "biological" > so earnings will increase

Questions for Round 1 Delphi

Participant #:	3
Expertise:	Bioprocess technology

Warm up questions:

1. How have you experienced the transition towards the biobased economy?

   Very slow, in my opinion, it has not really started yet.

2. Where along the value chain of biotechnology are companies mainly innovating? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

   Main focus seems to be on new product development in the area of protein and meat replacements now.

3. Who are the main stakeholders when it comes to develop a biobased product?

   Manufacturers, consumers, large retailers and – a bit of – government.

Question regarding the company: (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

Value proposition:

4. What kind of solution do you bring to the biobased chemical industry?

   Adding new – integrated – unit operations to increase toolbox / reduce manufacturing cost of biobased chemicals to increase market for these products.

5. What makes your solution unique to solve your customers' needs?

   Hardware solutions were not available yet, these are the core of FAST package.

6. How may this solution evolve towards sustainability?

   Through improving productivity and yields, we aim to reduce the environmental footprint and reduce cost to make biobased chemicals (more) affordable. In combination with renewable energy, we aim to make these value chains sustainable.

7. What could be the potential market segments? (focus on 2PE molecule)

   Initially, higher end fragrance industry. Beyond that, broader 'chemical industry'.

8. What are the current markets?
   'Chemical 2PE' is mainly used as fragrance (rose). It also has some application as anti-microbial.
   FAST tech in general focusses on the biochemical manufacturing industry (B2B).

9. Through which channels you approach to them?

   Conferences, LinkedIn.

Value creation and delivery

10. Where in the value chain of the biobased industry is DAB positioned? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

    DAB is a technology supplier, it offers separation technology to *process development* and – ultimately – *manufacturing*. We also offer CRO (contract research, *process development itself*) services, although that has been limited so far (wishlist).

11. Is DAB aiming to be present on another stage of the value chain?

As an intermediate, we could offer CMO (contract manufacturing) services but that's not a long term goal.

12. How many prototypes/pilots of the technology has the company developed?

    So far, two pilot demo units have been built plus a lab scale unit (three total).

13. How has the technology changed over time?

    Don't know.

14. In your opinion, how do you think the technology will create social benefits?

    It will broaden the biobased manufacturing toolbox, enabling faster development and implementation of biobased chemicals which – in turn – will speed up the transition to the biobased economy which – in turn – will reduce greenhouse gas emissions and provide a sustainable and healthier future. The latter will be the main social benefit in my opinion. (it will also create jobs, but at the same time, take jobs away elsewhere, so mainly shifting).

15. In your opinion, how do you think the technology will create environmental benefits?

    As 14. It will broaden the biobased manufacturing toolbox, enabling faster development and implementation of biobased chemicals which – in turn – will speed up the transition to the biobased economy which – in turn – will reduce greenhouse gas emissions and provide a sustainable and healthier future.

16. In your opinion, how may producers and end users need to change the way they are currently doing business when the technology is within the market?

    I don't think the way business is done will change. The technology will gradually become part of the established toolbox and new products will become available, but as said, I think the current way business is done, will not change.

17. Who are the current DAB's partners? (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

    Mainly start-ups in the field of biobased chemicals.

18. How have these relationships evolved overtime?

    Don't know.

19. Who do you think will be an appropriate partner for the company? Why?

    For the next stage of technology demonstration at full scale, we'll need to partner with a manufacturing organisation to be able to use existing (physical) infrastructure as well as business network.

Value capture:

20. In your opinion, how may the introduction of this technology generate changes within the revenue model and costs for a producer?

    We aim to reduce manufacturing cost of new chemicals and in that way, broaden the chemical portfolio. This will create new value chains from bio-source to end-products. But I don't expect the revenue model itself to change at this stage.

Questions for Round 1 Delphi

Participant #:	4
Expertise:	Finances

Warm up questions:

1. How have you experienced the transition towards the biobased economy?

   It is an exciting perspective but going slowly, which is a lost opportunity for the environment.

2. Where along the value chain of biotechnology are companies mainly innovating? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

   Currently mostly at the beginning of value chain – development of strains.

3. Who are the main stakeholders when it comes to develop a biobased product?

   All along the value chain – producers of strains, manufacturers (technology owners like DAB.bio) and CMOs (infrastructure owners), customers (first business customers) and ultimately the final users).

Question regarding the company: (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

Value proposition:

4. What kind of solution do you bring to the biobased chemical industry?

   An efficient production technology that ensures economic viability of biobased production.

5. What makes your solution unique to solve your customers' needs?

   It increases efficiency of production thanks to an innovative technological solution and makes it economically viable to introduce biobased materials as components of other products, effectively replacing hydrocarbons.

6. How may this solution evolve towards sustainability?

   If introduced at a large scale, it will allow to replace hydrocarbons and potentially also plant-based production (i.e. diminish use of land).

7. What could be the potential market segments? (focus on 2PE molecule)

   All markets that use rose fragrance: food, cosmetics, chemical industry.

8. What are the current markets?

   Currently the product is under development, so no final markets yet with the proprietary technology of the company.
   The current markets use the product manufactured based on currently available technologies, which we will replace.

9. Through which channels you approach to them?

   Industry conferences,
   Identification of potential interested parties and direct contact with interested customers (both reaching out to them and them reaching out to us).

Value creation and delivery

10. Where in the value chain of the biobased industry is DAB positioned? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

    Manufacturing (but also extending to include process development and co-development of products).

11. Is DAB aiming to be present on another stage of the value chain?

    It might – as an owner of a strain, it would reach 'upstream' in the process.

12. How many prototypes/pilots of the technology has the company developed?

    This question could be considered in two ways:
    - Development of the fermenters themselves: a large scale fermenter developed and in operation, no industrial scale fermenter developed yet (the development is planned)
    - Development of the technology with 'real' strains in the FAST fermenters: tests successful with a number of customers (owners of different types of strains)

13. How has the technology changed over time?

    The DAB technology has been brought in from a wastewater treatment technology. It has been than changed over time to work in its current state.

14. In your opinion, how do you think the technology will create social benefits?

    Social benefits include:
    replacement of hydrocarbons in many products creating independence of oil producers and distribution of the production abilities of a large number of chemicals among many countries (rather than dependency on oil producing nations)
    replacement of plant use in many products allowing for land use for food production allowing production of affordable biobased products.

15. In your opinion, how do you think the technology will create environmental benefits?

    replacement of hydrocarbons in many products resulting in emissions reduction
    replacement of plant use in many products allowing for avoiding de-forestation.

16. In your opinion, how may producers and end users need to change the way they are currently doing business when the technology is within the market?

    Many, which is a challenge.

    This includes companies that use hydrocarbon-based products (in chemical, food and other industries), owners of strains, CMOs, and final consumers (choosing for biobased products).

17. Who are the current DAB's partners? (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

    Strain producers, CMO facility (and hopefully more CMOs in the future), shareholders.

18. How have these relationships evolved overtime?

    NA.

19. Who do you think will be an appropriate partner for the company? Why?

    Strategic strain owners who develop product together with DAB.
    CMOs where fermenters will be placed.

Value capture:

20. In your opinion, how may the introduction of this technology generate changes within the revenue model and costs for a producer?

    Costs of production based on fermentation technology will be significantly reduced.
    Revenues of the producers will be higher (with higher volumes of production and lower costs) and can allow many products to become competitive with current hydrocarbon-based technologies.

Questions for Round 1 Delphi

Participant #:	5
Expertise:	Microbiology, molecular biology

Warm up questions:

1. How have you experienced the transition towards the biobased economy?

   It's been slow.

2. Where along the value chain of biotechnology are companies mainly innovating? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

   For pharmaceuticals, everywhere because there's money in it.
   For industrial biotechnology – in strain development (before any of the above examples.)

3. Who are the main stakeholders when it comes to develop a biobased product?

   Strain developers (b2b), Process developers (b2b), Manufacturers of biobased products (b2b or b2c), Product Formulators + so many more.

Question regarding the company: (It is not necessary to mention the name of companies or investors, only the type of organisation and the sector)

Value proposition:

4. What kind of solution do you bring to the biobased chemical industry?

   Fermentation hardware that has the potential to lower costs and enable entirely new biochemicals to enter the market.

5. What makes your solution unique to solve your customers' needs?

   No other hardware exists that can do what our technology does as quickly, cheaply, and elegantly as ours. Other solutions are expensive, messy, and are very difficult to scale.

6. How may this solution evolve towards sustainability?

   Our solution? We can adapt our hardware to enable fermentation processes that reduce, reuse, recycle the inputs and outputs of the fermentation vessel. And we can use less solvent (reduce) and recycle the solvent we do use.

   If we adapt our hardware to enable fermentation processes that reduce, reuse recycle inputs and outputs, (or if we eventually produce 2PE for the market) we can enable our customers to:
   Use waste as a feedstock.

Recycle water.
Sell microorganisms after a run as feed. (reuse) (NB not possible with current EU regulation)
Sell by-products for cheap. (reuse).

7. What could be the potential market segments? (focus on 2PE molecule)

   Our technology can enable cost effectiveness of plenty of products. 2PE is probably one of the least 'sustainable' ones.

8. What are the current markets?

   What are the markets that our technology can enable?
   Our customers are producers of biofuels, bulk chemicals, specialty chemicals (that can be used as fuels, ingredients for food, personal care items, building blocks for plastic bottles, building blocks for formica cabinets, etc, etc.).

9. Through which channels you approach to them?

   Conferences, LinkedIn, twitter, website, business development approaches customers who aim or who make products that fit well with our technology (cold calling).

Value creation and delivery

10. Where in the value chain of the biobased industry is DAB positioned? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution).

    Manufacturing and Sales and Distribution of Fermentation Hardware.

11. Is DAB aiming to be present on another stage of the value chain?

    Potentially all of the above to produce 2PE.

12. How many prototypes/pilots of the technology has the company developed?

    3 -all different sizes.

13. How has the technology changed over time?

    Don't know.

14. In your opinion, how do you think the technology will create social benefits?
    Lessen our dependence on fossil fuels for many products. Make more sustainable products affordable.

15. In your opinion, how do you think the technology will create environmental benefits?

    It depends on whether our customers develop the items in question #6.

16. In your opinion, how may producers and end users need to change the way they are currently doing business when the technology is within the market?

    There has to be some initial adaptation (a small market) for our more expensive products. For us to gain a major market share, we will have to implement all the things in #6 to make production cheaper and more carbon efficient than fossil fuel products.

17. Who are the current DAB's partners? (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

    SynBio companies
    Process Development companies
    Down stream processing companies
    Potentially buyers of 2PE

18. How have these relationships evolved overtime?

    Don't know.

19. Who do you think will be an appropriate partner for the company? Why?

    Don't know.

Value capture:

20. In your opinion, how may the introduction of this technology generate changes within the revenue model and costs for a producer?

    It can enable chemical companies to make a bunch more products biobased – to respond to Sustainable Development Goals (potentially).

Questions for Round 1 Delphi

Participant #:	6
Expertise:	Process design, projects

Warm up questions:

1. How have you experienced the transition towards the biobased economy?

   Slow, Hesitant, waiting on what to come.

2. Where along the value chain of biotechnology are companies mainly innovating? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

   I don't know, that is very company specific and maybe even product specific.

3. Who are the main stakeholders when it comes to develop a biobased product?

   Strain developers, formulators, chemical companies, farmers, traders.

Question regarding the company: (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

Value proposition:

4. What kind of solution do you bring to the biobased chemical industry?

   A fermentation reactor technology that reduces both OPEX and CAPEX substantially.

5. What makes your solution unique to solve your customers' needs?

   Converts a batch process into a continuous/semi-continuous process and thereby reducing OPEX and CAPEX substantially enabling more economically feasible production.

6. How may this solution evolve towards sustainability?

   Cost reduction means cheaper product means people have access to more sustainable products.

7. What could be the potential market segments? (focus on 2PE molecule)

   Flavors, fragrances (for 2PE of course, other molecules have other markets).

8. What are the current markets?

   Flavors, fragrances.

9. Through which channels you approach to them?

   Conferences, companies, traders, formulators, strain developers, advisors.

Value creation and delivery

10. Where in the value chain of the biobased industry is DAB positioned? (consider value chain as raw material extraction, product/process development, manufacturing, sales and distribution)

    product/process development, manufacturing.

11. Is DAB aiming to be present on another stage of the value chain?

    We could be, I'm not sure if aiming would be the right word.

12. How many prototypes/pilots of the technology has the company developed?

    A number.

13. How has the technology changed over time?

    Lab -> Pilot -> demo scale.

14. In your opinion, how do you think the technology will create social benefits?

    Yes, as more people will have access to more sustainable products.

15. In your opinion, how do you think the technology will create environmental benefits?

    Yes, as it enables biobased processes that otherwise wouldn't be economically feasible.

16. In your opinion, how may producers and end users need to change the way they are currently doing business when the technology is within the market?

    I think the technology will pretty much outcompete the players in the same market.

17. Who are the current DAB's partners? (It is not necessary mention the name of companies or investors, only the type of organisation and the sector)

    I don't know.

18. How have these relationships evolved overtime?

    I don't know.

19. Who do you think will be an appropriate partner for the company? Why?

    I don't know.

Value capture:

20. In your opinion, how may the introduction of this technology generate changes within the revenue model and costs for a producer?

    Reduces OPEX and CAPEX.

Appendix X

Answers round 2 Delphi

The following section shows the feedback, remarks, and further information given by the participants to the summary of round 1 of Delphi.

Summary of Round 1 Delphi	
Participant #:	1
Expertise:	Bioprocess technology

Comments:

Not many transition in market implementations/entries are currently occurring. This may be considered as a lost opportunity for the environment as sustainable transition is not rapidly occurring.

"…In the case of the pharmaceutical industry innovation occurs on the whole value chain…" Why is this? they create a lot of waste per product.

The solution addresses efficiency and sustainability either by process efficiency increase or by enabling or by replacing chemicals.

DAB can own its own strain and work as a virtual CRM.

FAST is technology platform benefitting from availability of more production strains & processes to be available.

Summary of Round 1 Delphi	
Participant #:	2
Expertise:	Fermentation and molecular biology

Comments:

Not sure if FAST required less solvent. You would likely require more solvent as there is more product that you want to extract. Also, a little bit of solvent is continuously lost through the bleed I think.

Will the replacement of plant extraction reduce de-forestation? Aren't these specific plants grown in large-scale agricultural operations? And this agricultural land will just be used for something else when these plants are no longer needed.

I think BBEPP is a CMO and not a CRO.

Summary of Round 1 Delphi

Participant #:	3
Expertise:	Bioprocess technology

Comments:

"Biotechnology companies are innovating mainly on products in the area of protein and meat replacement, process development, and strain design." It's a bit unclear to me. Do you mean 3 different areas here? Or just the area 'protein and meat replacement' where process development and strain are part of it. Or is 'process development' and 'strain' an area, but that's quite vague.
Current partners, your list is quite complete but who are the shareholders, other than investors? Is BPF an active partner at this stage? Not sure if you want to differentiate, but you could consider to mention both private and public funding (subsidy). And lastly, employees and Planet.bio are also stakeholders.

Summary of Round 1 Delphi

Participant #:	4
Expertise:	Finances

Comments:

I agree with the above summary. However, I would add the important challenge that DAB.bio is facing with the technology adoption by customers – on one hand, getting the strain owners / developers to work with DAB.bio on the development of the strain early in the process, so that the benefits of the technology could be fully realized for the strain; on the other hand, the readiness of investment into FAST technology-based fermenters by the manufacturers or customers (or alternatively accessing significant financing to invest in FAST-based fermenters as CMOs directly).

Summary of Round 1 Delphi

Participant #:	5
Expertise:	Microbiology, molecular biology

Comments:

The company does not necessarily have the opportunity to reduce deforestation with 2P E. If the market volume remains the same the only opportunity of using biobased 2-phenylethanol is that fossil resources will be replaced with sugars used to feed the microorganisms.
The technology was not designed for wastewater plants the technology was designed based on wastewater plant.

Summary of Round 1 Delphi

Participant #:	6
Expertise:	Process design, projects

Comments:

The only thing that really jumped out to me was going directly to demo scale. I'm not sure that is true, there have been pilot models of the reactor.

Appendix XI

Chemical route for 2PE synthesis

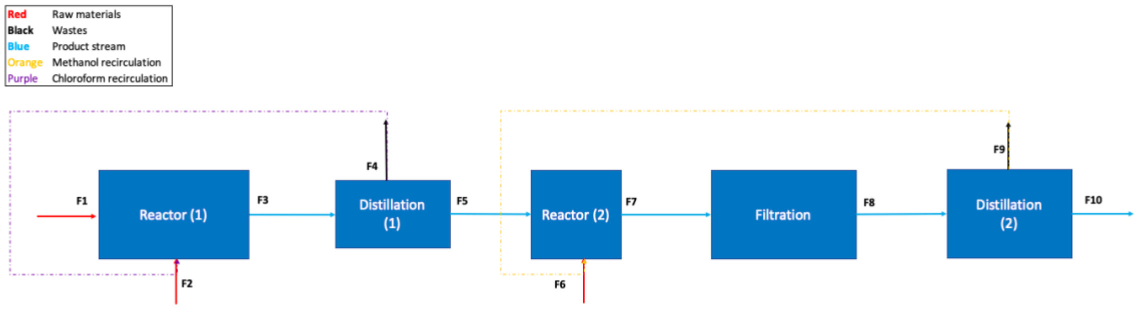

Figure 45: Chemical route for 2PE synthesis (courtesy of DAB)

Table 23: Mass flows of chemical route for 2PE synthesis (courtesy of DAB)

kg per run	F1	F2	F3	F4 Recycle	F4 Waste	F5	F6	F7	F8	F9 Waste	F9 Recycle	F10
Styrene	540		37.8		37.8							
Chloroform recycle		844.64	844.64	844.64								
Chloroform make up		44.45			44.45							
Peroxybenzoic acid		557										
Styrene oxide			492			492		5	5		5	
Benzoic acid			484		484							
2-PE								485	485			485
1-PE								2	2		2	
Methanol recycle							142	142	142	142		
Methanol make up							7				7	
Sodium carbonate							3		0			
Ions + water								3	3		3	
Byproducts			82.62									
SUM	540	1,446	1,859	845	566	492	152	637	637	142	18	485

Table 24: Raw materials per kg of 2PE (courtesy of DAB)

Main raw materials	kg/kg 2-PE
Chloroform	0.09
Peroxybenzoic acid	1.15
Styrene	1.11
Methanol	0.02
Sodium carbonate	0.01

Table 25: Main waste streams per kg of 2PE for chemical route (courtesy of DAB)

Main wastes	Streams	Amounts	kg/kg 2-PE
Waste (1)	F4	566	1.17
Waste (2)	F9	18	0.04

Note: Around 80 % of the individual emission factors of more than 80 chemicals are between 1 and 3 kg CO2/kg raw material. For Chloroform & Peroxybenzoic acid a nominal emission factor of 1.5 kg/kg is assumed - needs validation. Assuming all of the waste streams are disposed & treated and no side stream evaluation is taking place.

Note: Distillation separation after first reaction (Styrene -> Styrene oxide) takes place in 2 steps. Chloroform is separated in first distillation as the most volatile. Peroxybenzoic acid in the second step from top and styrene oxide from the bottom. 5 % losses for the solvents (chloroform & methanol) is assumed for the overall process to match solvent losses of FAST case.

FAST route for 2PE synthesis

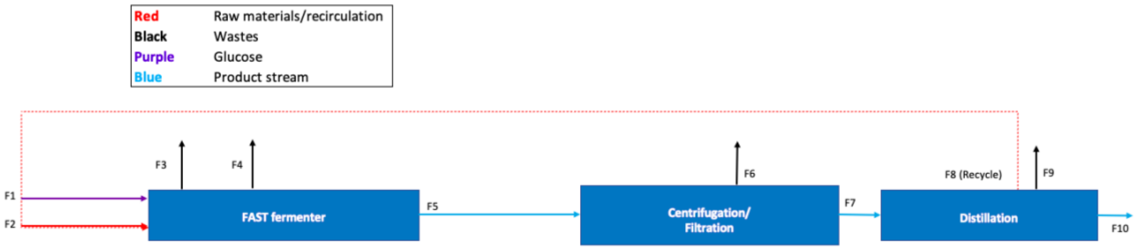

Figure 46: FAST route for 2PE (courtesy of DAB)

Table 26: Mass flows of FAST route for 2PE synthesis (courtesy of DAB)

	Fermentation					**DSP**					
	F1 (inlet)	**F2 (solvent)**	**F3 (s)**	**F3 (aq)**	**F4 (gas)**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
kg/run	**Inlet (feedstock/water)**	**Solvent**	**Biomass - Sludge**	**Aqueous broth - Wastewater**	**Gas outlet-Offgas waste**	**Product stream**	**Wastewater**	**Product stream**	**Recycle**	**Wastewater**	**Product stream**
Glucose	51,429	-	-	-	-	-	-	-	-	-	-
Water	68,320	-	-	87,666	6,000	5,511	5,511	-	-	-	-
Biomass dry	-	-	7,644	-	-		-	-	-	-	-
Carbon Dioxide	-	-	-	-	34,794	-	-	-	-	-	-
Castor oil (makeup)	-	3,789	-	1,421	-	2,368	-	2,368	-	2,368	-
Castor oil (from recycle)		185,684	-	-	-	185,684	-	185,684	185,684	-	-
Ammonium Sulfate	1,000	-	-	-	-	-	-	-	-	-	-
Magnesium Sulfate	50	-	-	-	-	-	-	-	-	-	-
Monopotassium phosphate	600	-	-	-	-	-	-	-	-	-	-
1000x Vitamin Stock *	100	-	-	-	-	-	-	-	-	-	-
1000x Trace elements *	100	-	-	-	-	-	-	-	-	-	-
2-Phenyl Ethanol	-	-	-	200	-	7,000		7,000	-	-	7,000
Hydroxyl Phenyl Ethanol	-	-	-	25	-	25	-	25	-	25	-
Oxygen	30,366	-	-	-	-	-	-	-	-	-	-
Other (organics)	-	-	-	1,179	-		71	-	-	-	-
Salts	-	-	-	1,724	-	-	102	-	-	-	-
SUM	151,964	189,474	7,644	92,214	40,794	200,588	5,582	195,077	185,684	2,393	7,000

Table 27: Main waste streams of FAST process (courtesy of DAB)

Stream	**Waste source**	**Type of waste**	**Waste Fate**
F3	Aqueous broth from fermentation	Wastewater	Wastewater treatment
F3	Biomass from fermentation	Sludge	Sludge disposal
F4	CO2 from fermentation	Off-gas	GHG emission
F6	Centrifuge supernatant	Wastewater	Wastewater treatment
F9	Top product (distillation)	Wastewater	Wastewater treatment

Table 28: Main waste streams per kg of 2PE for FAST route (courtesy of DAB)

Type of wastes	Streams	Value	Units
Off-gas	F4	5,0	kg waste/kg 2-PE
Wastewater	F3, F6, F9	14,3	kg waste/kg 2-PE
Biomass	F3	1,09	kg waste/kg 2-PE

Notes: Not including LCA cost of hardware and transportation costs Assuming solar/renewable energy sources for electricity generation overall footprint is at 1.78 kg. CO2/kg 2-PE. Assuming natural gas energy source for electricity generation overall footprint is at 6.55 kg CO2/kg 2-PE. For Castor Oil assuming that land usage has been incorporated to the emission factor

CO2 emission per energy source:

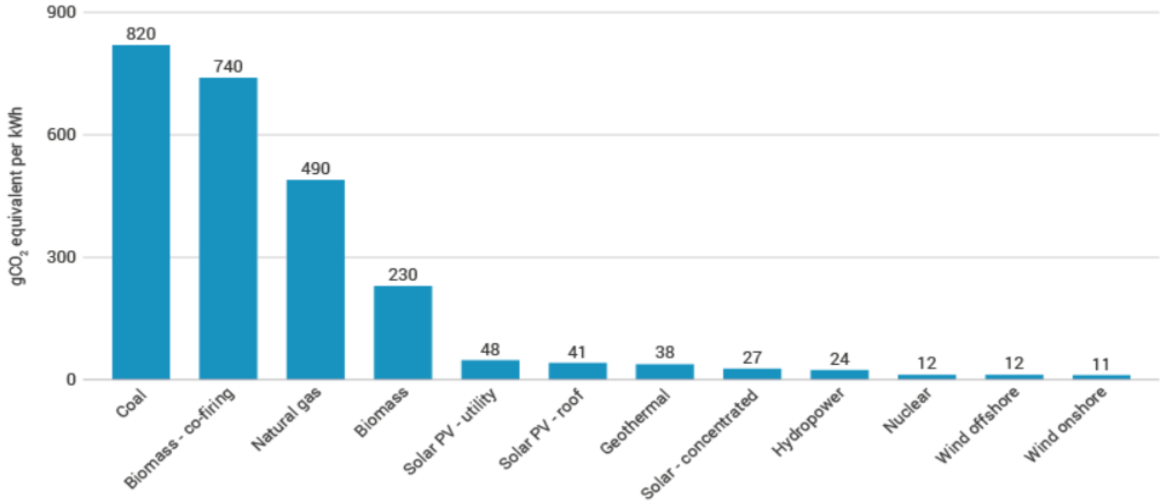

Figure 47: CO2 emissions per energy source (World Nuclear Association, 2021)

Appendix XII

Business model considering DAB as a licensor of the FAST technology to produce of 2PE can be found in is outlined using Joyce & Paquin's (2016) TLBMC:

Economy layer

In this case, the sustainability indicators that are considered are: (1) "Process innovation", (2) "Product efficiency", (3) "Market potential", (5) "Capital productivity", and (5) "Energy cost". The components of the layer are mentioned as follows:

1) **Value proposition:** Efficient and cheaper bioproduction of chemicals. Indicators: (1) (2)

2) **Customer segments:** Chemical companies, biotechnology companies. Indicators: (3)

3) **Channels:** Conferences, LinkedIn, cold-call, traders, advisors.

4) **Customer relationships:** Direct contact with licensees.

5) **Revenues:** Down payment for licencing FAST, royalty for the sales of 2PE.

6) **Key resources:** People, know-how, laboratory, patents, demo plant, knowledge of licensees.

7) **Key activities:** R&D, marketing, patenting, audit licensees. Indicators: (1)

8) **Key partnerships:** Strain owners, green energy companies, investors, biotechnology start-ups, licenses, BBEPP, process development companies, DSP companies, suppliers, auditory companies.

9) **Cost structure: Fixed:** Salaries, patent fees, R&D, marketing. Indicators: (2) (4) (5)

Figure 48 shows the component on the economy canvas.

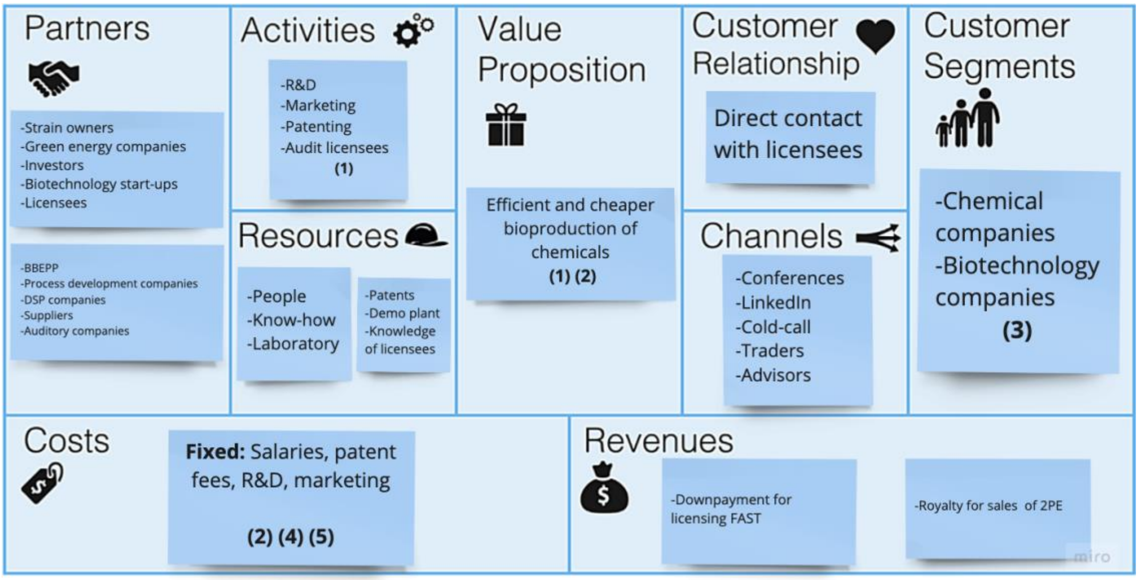

Figure 48: Economy canvas for DAB as a licensor for 2PE production

<u>Social layer</u>

In this case, the sustainability indicators that are considered are: (6) “Human toxicity”, (7) “Fatal work injuries”, (8) “Job creation”, (9) “Product transparency”, and (10) “Acceptance of biobased materials”. The components of the layer are mentioned as follows:

1) **Social value:** Provide access to sustainable biobased chemical products. Indicators: (9)

2) **Employee:** Safer working place, less workload, less heavy work. Indicators: (6) (7) (8)

3) **Governance:** Hierarchical organisation for managing the licensees.

4) **Communities:** Start-ups, suppliers. Indicators: (6) (8)

5) **Societal culture:** Encourage culture of promoting environmental awareness to licensees.

6) **Scale of outreach:** Europe, USA, Mexico, Canada, China, Japan, South Korea, Australia.

7) **End-users:** Users of food, fragrances, or chemical compounds. They are addressed by offering a sustainable product at lower price and the potential access to new chemicals. Indicators: (9) (10)

8) **Social impacts:** Odour generation, land usage that could be used for building households or agriculture for food. Use of food as a raw material for manufacturing chemicals.

9) **Social benefits:** Job creation, cleaner environment. Indicators: (6) (8)

Figure 49 shows the component on the social canvas.

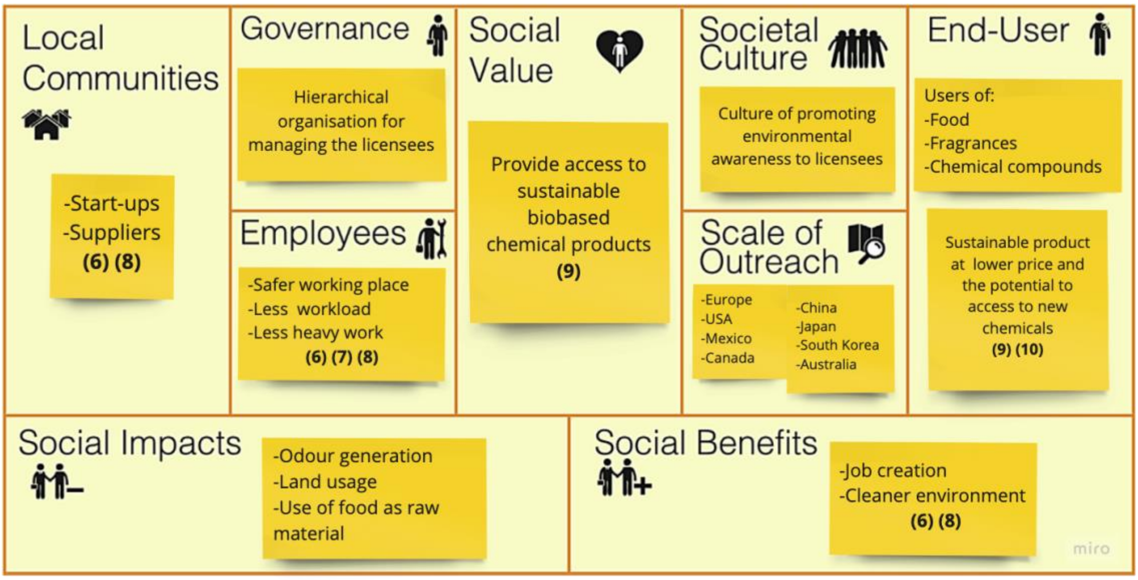

Figure 49: Social canvas for DAB as a licensor for 2PE production

<u>Environmental layer</u>

In this case, the sustainability indicators that are considered are: (11) "GHG emissions", (12) "Raw material efficiency", (13) "Water consumption", (14) "Waste generation", and (15) "Energy efficiency". The components of the layer are mentioned as follows:

1) **Functional value:** 1 [kg] of 2PE.

2) **Materials:** Glucose, castor oil. CO_2 emissions: -4.25 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Raw materials: 8.13 $[\frac{\text{kg}}{\text{kg 2−PE}}]$. Indicators: (11) (12)

3) **Production:** This component considers CO_2 emissions and mass flows of the waste generation. Waste is composed by off-gas, wastewater, and biomass. CO_2: 5.12 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Mass flow: 20.38 $[\frac{\text{kg}}{\text{kg 2−PE}}]$ (Off-gas: 4.97, Wastewater: 14.31, Biomass: 1.09). The wastewater (broth) must be sterilized and disposed (*Draft Law on Genetically Modified Organisms*, 2016). Water consumption, CO_2 of supplies and materials are considered on other components. Indicators: (11) (14)

4) **Supplies and outsourcing:** Utilities. Using wind onshore energy: CO_2: 0.50 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Power: 12.91 $[\frac{\text{kWh}}{\text{kg 2−PE}}]$ (10.79 from electricity, 2.12 from natural gas). Water: 25 $[\frac{\text{kg}}{\text{kg 2−PE}}]$. Indicators: (11) (13) (15)

5) **Distribution:** Unknown. Indicators: (11)

6) **Use phase:** Unknown. Indicators: (11)

7) **End-of-life:** Unknown. Indicators: (11) (14)

8) **Environmental impacts:** Net CO_2 emissions: 1.38 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$, Water: 25 $[\frac{\text{kg}}{\text{kg 2−PE}}]$, Waste: 20.38 $[\frac{\text{kg}}{\text{kg 2−PE}}]$, Power using wind onshore: 12.91 $[\frac{\text{kWh}}{\text{kg 2−PE}}]$ (10.79 from electricity, 2.12 from natural gas). Indicators: (11) (13) (14) (15)

9) **Environmental benefits:** Biogenic raw materials. CO_2 -4.25 $[\frac{\text{kg } CO_2}{\text{kg 2−PE}}]$. Indicators: (11)

Figure 50 shows the component on the environmental canvas.

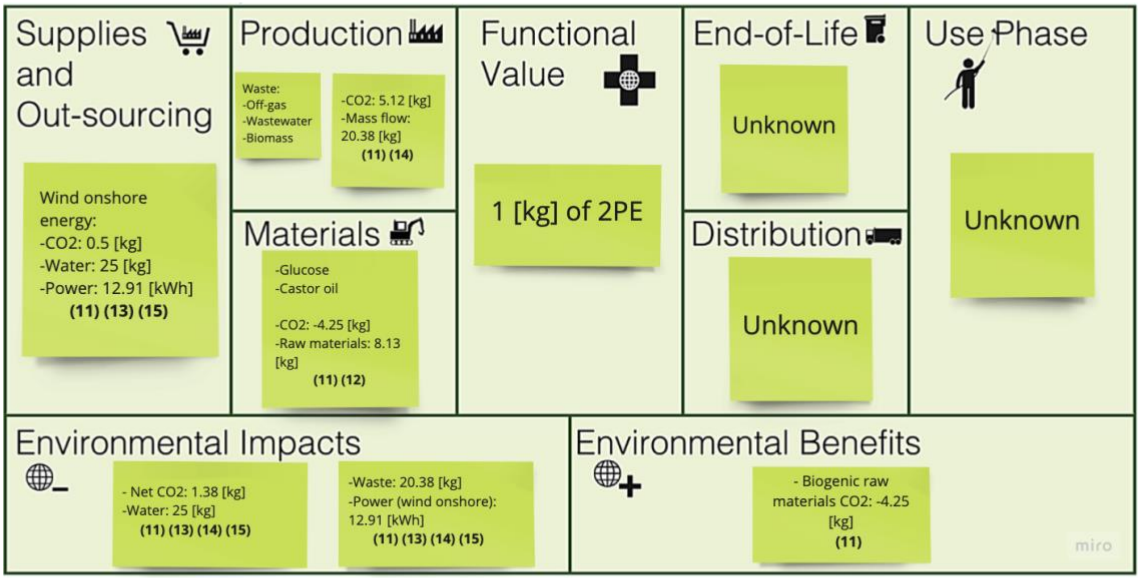

Figure 50: Environmental canvas for DAB as a licensor for 2PE production