A consumer and supply chain analysis on the circularity of heat pumps: investigating the potential implementation of a circular business model

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Inhoudsopgave

List of abbreviations

ASHP Air source heat pump
BM Business model
BMC Business model canvas
BMI Business model innovation
CBM Circular business model
CBMC Circular Business model Canvas
CE Circular Economy
COP Coefficient of Performance
C2C Cradle to Cradle
DCE Discrete Choice Experiment
EoL End-of-life
GWP Global Warming Potential
GHG Greenhouse Gas
GSPH Ground source heat pump
HP Heat Pump
HPP Hybrid Heat Pump
SROI Social return on investment
WTP Willingness to Pay
WEEE Waste of Electrical and Electronic Equipment

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Executive Summary

This Master's Thesis for the programme Sustainable Business and Innovation investigates the potential implementation of a circular business model in the Dutch heat pump sector, with a case study focussed on Eneco's end-of-life supply chain. This research aimed to answer the main research question: " What are the drivers and barriers for implementing a circular business model for heat pumps in the Netherlands?" The research used both quantitative and qualitative research methods to examine the economic viability, consumer desirability, technological feasibility, and environmental impacts of implementing a circular business model for Eneco.

The thesis starts by highlighting the current threat of climate change and the carbon-intensive nature of heating in the European Union. The transition from fossil fuel-based heating to electric heating using technologies like heat pumps, is seen as the major step towards for decarbonizing the heating sector. The European Union has introduced various policies stimulating circularity of general electrical equipment or energy-efficient technologies, such as heat pumps in specific. The Circular Economy Action Plan, introduced in the Green Deal which is such a regulatory initiative (European Commission, 2020).

The research identifies a gap in the literature regarding the use of circular business models in the heat pump sector and emphasizes the importance of investigating the factors that support or undermine the adoption of potential implementing of a circular business model for heat pumps. Bocken & Konietzko (2022) mention the need of investigating four pillars of desirability, feasibility, viability and environmental impact when the assessment is made on implementing a CBM. The fourth pillar is an added perspective of Brown (2008), who mentioned that a business model could only be successfully implemented when a match occurs between the customer desirability, technologically feasible and economic viability. In this research, the consumer desirability is generalisable to the broad population of potential consumers of heat pumps. While the other three pillars are case specific to the context of Eneco's supply chain. With the aim of forming a benchmark for other utility companies specialized in heat pumps.

The theoretical framework explores how the traditional "take-make-use-dispose" economic model can transform from a linear economy to a circular economy (Lewandowski, 2016). The CE aims to keep resources in use for as long as possible, reduce environmental impacts, and contribute to economic growth (Kirchherr et al., 2017). Circular business models play a crucial role in achieving the goals of the circular economy by integrating circularity into business models, focusing on profitability and closing material and energy loops (Bocken et al., 2014). Furthermore, the general factors (i.e. building blocks) that influence each of the pillars and the subsequential implementation of a CBM are discussed. Moreover, common drivers and barriers found in CBM literature are elaborated on.

The methodology employed a mixed-methods descriptive design, including quantitative and qualitative phases, as well as desk research. The consumer desirability is for the most part analysed by utilizing a discrete choice experiment to assess customer preferences for heat pump features and circular strategies. The technological feasibility and economic viability were explored by interviewing stakeholders along Eneco's supply chain. The analysis of the economic viability was complemented with Willingness to Pay calculations of specific attribute levels of heat pumps. The environmental impact was investigated with desk research of Life Cycle Assessments, to conduct estimated calculations of the environmental impacts of material depletion and climate change.

The results indicate that customers lay the highest priority on a heat pump offered with warranty, a high level of Coefficient of Performance (COP) and low investment costs. Although the attribute circularity percentage is secondary compared to the preference laid on the other attributes, it still positively influences the choices made by the respondents. Even when an increase in circularity would result in a decrease in COP or warranty, the circular heat pump may still be preferred if the investment costs also decreases. This implies that if heat pumps were to become (partially) circular, a combination of specific conditions would need to be met for potential future consumers to prefer the circular heat pump over a regular heat pump. However, that circularity is the least influential, posing a challenge for companies who want to implement the principles of circularity into heat pumps.

Technological feasibility is supported by the technological expertise of the recycling company involved in the case study (Refurn). It is technological feasible to set up a material loop which will be focused on component refurbishment and partly on reuse. Producers are to some extent willing to receive revised components back. However, specific components become obsolete due to: ongoing innovations and regulations during its 15 year life cycle (Yang et al., 2021). Findings from this study show which components have a high probability of becoming obsolete in the near future.

An economically viable end-of-life supply chain, focused on component reuse and refurbishment, appears promising in collaboration with a recycling company. Most importantly, customers are willing to pay a significantly higher price for a heat pump with a higher circularity percentage. Secondly, Refurn believes that the operation of the revision process would yield higher revenues than it would cost. Moreover, it would improve environmental and social impacts and creates several revenue streams via tax breaks, sustainability assessment tools, and corporate social responsibility, ultimately improving the business case.

The implementation of the circular business model is estimated to gain a 7,5% increase in the recycling rate of the materials and the refrigerant. Subsequently, at least 880 metric tons of Fe and 1.644 metric tons of CO_2-eq could be annually mitigated by Eneco if their aim of becoming market leader in 2026 succeeds. When compared to other potential action, it is shown that the potential impact on material depletion and CO_2 emissions is substantial.

The main managerial advice for Eneco is to aim for a circular business model that focusses on component refurbishment, embracing the overlap in desirability, feasibility, sustainability and to some extent viability. Further recommendations would be to establish a task team to manage the circular activities, by establishing a shared vision regarding the direction of this circular business model. They could convince internal and external stakeholders with the success factors that are elicited from this research.

The focus on component reuse and refurbishment comes with barriers relating to the obsolescence of components because of continuous innovations and regulations. Eneco needs to overcome this barrier by listing the demand for revised components for all producers and installers. Together with incorporating circularity specifications in procurement processes. These activities may cause the challenges to outweigh the success factors, creating a unique opportunity for the implementation of the circular business model.

In conclusion, the study shows that the four pillars overlap within the specific circular material strategy of refurbishing components. The circular business model aligns with consumer preferences and shows a model which is technological feasible, economic viability, and significant estimated environmental benefits. The research provides insights for policymakers, businesses, and utility companies.

1. Introduction

1.1 Research Background

The residential building sector is responsible for 17% of global greenhouse gas (GHG) emissions (Abergel et al., 2017), with space heating and cooling accounting for nearly half of the European Union's (EU) overall energy demand (European Commission, 2022). The use of renewable energy for heating has grown in the EU, promoting a shift from fossil fuel-based heating to electric heating solutions like as heat pumps (HPs) (EEA, 2021; Gaur et al., 2021). Among multiple alternative sustainable heating systems, it seems that HPs are leading the transition in Europe's heating sector (Gaur et al., 2021). A heat pump (HP) generates heating and cooling by transferring heat from water, ground or air sources (Valancius et al., 2019). HPs offer high energy efficiency ratio, resulting in reduced CO_2 emissions and enhanced energy security by reducing the reliance on fossil fuels (IEA, 2018).

Although the wider adoption of HPs reduces energy consumption, it continues to downcycle resources following a wasteful linear economic model (North & Jentsch; 2021). The disposal of these HPs will drastically increase in the near future, because the Dutch government has implemented initiatives to increase the use of HPs (EZK, 2021). Currently, close to one million HPs are installed in the Netherlands. However, only 4000 of those HPs were discarded in 2022 (CBS Statline, 2022). With an average lifetime of 15 years, a vast quantity of HPs need to be discarded at the same time. In other words, accumulation of HPs reaching their end-of-life (EoL) phase is causing environmental concerns (CBS Statline, 2022; Yang et al., 2021).

The HPs' EoL treatment connects to substantial impacts to the environment (Lin et al., 2021), and more specific to a company's scope 3 emissions, which encompass indirect GHG emissions from the entire supply chain (GHG Protocol, 2013). If left unaddressed, these emissions could form a bottleneck for energy companies commitments to reach "carbon neutral" status (IPCC, 2018). Eneco and Vattenfall, for instance, have reported ambitious targets of achieving "carbon neutrality" by 2035 and 2040 respectively (Vattenfall, 2021; Eneco, 2022). One way to reduce these EoL emissions is by implementing the principles of circular economy (CE) during the latest phase of a product's lifetime (Ellen MacArthur Foundation, 2016).

1.2 Principles of Circular Economy

The CE steps away from society's traditional linear production and consumption system following a 'take-make-use-dispose' model (Lewandowski, 2016), focusing instead on maximizing resource usage through a range of approaches, including recycling, refurbishing and reusing products. The CE reduces environmental impacts, resource scarcity, and contributes to economic growth by prioritizing product preservation and longevity (Ellen MacArthur Foundation, 2013).

Achieving CE goals requires businesses to integrate circularity into their business models. Geissdoerfer et al. (2020) states that a diverse range of definitions exist and no common understanding of the Circular Business Model (CBM) concept has been established. Nußholz (2017) defines a CBM as the process of how a company creates, captures, and distributes value with the value creation logic intended to improve resource efficiency by extending the lifetime of products and components and closing product, material, and energy loops.

Connelly and Koshland (2001) state that adopting a CE-based sustainable building heating strategy offers an opportunity to move beyond the existing energy efficiency methods to further reduce energy resource consumption until consumption is eventually disconnected from resource depletion.

1.3 Research Problem and Objectives

Despite the recognized environmental urgency and the growing uptake of HPs in the Netherlands, a critical gap exists in the understanding and practical implementation of CBMs in the heat pump industry. The successful adoption of a CBM depends on the drivers and barriers underlying the implementation of circular practices. Scholars have identified four important categories that influence CBM adoption, namely Technological, Economic, Consumer and Environmental (Agyemang et al., 2019; Hina et al., 2022; Rios & Grau, 2019; Tura et al., 2019). However, it is unclear how these directly impact the Dutch heat pump industry. This research aims to address this gap by exploring the various drivers and barriers involved in implementing a CBM for heat pumps, ultimately to assess the possibility for a successful CBM implementation in the Dutch industry.

Scholars on CE noticed that the literature of CBM lacked the dimension to assess the process necessary to move towards the implementation of CBMs (Baldassarre et al., 2020; Weissbrod & Bocken, 2017). Thus, they have started with connecting CBM with design thinking to evaluate its potential implementation. Design thinking is an innovation-driven problem solving approach suggesting that innovation occurs at the intersection of consumer desirability (i.e., what users want), technological feasibility (i.e., what is technically achievable), economic viability (i.e., what is financially possible), of a new business model implementation (Brown, 2008, 2020). However, "While there is still a high focus on business testing desirability, feasibility, and viability of CBMs (Bland & Osterwalder, 2020; Bocken et al., 2018), environmental sustainability needs to be more thoroughly assessed" (Bocken & Konietzko, 2022, p. 811). Thus, a fourth pillar of Environmental impact is added to fit the context of circular practices.

The first pillar of **Consumer Desirability** relates to the consumer preferences of HPs, including their preferred circular material strategy (e.g. refurbish, recycle). The second pillar of **Technological Feasibility** regards the analysis whether HP producers or recycling companies have the technological expertise and capacity to collect, disassemble, and possibly after revisioning, re-incorporate resources into production. The third pillar of **Economic Viability** relates to the profitability of the CBMs compared to traditional business models. The final pillar of **Environmental Impact** regards the relevance for a CBM to address environmental challenges.

For assessing whether a CBM is technologically feasible, economically viable and provides environmental impacts, it is necessary to study a company's supply chain in practice (Baldassarre et al., 2020). In this case, Eneco is used as a case study. Eneco is a leading Dutch energy company, involved in installing and maintenance of HPs (Eneco, 2023). The selection of this case study was critical due to their significant role in the Dutch energy sector (van Overbeeke, 2001), and its ambition to become market leader in the heat pump industry in 2026. An important note is that Eneco solely sells hybrid heat pumps (HHP), which is a HP that operates in conjunction with a gas boiler (Chua et al., 2010). Thus, when an HP is mentioned in the research, it can be assumed that it is a hybrid heat pump working in conjunction with a gas boiler (section 6.2 will reflect on this). Beyond providing insights for Eneco, the case also examines whether the drivers and barriers allow for the implementation of a CBM, potentially forming a benchmark for other Dutch energy companies to create more effective CE policies.

Thus, the first pillar of Desirability will be generalizable to the population of potential consumers, and analysed with the use of a Discrete Choice Experiment, to elicit the specific consumer preferences (Hanley et al., 2016). While the other three pillars are specific to the case of Eneco, interviews with Eneco's supply chain actors will evaluate the technological feasibility and economic viability. The environmental impacts of the hypothetical implementation of a CBM will be estimated by extracting useful data from LCAs for basic calculations on material use (i.e. resource depletion) and CO_2 emissions (i.e. climate change).

Given the identified academic and practical gaps, the following research question arose: *What are the drivers and barriers for implementing a circular business model for heat pumps in the Netherlands?*

1.5 Social relevance

As the Dutch government intensifies its initiatives towards renewable energy heating solutions, for instance by obligating homeowners to replace their gas boiler alongside with a hybrid heat pump in 2026 (Rijksoverheid, 2022), it is crucial to ensure that these sustainable solutions truly benefit society and environment. According to Famiglietti et al. (2023) will the adoption of an increased circular supply chain for HPs ease the environmental impact associated with the energy transition, particular the end-of-life treatment of sold HPs. Ultimately helping society to address the threat of climate change.

By evaluating the potential for implementing circular practices for HPs, it can be ensured that these systems can be made and circulated in a way that is least environmentally impactful. Addressing EoL emissions and recourse waste, by ensuring that HPs bear the lower negative environmental externalities, and holds significant social relevance. This study elicited consumer preferences for circular strategies for HPs, emphasizing the importance of societal desirability for sustainable strategies. These findings will help policy makers and industry stakeholders in decision-making that aligns with societal desires and environmental impacts.

1.6 Scientific relevance

A clear gap exists in understanding the real-world implementation of CBMs within industries like heat pumps in the Netherlands (Lin et al., 2021). This research address this gap, offering a pioneering exploration of the drivers and barriers tied to CBM implementation for heat pumps. Furthermore, by connecting CBM with design thinking and assessing trade-offs within circular strategies, this study adds a new dimension to the field of sustainable business and innovation research, setting the stage for future investigations for other companies and subsequent industry actions.

This thesis is structured in the following manner: Chapter 2 provides the technological background and regulatory framework. The theoretical framework, in Chapter 3, introduces the concept of CE, CBM and strategies for material loops. It also discusses the drivers and barriers in CBM literature for every research pillar. Chapter 4 will elaborate on the mixed-methodological design. The results are divided into four research pillars. Consumer desirability is primarily elaborated upon through the results of the discrete choice experiment (DCE). The technological feasibility and economic viability presents the findings from the stakeholder interviews. The results on the environmental impact of climate change and resource depletion close this chapter. The discussion sheds light on the limitations and connects the results with theory by critically reflecting them, ending by proposing avenues for future research. The conclusion will concisely conclude on the desirability, feasibility, viability, and environmental impact and comprehensively answers the main question.

2. Technological Background

2.1 Heat Pump Types and Regulations

The majority of Dutch homes are currently heated by natural gas-fired boilers (Kieft et al., 2021). HPs are seen as key solutions to improve the efficiency of domestic space heating (Kieft et al., 2021). An electricity-driven HP can commonly produce three to four times the amount of heat than the electricity used. Therefore, this technology is gaining popularity and is expected to play a significant role in decarbonizating heating in buildings (Kieft et al., 2021; Valancius et al., 2019).

Heat pumps, in essence, "pump heat" from a low-temperature heat source to a high-temperature heat sink (Berntsson, 2002). There are three main types of heat pumps: air-source, water-source and ground-source (Çakir et al., 2012). The HPs that are generally used in The Netherlands, are the air source heat pump (ASHP) and ground source heat pump (GSHP) (CBS Statline, 2022c).

GSHPs use pipes buried in the ground to exchange heat with earth. This system has, compared to an ASHP, a high energy efficiency and does not require outdoor units (Self et al., 2013). In addition, ASHP are less expensive to build (Li et al., 2014). However, GSHPs require a buried ground loop which needs to be excavated, making it unsuitable for some locations such as for flats or apartments (Wu, 2009), accounts for 25,9% of Dutch houses (CLO, 2020). This might give reason to the fact that ASHPs are the most widely used efficient heat technology, as 966,332 ASHPs installed in residential houses compared to 96,992 GSHPs (CBS Statline, 2022). Henceforth, in this research proposal the term 'heat pump' will refer to an ASHP.

While HPs are a popular choice for efficient heating, fossil-based systems are still the most used heat systems (Gaur et al., 2021), switching from a fossil fuel system to an HP comes with high transition costs. The Dutch government is incentivizing building owners to invest in HP systems. Several measures are implemented, including tax incentives and financial subsidies. The Netherlands has set a target to have at least 1.5 million heat pumps installed by 2030. To help achieve this goal, the government has introduced the 'SDE++' subsidy program (EZK, 2021).

Given the complex and sometimes dangerous mix of components used in equipment, the EU policy on Waste of Electrical and Electronic Equipment (WEEE) aims to contribute to circularity (European Commission, 2012). The European Commission (2020) introduced the Circular Economy Action Plan in their Green Deal. It implements measures aiming at fostering circularity in sectors such as construction, electronics or plastics. While the plans cover multiple sectors, they also address the transition to a more circular heating sector. The plan encourages the adoption of energy-efficient technologies, such as HPs, to replace traditional fossil fuel-based heating systems. To promote circularity, the plan emphasizes the efficient use of resources in the design and production phase. The Ecodesign and Energy Labelling Working Plan 2022 - 2024 focuses on heating and cooling appliances in terms of energy and material savings.

These incentives are put in place to promote both the large-scale use of HPs and to decrease CO_2 emissions (ibid.). However, with the wide application of HPs environmental impacts are expected to take place in the disposal phase. Here, certain components and portions of materials and up in landfills (Lin et al., 2021). That is why the theoretical background on CE needs to be discussed and its theories subsequently tested in the Dutch HP-sector.

3. Theoretical Framework

3.1 Circular Economy

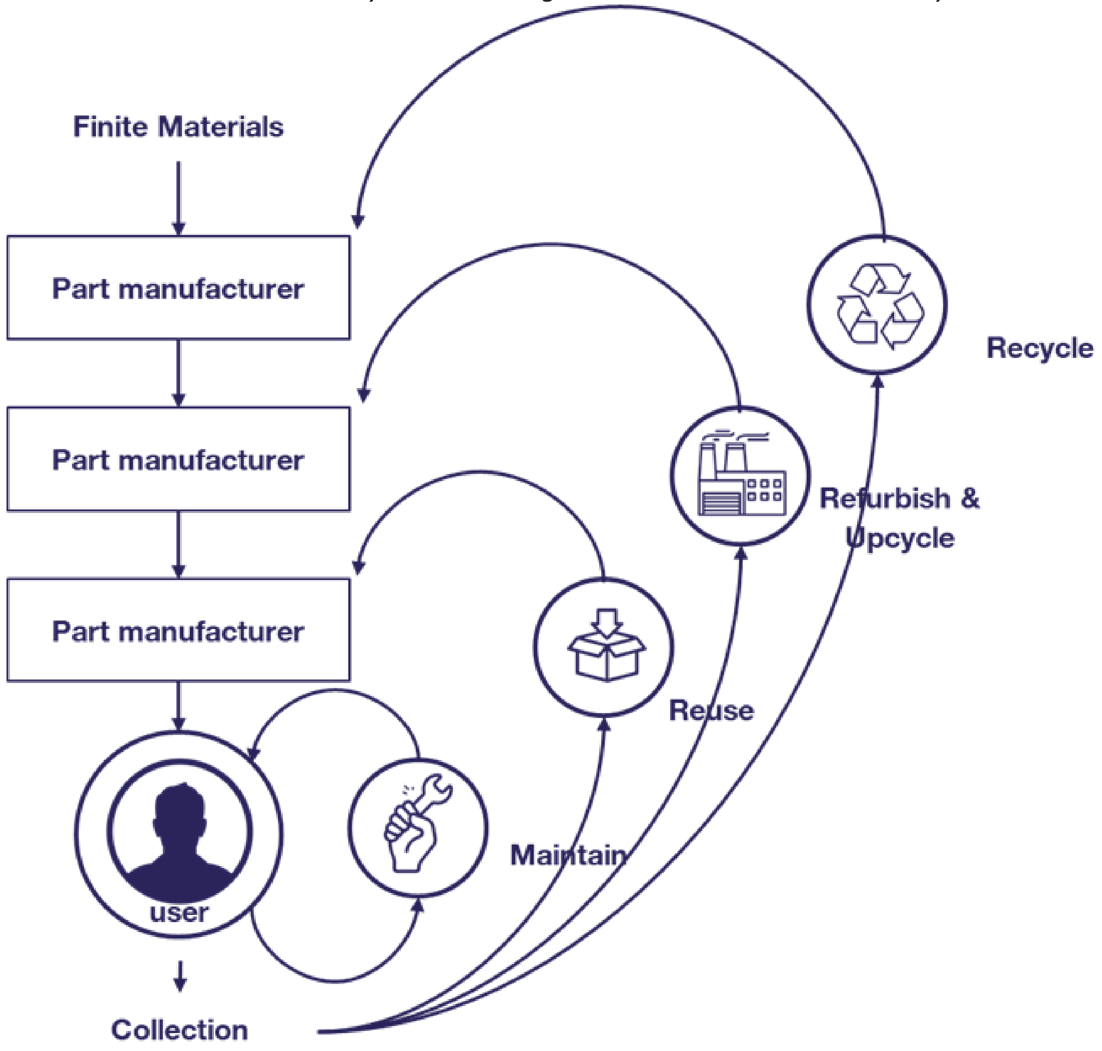
Society's production and consumption systems are traditionally designed in a linear manner. Raw materials are collected, converted into products, and eventually discarded as waste once they serve their purpose (Lewandowski, 2016). The primary objective of this economic system is to manufacture and sell as many products as possible, maximizing economic value. However, it has become evident that the effects of this linear model harm the environment (Lacy & Rutqvist, 2015). The impact on the environment could be mitigated by focussing on a system where unnecessary destruction of resources are mitigated. Furthermore, economic gains could be met by shifting to a more resource-efficient economic system, as the price volatility of natural resources is growing due to the depletion of non-renewable resources (Ellen MacArthur Foundation, 2013).

In contrast, an economic structure based on circularity could achieve the necessary transition. The Circular Economy (CE) seeks to keep resources in use for as long as possible through a closed-loop system (Lewandowski, 2016). By emphasizing the longevity and utilization of products, a reduction in the demand for new production is created. The CE aims *"to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Kirchherr et al., 2017, p. 229).*

In the context of CE, both a technological and biological cycle exists. This emerged from the Cradle to Cradle (C2C) philosophy from Braungart and McDonough (2009). In a C2C system, both cycles are maintained as waste from one process serving as input for another. The biological cycle includes the flows of renewable materials which could be returned safely to nature. However, as HPs are made out of processed materials (Lin et al., 2021), this cycle is unqualified for the research objective.

According to the Ellen MacArthur Foundation (2013), the technological cycle, depicted in Figure 1, includes three major strategies: reusing, refurbishing and recycling to implement the principles of CE in product supply chains (Geissdoerfer et al., 2017). A fourth strategy will be incorporated in this study called upcycling. **Reused** products are used by someone else without being altered (McDonough & Braungart, 2002). While **refurbished** products have been repaired to a like-new condition before being resold. **Recycling** is a strategy where waste materials are converted into new products (ibid.). **Upcycling** is a mix between "upgrading" and "recycling" (Holgado & Aminoff, 2019; Wegener, 2016). Upcycling can be defined as the process of taking something that is disposable and turning it into something more valuable (ibid). Upcycling is incorporated because HPs have a long lifetime, at the end-of-life their quality will be lower compared to new HPs due to continuous innovations (Chua et al., 2010), upcycling could counter this and increase the quality. While different R-frameworks or R-imperatives exist, and range from 3Rs (Ghisellini et al., 2016; Kirchherr et al., 2017) to 10Rs (Bag et al., 2021; Morseletto, 2020). Although the count of Rs varies across literature, all share a common hierarchy in the strategies with the aim of retaining as much energy and minimising environmental impact (Henry et al., 2020).

***Figure 1: The Technological Cycle of CE** depicts four major strategies for Circular Economy adopted in this study. These strategies have a clear mutual hierarchy*



Ellen MacArthur Foundation, 2016

3.2 Circular Business Models

An increasing number of companies are looking to incorporate the principles of CE into their business operations. This is a result of new regulations and due to an increase of material scarcity and subsequently higher resource prices (Ellen MacArthur Foundation, 2013; European Commission, 2020). Velenturf and Purnell (2021) state that the successful transition to a CE hinges on companies and organizations adopting CE principles and strategies into their business models. These incorporated principles of CE are embodied in Circular Business Models (CBMs) (Heyes et al., 2018).

A CBM is a specific type of sustainable business model that lays an emphasis on long-term value creation through environmental and economic, and potential social considerations (Geissdoerfer et al., 2017). A CBM primarily focuses on preserving resources and promoting a circular flow of materials and products in closed-loop supply chains to maximize value (Kirchherr et al., 2017). These models are specifically designed to function at a micro-level and strive to achieve both profitability and the closing of product, material, and energy loops (Bocken et al., 2014). Additionally, they emphasize the importance of reverse resource flows and conscious consumer attitudes (Reike et al., 2018).

The ‘closed loops’ stand out as a defining feature for the circular transition. In addition to closure, there's potential to extend the lifetime of material loops, and unnecessary material flows may be prevented by conscious consumer attitude. This is captured by the categorization of approaches for reducing resource use by Bocken et al. (2016). Bocken et al. (2016) describe three circular business strategies of slowing, closing and narrowing resource loops. (The subsequent paragraphs will elaborate on these strategies.)

Slowing resource loops refers to extending the product-life (e.g. repair and remanufacturing) (Bocken et al., 2016). **Narrowing** flows have the goal of utilizing fewer resources per product (Bocken et al., 2016). "Slowing" and "narrowing" may have the same outcome (less resources flowing through the system) but, "narrowing" accepts the speed of resource flows, whereas "slowing" establishes a clear relationship with time. **Closing** loops means that materials and energy are recycled within the system, by reuse, refurbishing, recycling and upcycling to ultimately create a continuous flow of resources (see section 3.1) (Bocken et al., 2016).

It is important to note that there is a wide spectrum of understandings and definitions associated with the concept of CBMs (Geisendoerfer et al, 2020). A standardized, universally accepted definition for CBMs does not exist due to the evolving and multidisciplinary nature of the topic. In their review, Geisendoerfer et al. (2020) emphasized that most definitions are centred around value creation.

3.3 Successfully Implementing a CBM

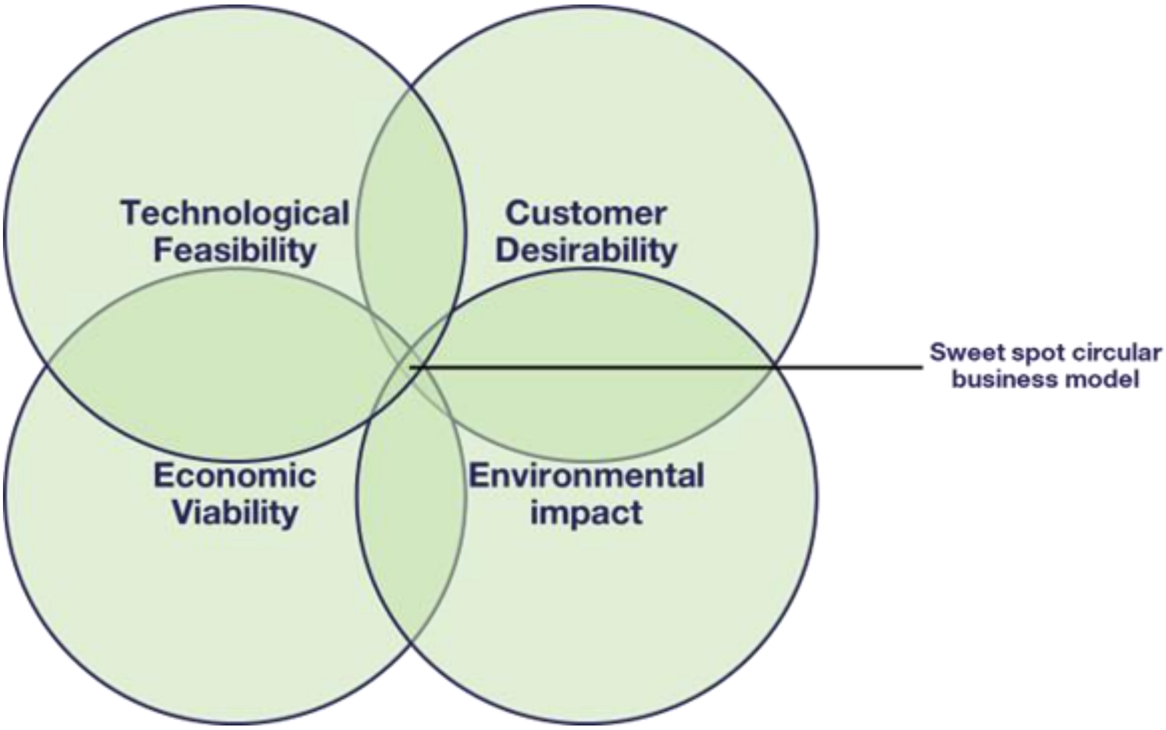
To successfully implement a new business model, organisations need to simultaneously consider the consumer desirability (i.e., what users want), technological feasibility (i.e., what is technically achievable), economic viability (i.e., what is financially possible) (Baldassarre, et al., 2020; Brown, 2020). Brown (2008) suggesting that innovation occurs at the intersection of the three research pillars. “Balancing desirability, feasibility, and viability in view of systems is key to effectively implementing new products, services, and the business models around them (Baldassarre et al., 2020, p.3). In other words, A BM can only be successfully implemented when a match occurs between people’s needs with what is technologically feasible and with a viable business strategy which can be converted into customer value (Brown, 2008).

> *“While there is still a high focus on business testing desirability, feasibility, and viability of CBMs (…), environmental sustainability needs to be more thoroughly assessed during the experimentation phases to avoid negative rebound effects (Das et al., 2022). (Bocken & Konietzko, 2022, p. 811).”*

Although a CBM aims to promote circularity, which should inherently lead to environmental benefits, the feasibility, viability, desirability- framework lacks a clear mechanism for assessing the environmental impacts (both positive and potentially mitigated negative impacts) of adopting a CBM (Baldassarre et al., 2020). Without such a mechanism, it becomes challenging to measure, track, or communicate the environmental performance of businesses which want to utilize a CBM. Thus, it was important to incorporate a fourth research perspective, ‘environmental impact,’ into the academic framework to assess whether the CBM contributes to a company’s sustainability targets (see Figure 2).

All in all, a CBM could only be successfully implemented when a match occurs between what is desirable from a human perspective with what is technologically feasible and with a viable business strategy which can be converted into customer value and environmental impact (Baldassarre et al., 2020; Brown, 2008; Gideon, 2009; Santa-Maria et al., 2021).

Figure 2: The Analytical Framework; Four pillars of Circular Business Model, when a match occurs a CBM can be implemented. Inspired by Baldassarre et al. (2020), Bocken & Konietzko (2022), Brown (2008), Santa Maria et al. (2021), Shapira et al. (2017).



Brown (2008) mentioned that the pillar of 'customer desirability' should be generalizable to the entire customer group of the product or service at hand. The perspectives 'technological feasibility', 'economic viability', and 'environmental impacts' are commonly assessed specific to a company, therefor they are often not generalizable beyond the context of a case study (Santa Maria et al., 2021).

The next sections will explain the four pillars separately, the general factors (i.e. building blocks) that influence the pillars and subsequently, the implementation of a CBM (see Figure 3, page 21, for a depiction of the theoretical structure and its building blocks). These sections will elaborate on the underlying drivers and barriers to CBM adoption, as identified in literature. In the event where little drivers and barriers were found in CBM literature, a sidestep was made to explore the prominent drivers and barriers for adopting heating system or Electric Vehicles. The latter comparison is relevant since both technologies can be considered disruptive innovations. Defined by Christensen et al. (2013) as entrants to a market targeting un(der)served customers, and over time overtake and replace established products and services. Both electric vehicles and heat pumps are disruptive, they have changed their industries by introducing electricity as power and offer a (significantly) more energy-efficient alternative to established fossil fuel technologies.

3.3.1 Consumer Desirability

From a BM perspective, desirability is a property of value proposition. Central to this pillar is the question "How desirable is the value proposition for the customer?" (Bland & Osterwalder, 2020; Bocken & Konietzko, 2022, p. 810). Within this pillar the aim is to analyse whether the (circular) product or service makes sense to consumers (Brown, 2008). Consumer Desirability is described by four building blocks: value proposition, customer segments, customer relationships, and channels. Collectively, they explain the desirability of the circular product to the customers.

A. Value Proposition

The value proposition is a central component to the desirability of a CBM. It entails a product or service that generates value for a specific customer segment (Osterwalder & Pigneur, 2010). As societal awareness about environmental issues grows, so does the demand for responsible production and consumption (Hina et al., 2022; Rizos & Bryhn, 2022), ultimately driving the adoption for circular practices (Russell et al., 2020; Tura et al., 2019).

Circular products require designs that utilize reused, refurbished, or recycled materials, alongside the incentives that support product life cycle extension, such as take-back systems (Lewandowski, 2016). Although circular products align with environmental values, consumer responses can be difficult to predict because they are influenced by a range of social norms and external conditions. According to Baxter et al. (2017), consumers hold false perceptions regarding refurbished or recycled goods and even consider these goods unreliable. Therefore, consumers are less willing to purchase these goods because of the risks associated with their quality. However, these concerns in quality can be countered through certain attributes that enhance consumer desirability. For example, (extended) warranty period, in the case of circular mobile phones, have shown to increase the willingness to purchase (Boyer et al., 2021). Other attributes regarding transparency in product attributes, like the 'Circular Economy Score' and 'repairability', have also proven to increase the consumer desirability for the circular phones.

Incorporating the principles of the circular economy into the value proposition asks for significant changes into consumers' everyday lives. Examples of such changes relate to letting go of the desire for ownership or novelty (Rizos & Bryhn, 2022). These changes are hindered by the ‘buy-new’ mentality (Rizos & Bryhn, 2022), or the ‘ownership mentality’ (Hina et al., 2022). These changes hinder consumer acceptance, and subsequently the success of businesses to adopt CBMs.

B. Customer Segments

Customer segments are defined as the specific groups of individuals or institutions that the business model is aiming to reach and serve. Finding which customer segment fits the value proposition is crucial for the adoption of BM. Customer segments are often categorised based on shared characteristics (Osterwalder & Pigneur, 2010), including by demographics, locations, and behavioural characteristics.

Demographics have been shown to influence the preferences for alternative vehicles. Ziegler (2012) and Hidrue et al. (2011) revealed consumers' intention to buy electric vehicles is positively connected with their age, education, and income levels. Carley et al. (2013) and Hackbarth and Madlener (2013) discovered that people interested in electric vehicles are well-educated and concerned about the environment.

Pro-environmental behaviour is a significant factor for the adoption of sustainable innovations. Including electric vehicles (Egbue & Long, 2012; Schuitema et al., 2013). Consumer acceptance of electric vehicles has been closely linked to pro-environmental behaviour, with attitudes, values, beliefs, and norms affecting people's purchase intentions. In particular, some adopters view environmental protection as the main motivation for their decision (Skippon and Garwood, 2011).

C. Customer Relationships

Customer relationships involve establishing a connection with and retaining customer segments, which can facilitate one of the main goals of the circular economy, eliminating waste (Lewandowski, 2016). For consumers to return their used goods and purchase a remanufactured product, strong customer relationships are needed (Hina et al., 2022). When customer relationships are not maintained, the customers will most definitely lack awareness of the opportunities to return reusable products and instead choose to simply dispose them, this limits the success of the CBM (Kirchherr et al., 2018).

Geissdoerfer et al. (2020) mentioned that long-life products that are maintained throughout their lifetime can create brand loyalty which forms a driver for consumer desirability. Long-term customer relationships, and open up new revenue streams during the use phase of the products through service packages or customised contracts. Lewandowski (2016) mentioned that strong customer relationships enable businesses to involve their consumers in the co-creation of circular goods, respectively increasing acceptance. A barrier for implementing CBM, relevant for customer relationships, regards the level of assistance which the company offers. Rouvinen and Matero (2013), found that if more work is needed, homeowners are less inclined to purchase a sustainable heating system.

Furthermore, customer relationships are crucial in continuously obtaining an objective view of the customer needs and to create social awareness. Thus, relationship allows businesses to align their circular practices closely to the preferences of their consumer segments (Hina et al., 2022).

D. Channels

This "building block describes how a company communicates and reaches its customer segments to deliver a value proposition" (Osterwalder & Pigneur, 2010, p.26). In a transition towards the implementation of circular practices, its channels take on an expanded role. They are not only pathways for transactions, but also serve additional mediums for communicating the value of the circular products to consumers (Antikainen & Valkokari, 2016).

The way these channels are utilized, especially for communication and educational purposes, plays a crucial role for the consumer desirability of circular products. The driving force of these channels is that they are not just for communication; it entails the collaboration with consumers and stakeholders (Vermunt et al., 2019). Take for instance that the value of a specific CBM is a reduction in waste generation, then can the channels be used to deliver this value proposition and promote a return stream of used products.

From an internal perspective, a lack in communication among departments and unclear responsibilities of those departments towards the organisation's circular practices hinder the implementation of a CBM (Jabbour et al., 2020).

3.3.2 Technological Feasibility

From a BM perspective, feasibility is a property of value creation and delivery. Central to this pillar is the question "How feasible is it to organise resources needed to create and deliver the value proposition?" (Bland & Osterwalder, 2020; Bocken & Konietzko, 2022, p. 810). Within this pillar the aim is to analyse whether the (circular) product or service is functionally possible (Brown, 2008). Technological feasibility is described by the 'key resources' to enable circular flows and feedback mechanisms; the 'key activities' required to provide the circular product, the 'key partnerships' needed, and the 'take-back system' (Kalair et al., 2021).

E. Key Resources

Key resources are the essential assets needed for a BM to function. It can be categorised in physical, intellectual, human and financial (Osterwalder & Pigneur, 2010). Lewandowski (2016) aligns this building block with the principles of CE in two ways.

- Changing input of materials and products through the implementation of circular sourcing.
- Substitution of resources with less harmful or technologically superior alternatives.

The Key Resources can form a barrier for the technological feasibility of a CBM in multiple ways. Barriers include a lack of information related to the understanding of CE (Hina et al., 2022; Tura et al., 2019). Furthermore, organizations have trouble recognizing new BM opportunities or lack the resources for scalability (Hina et al., 2022; Salmenperä et al., 2021). The absence of financial, and organisational resources, along with public funding for supply chain collaboration, also significantly undermine CBM implementation (Agyemang et al., 2019).

A major driver for the technological feasibility of circular practices is the accessibility of new technologies targeted for circularity (Brown et al., 2019; Rizos & Bryhn, 2022). Tura et al. (2019) and De Jesus and Mendonça (2018) specify further that availability of technologies make it more feasible to optimise resource efficiency, re-manufacture goods, and regenerate by-products as input in other processes.

The availability of various resource types, such as material, knowledge, and technological resources, is essential for the feasibility of circular practices. This is because the CE aims for a regenerative production system and resources in circulation within a closed loop. As a result, the demand for new materials in the production system has decreased (Genovese et al., 2017; Hina et al., 2022). Knowledge is widely recognized as a resource facilitating the CBM implementation. Currently, technological information presents unique opportunities for businesses moving to CE. The creation of BMs with digital technologies at their core accelerates the adoption of CE principles (Hina et al., 2022).

F. Key Activities

Key Activities describe “the most important things a company must do to make its business model work” (Osterwalder & Pigneur, 2010, p.36). These activities are needed to realise, offer and deliver the value proposition. Key activities can apply the principles of CE in various ways. Some focus on improving performance, technological exchange, and product design, while others centre on recycling or refurbishing (Lewandowski, 2016). Dedicating activities to improve product design is crucial for making it suitable for circular material loops or less harmful to the environment (Bakker et al., 2014).

Certain key activities mentioned in CBM literature form barriers to the technological feasibility of circular practices, particularly the redesign of the recovery processes. This challenge emerges from a lack of systemic planning in circular material use (Salmenperä et al., 2021). Scholars have reported that the design of technology, particularly in the build industry, hinders the CBM implementation process. A significant challenge involves figuring out how components designed decennia ago can be reused today (Adams et al., 2017). Since these components were not intended to be reused, new methods have to be developed to overcome this challenge.

Implementing pilots of the circular concept and encouraging experimentation at scale are implied to overcome technological challenges (Brown et al., 2019), particularly in industries with multiple players and comparable product propositions, like heat pumps.

G. Key Partnerships

Key Partnerships describe “the network of suppliers and partners that make the business model work” (Osterwalder & Pigneur, 2010, p.38). Partnerships enhance obtaining key resources and performing key activities, thus enabling external benefits and spillovers. Lewandowski (2016) emphasises the significance of selecting and collaborating with partners who align with the principles of CE along the supply chain.

Establishing Key Partnerships affect the technical feasibility of a CBM by creating the opportunity to utilise the specific technological expertise of other companies (Averina et al., 2022). If a company transitions for the first time towards a CBM, a lack of technological expertise may be countered by collaborating with actors who already know how to best recover specific components or materials. Once a relationship is formed, organisations can establish long lasting bonds with partners Rizos & Bryhn, 2022) and encourage cross-functional cooperation and open communication within supply chains (Salmenperä et al., 2021; Tura et al., 2019). The development of a technologically driven

CBM may be promoted by strategic partnerships, especially those within close geographical proximity (Urbinati et al., 2021). Such collaborations utilize the available resources and capabilities through a multidisciplinary lens. Moreover, the pressure stakeholders lay on using responsible resources also drives the assimilation of circular practices within businesses (Hina et al., 2022).

A major barrier to the transition is the absence of collaboration throughout the supply chain (Rizos & Bryhn, 2022; Tura et al., 2019). To generate enough commitment, it is necessary to address issues related to ownership, sharing of costs and benefits, trust, information exchange, and shared incentives (Brown et al., 2019; Hina et al., 2022; Rizos & Bryhn, 2022; Salmenperä et al., 2021). A lack of suitable network support and partnerships may be caused by an industrial-focus and resistance to change traditional activities (Tura et al., 2019). The lack of a shared understanding in the CE vision across (potential) partnerships further hinders the transition (Brown et al., 2019).

H. Take-Back System

For a CBM to work, consumer products must be collected and returned (Govindan et al., 2015). This is a vital element of a CBM (Bocken et al., 2016), often involving collaboration with external partners, such as logistical companies or waste management companies (Lewandowski, 2016).

Witjes and Lozano (2016) identified that one of the primary challenges in implementing CBMs lies in the presence of restrictive company policies. For instance, the lack of training that managers receive to assess the quality of a finished product when reusing recycled materials underscores the absence of a strategic approach to implementing CBMs (Hina et al., 2020). This challenge emphasises the need for a more thoughtful consideration of strategic elements in CBM adoption.

Furthermore, take-back systems face logistical and economic barriers, including high costs linked to widespread geographic distribution and uncertainty of the material flow (Gupta et al., 2019). Take-back systems often suffer from the fragmented nature of supply chains, which may make it difficult for supply chain actors to track the activities of other actors (Govindan et al., 2015), this is especially important in the untransparent supply chains of heat pumps. Another barrier of the take-back system is simply the uncertainty of consumers to actually return their used goods (Hina et al., 2022).

Despite these barriers, there are opportunities to leverage take-back systems as a driver for CBMs by utilising new take-back management systems that can generate additional revenue, as discussed in section J. Revenue Streams (Lewandowski, 2016)

3.3.3 Economic Viability

From a BM perspective, viability is a property of value capture. Central to this pillar is the question “Is the business model profitable?” (Bland & Osterwalder, 2020; Bocken & Konietzko, et al., 2022, p. 810). Within this pillar the aim is to analyse whether the (circular) product or service is likely to become a business model which can be sustained in relation to the cost and time budgets (Brown, 2008). Economic Viability is described by the revenue and cost structure.

I. Cost Structure

This building block entails the most relevant costs inherent to the specific BM (Osterwalder & Pigneur, 2010). Transitioning to a CBM often necessitates organizational changes impacting materials, energy, and employee behaviour, which ultimately will affect the BM's complexity and economic viability (Lewandowski, 2016). Factors such as an efficient allocation of resources, strategies to minimise costs, and a clear understanding on the impact of the costs to the overall BM are essential for a successful adoption of circular practices. Coelho et al. (2020) have identified key factors that influence the viability of a CBM specific to reusable package systems. Which are: market volume, logistics and transportation, level of standardisation, return rates of reusable containers, and labour involved in the process (Coelho et al., 2020). In literature regarding consumers' willingness to purchase home heating systems, Scarpa and Willis (2010) found in multiple examples of factors that influence the cost structure, such as capital cost, maintenance cost, energy bill per month, contract length.

The main barriers to implementing CBMs lies in the increased costs, especially the startup costs which tend to get worse due to a lack of resources (Hina et al., 2022; Kühl et al., 2023; Salmenperä et al., 2021), and the high costs of new technologies (e.g. re-processing metals of heat pumps). CBMs entail higher costs because of the complexities involved in the take-back structure and refurbishing and remanufacturing processes (Hina et al., 2022). Furthermore, companies often need to keep the costs of the CBM low to stay competitive to new production, ultimately forming a barrier to remanufacture instead of producing new.

From an economic viability perspective, Hina et al (2022) mentioned that a reduction of raw material costs has been recognized as an opportunity for implementing CBM. However, a gap in research is acknowledged regarding the unclarity in whether lower costs are obtained at the expense of reduced product quality. Hina et al. (2022) also mentioned the external drivers of price volatility. As well as the industry specific industrial networks which could lead to reduced business costs and encourage efficient use of resources.

J. Revenue Streams

"Represents the cash a company generates from each Customer Segment" (Osterwalder & Pigneur, 2010, p.30). The main question here is: what value each customer segment is willing to pay. Which can create one or more revenue streams. (Murray & Scuotto, 2015). Lewandowski (2016) additionally mentions that revenue can come from payments for specific products, services, usage, availability provided by PSS, and implementing a material loop.

According to Upadhyay et al. (2021), businesses encounter difficulties to determine and define the revenue model for circular products. Financial uncertainty often arises with respect to reused or refurbished products because their profitability depends on the market demand, which is difficult to predict, especially in sectors where circularity has not been implemented such as the heat pumps sector. Consequently, businesses are hesitant to invest in circular projects. Such economic barriers were acknowledged as crucial by Wrålsen et al. (2021), who highlighted economic viability and incentives as key challenges. The barriers for the formation of an economic viable CBM can be further linked to the lack of measurement tools for long-term benefits (Tura et al., 2019), especially in a competitive marketplace (Jaeger & Upadhyay, 2020), such as the heat pump sector.

The drivers which are provided by implementing the principles of CE are linked to additional opportunities for revenue streams, an increase in competitiveness (Rizos & Bryhn, 2022), increased innovation and potential for new business development (Tura et al., 2019). Moreover, the way value is captured in a circular model could change from a one-time transaction to monthly fee or additional service costs (Averina et al., 2022). These novel payment structures could potentially improve the economic viability in the long-term.

3.3.4 Environmental Impact

While CBMs are designed to address sustainability issues by slowing, narrowing, and closing resource loops (Bocken et al., 2016). the term “circular” (business model) does not always guarantee a more environmentally friendly solution (Warmington-Lundström & Laurenti, 2020). Circular solutions with good intentions may have unintended rebound effects with a greater negative environmental impact (Siderius & Poldner, 2021). Thus, it is important to assess the environmental impacts during the experimentation phase to avoid rebound effects and missed opportunities (Das et al., 2022).

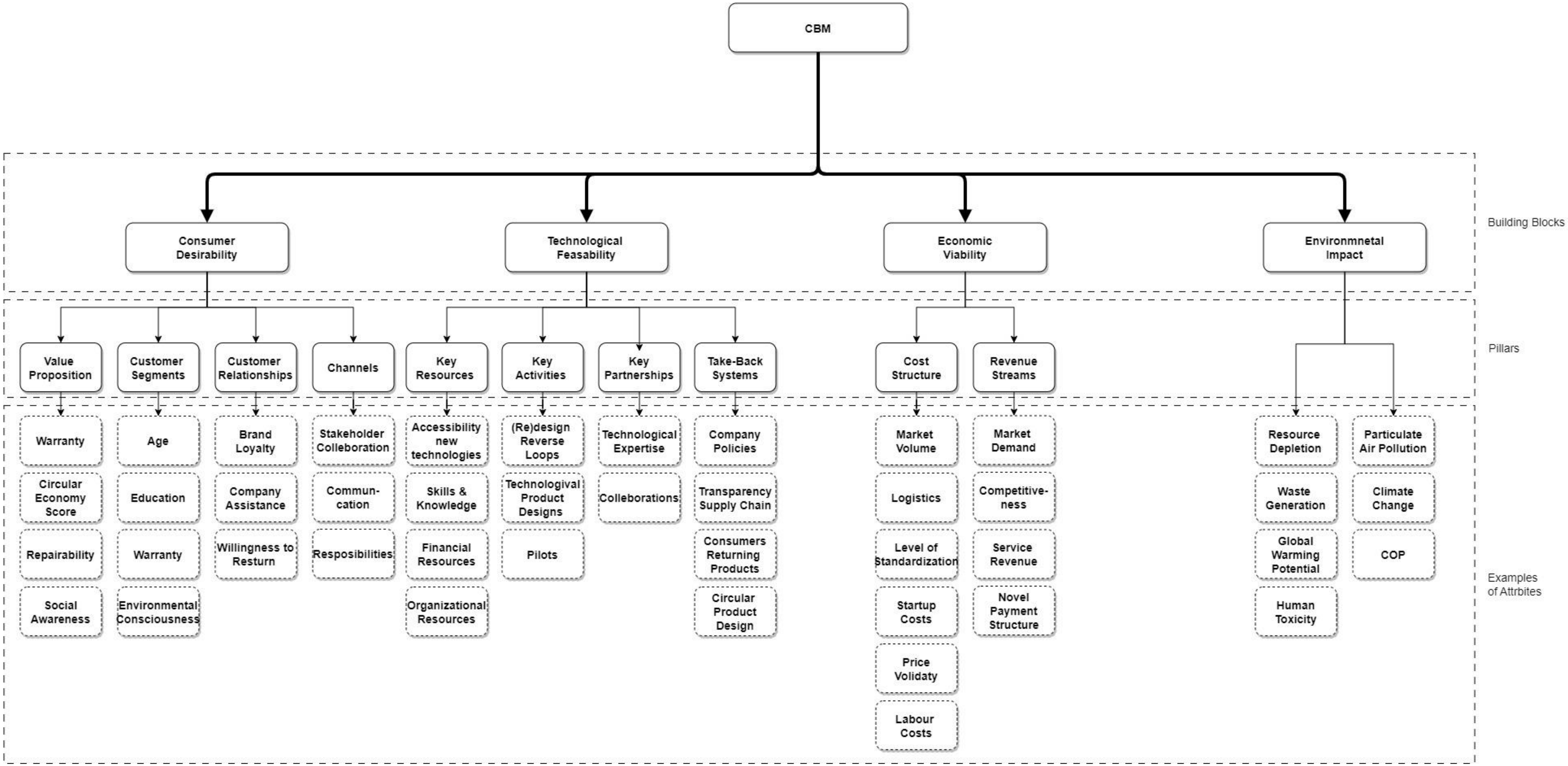
An environmental impact assessment is succinctly defined by UNECO (1991, p. 2) as “an assessment of the impact of a planned activity on the environment.” Typically, conducted by planning authorities to form judgements on whether a project or development should go ahead (DoE, 1989). When implementing a CBM into business operations, one should expect multiple impact categories to change. These include human toxicity, (life cycle) climate change (i.e. global warming potential or GHG-emissions), waste generation, and particulate air pollution (Bocken et al., 2016; Van Loon et al., 2021).

Heat pumps consist of a diverse and vast range of materials and metals (Sevindik et al., 2021). When implementing a CBM, Ellen MacArthur Foundation (2013) elaborates that these materials would be to a lesser extent downcycled, thus fewer raw materials are needed for input of the production phase. From these practices, a significant reduction of GHG emissions can arise.

The environmental impact of HPs is influenced by attributes, such as Coefficient of Performance, which is a measure for the energy efficiency (Rouvinen & Matero, 2013). COP is the ratio of the heating or cooling energy that is produced out of the required input of electrical energy (Ertesvåg, 2011). Chua et al. (2010) mention that the positive impact on the environment largely depends on the energy efficiency of the HP. Moreover, the choice of refrigerant is critical. Refrigerants can vary widely, from those with a high Global Warming Potential (GWP) to others with lower GWP but often other unfavourable characteristics such as a higher toxicity (Lin & Kedzierski, 2019).

On the next page, a diagram presents a comprehensive overview of the theoretical framework (Figure 3). Here it clearly illustrates the three-tier structure of this research, which is composed of three of complexity, encompassing 4 research pillars, 10 building blocks, and a wide variety of attributes found in literature that influence the implementation of a CBM or the adoption of a comparable technology.

Figure 3: Diagram of Theoretical Framework the four Pillars, their Building Blocks and Examples of Attributes from Literature, that influence CBM implementation or sustainable technology adoption.



4. Methodology

4.1 Research Strategy and Design

This study employed a mixed-methods sequential descriptive design, consisting of quantitative research methods, qualitative research methods, and desk research.

The pillar of **Customer Desirability** was analysed through a discrete choice experiment (DCE) conducted with potential future owners of HPs. The extracted quantitative data provided a general understanding of which specific circular strategy is desirable among potential customers. This pillar is generalizable to the broad population of potential future customers.

Technological Feasibility, Economic Viability and Environmental impacts were analysed through the case study of Eneco's supply chain. The pillar of **Technological Feasibility** was analysed by conducting interviews with Eneco's HP producers focused on their technological capabilities, circular goals and imposed supply chain improvements. Additionally, interviews with employees across different departments explored the feasibility of a take-back structure and a return stream within the supply chain. Furthermore, a recycling company was interviewed to evaluate their competence in establishing an end-of-life (EoL) supply chain for Eneco.

The pillar of **Economic Viability** was also analysed with the use of the same interviews with the actors of Eneco's heat pumps supply chain. Interview questions focussed on the economic viability of a take-back structure (i.e. return stream) and the most important cost and revenues. Furthermore, was the DCE used to enable the analysis of the economic viability through Willingness to Pay calculations.

The pillar of **Environmental impacts** used the interview with the recycling company as context for simple calculations on the impact of transitioning from a linear business model to a circular business model. The calculations were made with the use of Life Cycle Assessments (LCAs) on the environmental impacts related to climate change and material depletion. These four pillars are integrated in Figure 5, on page 33, which illustrates their corresponding research methods and measured attributes.

4.2 Consumer Desirability

Successful adoption of a product or service depends on the desirability among consumers, especially when compared to similar offerings (Ghimire et al., 2016). In the case of circular heat pumps, they must be as desirable, or more, than conventional HPs for the new CBM to be successfully implemented. To elicit consumer preferences in the absence of real-world data, Discrete Choice Experiments (DCEs) serve as a relevant method to obtain customer preferences for product attributes (Louviere et al., 2010).

4.2.1 Discrete Choice Experiment

A DCE is generally chosen as a research method for understanding (underlying) consumer preferences for certain product attributes and for comparing products with similar attributes but different levels (Hanley et al., 2016).

A DCE involves presenting respondents with choice sets in a survey design format (Louviere et al., 2010). It is a controlled experiment, where individuals select their preferred choice from a set of (realistic) hypothetical options. The DCE aligns with the research objective, because this analysis supported Eneco in making decisions, based on the real-life consumer preferences, on the potential offering of circular HPs.

4.2.2 Attributes of Choice Design

For a valid choice experiment, the choice design needs to closely represent reality. According to Ryan's et al. (2012) DCE guidelines, relevant attributes were identified that impact consumer desirability for CBM and heating systems through a literature review, discussed in the theoretical framework. Four key attributes were identified: circularity percentage, warranty, investment costs and Coefficient of Performance (COP).

The validity of a DCE depends on the appropriate allocation of levels of the attributes (Mangham et al., 2009). The levels should reflect the variety of expected conditions and they must be realistic from the HP-provider perspective. To ensure realistic levels, they were discussed with HP and CE experts from Eneco. The following section will elaborate on the attributes and corresponding levels.

Circularity percentage is the percentage of circular components from which a HP is made. Currently, are novel HPs are for only a small part made from recycled materials. This number is currently around 12% (EHPA, 2021). Holgado and Aminoff (2019) state that it is possible to create closed-loop systems, but for complex technologies, reaching 100% is challenging. Thus, 90% was seen as the current maximum, due to the need for new components (e.g. new piping) during re-installation. The levels shown in table 1, of 12%, 38%, 64%, and 90% were determined to provide a realistic and equal range.

Warranty serves as an indication for product's quality (Ijomah et al., 2004). Extending the warranty period for circular products provides the consumers with trust in the product (Boyer et al., 2021). In the EU are suppliers of electrical appliances required to offer a 2-year warranty guarantee (E.U., 2022). The average warranty period is 3-5 years for HPs (Madani & Roccatello, 2014). Most of Eneco's HPs have a warranty of 2 years, only Mitsubishi offers 5 years period (Eneco, 2023). However, circular HPs may lack a warranty due to expiration in their first lifecycle. Thus, levels of 0, 2, and 5 years were chosen to represent this case.

COP is the Coefficient of Performance, a measure of energy efficiency of HPs. The COP has a major impact on the environmental impact and the operational costs, therefore are developers constantly striving to increase the COP (Chua et al., 2010) mention that HP developers are constantly. A constant increase in COP over time means that HPs at their end-of-life, have a lower COP compared to new HPs. Eneco's HPs have on average a COP of 4,5 meaning that the HP delivers 4,5 times the heating or cooling energy for every unit of electrical energy consumed (Chesser et al., 2021; Eneco, 2023). Although the COP remains stable over an HP's lifetime, circular HPs have a lower COP due to technological advancements over time. Large innovations which affect the COP have already been made, the COP is expected to increase with 0,5 every 5 years (Mik Bosman, Bosman Senior Product Manager Eneco). Meaning that in 15 years the COP will be 6,0 with a midpoint of 5,25.

Investment costs depend on the specific system installed, the installation costs (Schlosser et al., 2020), and the 'SDE++'-subsidy (see Chapter 2: Technological background). The average investment cost for an HP from Eneco (2023) is €5500. Prices were expected to remain stable in the future (Mik Bosman, Senior Product Manager). Due to the fact that reused HPs could potentially be sold at a lower price point (€4000) compared to refurbished HPs (€4750), and upcycled HPs are seen by Eneco as a business case and would be sold at a higher price point (€6250). An overview of the attributes and their levels is provided in Table 1.

***Table 1: Levels and Attributes** that were used in the design of the DCE.*

Attributes	levels (with description)
Circularity percentage	0% circular 12% circular 64% circular 90% circular
COP	4,5 5,25 6,0
Warranty	0 years 2 years 5 years
Investment costs	€4000 €4750 €5500 €6250

4.2.3 Properties of Experimental Design

The goal of a choice experiment is to minimize the number of choice sets presented to respondents while still capturing meaningful data. Instead of displaying thousands of combinations, typically fewer than 30 sets can be shown. Findings from Bech et al. (2011) suggest that respondents effectively handle multiple choice sets, specifically around 17, without significantly affecting response variability or perceived difficulty in making choices. Because of this, in total 18 choice sets were used in the experiment.

Within the experiment, the following design properties were incorporated, such as level balance, minimum overlap, and d-optimal design (Ryan et al., 2012). To ensure level balance, which entails equal occurrences of each level, the appearances of the levels were counted. In appendix A, it is shown that level balance was met. The principle of minimum overlap suggests that attributes within each choice set should rarely share the same levels, which was also the case in this choice design. Finally, a d-optimal design is chosen over an orthogonal design. The property orthogonality is met when there is no correlation between different levels or attributes in a choice design. It ensures that changes to one level do not interact with changes made for other levels. Thus, making it possible to isolate and measure the impact of each individual level on the response variable without interference from other attributes or levels (Rose et al., 2008). Montgomery (2017) states that the number of choice options needed for an orthogonal design could be found by the following formula:

Number of choice sets = n^k
n = maximal amount of attributes
k = maximum amount of levels

= 4^4
= 256 choice sets

The filled-in formula shows that for this design to achieve orthogonality, 256 choice sets would be needed, making this design property unattainable. Orthogonal designs are designated for small-scale experiments with 2 or 3 levels (Dobney Research, 2012). This means that without altering the boundaries of the design, orthogonality cannot be met. In Appendix B, it can be seen that some levels correlate, meaning that the design is not orthogonal. However, orthogonality is not the only design criteria. Researchers frequently consider D-Optimal designs, whose focus is to find the best choice sets that minimizes the variability in estimated values (Dobney Research, 2012). Meaning that uncertainty in the estimating model values is at the lowest possible for the specific choice design. The d-optimal choice design was made in JMP. In Appendix B, it can be seen that the correlations between the levels are most of the time below 0,5, meaning that the design is D-optimal, a valid design property is obtained.

4.2.4 Survey Layout

The survey design, created in Qualtrics, consisted of five parts:

1. Introduction about the rationale of the questionnaire and privacy statements
2. Demographic questions
3. Explanation about HPs, the specific attributes and the relating levels. Together with an example question with explanation (see Figure 4)
4. All the choice sets
5. General questions and outro

The introduction aimed to mimic a real purchasing situation for an HP. Each option in the DCE presented two hypothetical HPs with varying attributes (Henser et al., 2005), and respondents chose among 18 options to increase the number of datasets. At the end, questions about the individual respondents' characteristics were asked, such as: sex, age, indicators of socioeconomic status, and living environment. These are used to gather information about customer segments for HPs with features relating to a circular HP.

Figure 4: Example of Choice Experiment *presented in the survey to respondents.*

4.2.5 Data Sampling and Analysis

The objective for the sampling strategy was to obtain a representative and random sample of potential future consumers of heat pumps. A random sample was obtained by giving away the survey at polling stations during the provincial elections on March 15, 2023. QR-codes for the survey were handed out during the day at multiple polling stations across the city of Utrecht, including the Central Station. The largest sampling group was obtained in collaboration with Panelclix. Panelclix provided the service of forming a 'panel' of individuals that have filled in a questionnaire for a small amount of money. Here, a stratified random sample of 175 respondents was obtained as they only included individuals with specific specifications of age (above 18 years old) and household type (house owners) into the questionnaire.

4.2.6 Quality of the Sample

To ensure that every respondent belongs to the population of potential future consumers, only homeowners were incorporated. The validity of the survey responses was verified by adding multiple filters to the data. Firstly, only fully completed surveys are added to the data set. Secondly, responses from speeders (that took less than 3 minutes) were deleted. As it is considered that respondents who completed the survey in less than 3 minutes were unreliable because they probably have clicked through the explanation or questions without reading or carefully choosing. Therefore, they are filtered out, ultimately increasing the validity of the results.

Ryan et al. (2012) emphasize the need for rationality and internal consistency checks; these are included in the form of controlling questions. According to Train and Sonnier (2005), controlling questions help to ensure the validity of the results by filtering out unreliable responses. Two controlling questions were added in the beginning (after choice question 2) and near the end (after choice question 13). The controlling question presented a choice set in which one option clearly dominated the other option. By including these in the survey it ensured committed engagement in the experiment. Thus, respondents who did not choose the obvious better alternative, were excluded. This resulted in a 15.4% reduction of the sampling group, because these individuals were not paying attention near the beginning and/or end of the survey. After the filters and data trimming, a respondent group of n=167 remained.

4.2.7 Operationalisation

The data from Qualtrics was transformed into three data tables in JMP. Information about the design structure of the DCE was generated by JMP in the first data table, which entailed the number of attributes, levels and choice sets specific to the experiment. The second data table obtained the choice answers of every respondent. The data input was either a 1 or a 2 (choice option 1 or choice option 2) answered 16 times for one respondent. In total, 2672[1] completed choice questions were located in this data table. The third and final data table is the subject data table. In this table, the data from the demographic and general questions per respondent was added.

The choice answers were analysed with a multinomial logit model (MNL) in JMP. The MNL has been the most widely used model for analysing discrete choice data. MNL computed separate continuous latent variables for each choice. These outcomes were interpreted by the model as evaluation scores specific to each respondent for each choice. The higher the score, the more likely a respondent is to select that particular alternative (Kropko, 2007). Ultimately, the MNL made it possible to estimate the relative importance of different attributes and how they influence the choices of individuals (Hensher et al., 2005).

[1] 16 choice questions per survey * 167 respondents = 2672 completed choice questions

After data collection of the DCE, it was possible to make a distinction between reuse, recycle, refurbish and upcycling, which enabled subsequently the assessment between the preferences for these strategies. In the data analysis the distinction between the circular strategies was made by combining assumptions about the quality and price of HPs with specific levels (presented in table 2). The assumptions were made in collaboration with a circular expert from Eneco. The combinations of levels enabled a comparison between types of circular HPs. Via the model in JMP it was possible to calculate the probability of choices associated with each type. Making it possible to assess which type has the highest probability of being chosen by the potential future consumers.

Table 2: Variety in Levels Related to Specific Circular Loops, *enabling a comparison between circular material strategies for heat pumps.*

Type of circular loop	Circularity percentage (CP)	COP	Investment costs (IC)	Warranty
Reused HPs	90%	4,5	€4000	0 years
Refurbished HPs	64%	4,5	€4750	2 years
Upcycled HPs	36%	5,25	€6250	5 years
Recycled HPs	90%	4,5	€5500	2 years
Regular HP (linear)	12%	4,5%	€5500	2 years

4.3 Case study

To enable the analysis of the other three pillars of Technological Feasibility, Economic Viability and Environmental Impact, empirical evidence from established actors were needed to investigate the drivers and barriers for a potential implementation of a CBM for heat pumps. Therefore, a case study was selected, with Eneco as the main actor, focussed on their supply chain. Eneco made it possible to contact, talk to, and conduct interviews with multiple supply chain actors. Ultimately, allowing for an in-depth analysis of the heat pump supply chain in the Netherlands, which aligns with the scope of this research. Moreover, the case study may serve as a benchmark for other utility companies, who may use the findings of this study as a comparison or base for their own assessment on whether a CBM could be a viable or for instance desirable organisational implementation for themselves.

4.3.1 Technological Feasibility and Economic Viability

The Technological Feasibility and Economic Viability of potentially integrating a CBM into Eneco’s supply chain was evaluated through interviews with Eneco's HP producers, employees of Eneco, and a recycling company called Refurn. The aim of the interviews was to explore the drivers and barriers for the implementation of a CBM, taking into account input from actors throughout the supply chain.

4.3.1.1 Interviews

Interviews have been conducted with three actors on the heat pump supply chain:

1. **Heat pump manufacturers**: Heat pumps used by Eneco's Dutch customers are supplied by four large-scale manufacturers: Alklima, Remeha, Vaillant, and Daikin. It was possible to make contact with the four manufacturers through a representative at Eneco. It was ensured that

the interviewees had expertise in the technological features of heat pumps and understood reusable, recyclable, or refurbishing strategies. Interviews were conducted with three out the four large HP-producers, namely Alklima and two who remained anonymous.

2. **Eneco:** Two employees with expertise in heat pumps, its supply chain and the current end-of-life activities for gas boilers and heat pumps, were interviewed.
3. **Recycling company:** The Director of Refurn, a recycling facility of gas boilers and electric boilers has been interviewed to elicit their potential technological expertise and cost and revenue structures.

All interviews enabled in-depth information to be secured about the technological feasibility and viability of implementing a CBM for HPs in the Netherlands.

4.3.1.2 Interview guides

For each group of supply chain actors different interview guides were formed. The questions were related to the factors that influenced the technological viability and economic viability, discussed in the theoretical framework. For the technological feasibility were those factors: Key Partners, Key Activities, Key Resources, and Take-back System; and for the technological viability were those factors the: Cost Structures, and Revenue Streams (Osterwalder and Pigneur, 2010; Lewandowski, 2016).

All three interview guides had a separate focus regarding the role and function the actor could play within a CBM. The interview guides were structured in the following ways:

1. **Heat pump producers** (see appendix D) were interviewed regarding the business of HPs, circular understanding and goals, aspects of feasibility of CBM, the economic viability.
2. The interview guide for **Eneco's employees** (see appendix E) addressed economic viability, the drivers and barriers for a Take-Back system, and comparative aspects with gas boilers.
3. The interview guide for **Refurn** (see appendix F) focused on the willingness for incorporating heat pumps in their material steams, their technological capabilities, and potential cost and revenue balance.

All interviews were semi-structured and were altered with regard to interviewee's expertise, keeping the generalizability of the results in mind.

4.3.1.3 Conducting Procedure and Operationalization

The interviews are, for the most part, performed face-to-face, and the interviewees were required to read and sign an informed consent form containing UU guidelines, information of the research' purpose and right to withdraw. Sanjari et al. (2014) state that, besides informed consent, other ethical considerations must be accounted for like confidentiality, meaning that personal information cannot be revealed without mutual agreement. Moreover, if anonymity is requested, names and brand information are removed from the research.

After the interviews were conducted, they were transcribed and coded. Generally, coding ensures validity and enabled advantages such as acquiring comprehensive insights, sorting the data which made it accessible and retrievable, and it ensured transparency (Linnberg & Korsgaard, 2019). The codes were linked to factors that influence the four pillars needed for a successful CBMC. This allows for the gathered data to give a broad understanding of the drivers and barriers for the implementation for a CBM.

4.3.2 Economic Viability

When real-world preference data is lacking, discrete choice experiments (DCEs) are used to monetary values associated with characteristics of non-marketed items (Ryan et al., 2012). According to Hanley et al. (2016) a DCE is generally chosen when the goal is to estimate the Willingness to Pay (WTP) for a specific good or service. Given that the economic viability of a CBM depends on whether the customers are willing to pay for the value proposition, the DCE aligns with the research objective. This analysis supported Eneco in making decisions regarding the offering of circular HPs.

4.3.3 Environmental Impact

The fourth and final research perspective focuses on the environmental impact of transitioning to a proposed CBM. Although, sustainability consists of three criteria, environmental, social and governance. The sustainability scope was focused solely on the environmental impact, because it was expected that the social and governance aspects would be elicited from the qualitative research phase, and because of the environmentally focussed sustainability goals of Eneco. Eneco makes an ambitious target of achieving "carbon neutrality" by 2035, and becoming a circular company by 2050 (Eneco, 2022).

The impact categories of climate change and resources depletion are two of the most influential in relation to the research scope, primarily due to the nature of heat pump technology, the expected impacts of a CBM from theory and the characteristics of Eneco's sustainability targets.

Heat pumps consist of a diverse and vast range of materials and metals (Sevindik et al., 2021), which are in a CBM to a lesser extent downcycled, thus a reduction of GHG emissions arises and fewer raw materials are needed for input of the production phase (Ellen MacArthur Foundation, 2013). Furthermore, Eneco's sustainability goal of "carbon neutrality" relates to the environmental impact category of climate change as its unit of measurement is in kg CO_2 (Eneco, 2023). Their goal of becoming a circular company relates to their material use and could be operationalised with the environmental impact category of resource depletion.

4.3.3.1 Desk Research on LCAs

The fourth pillar of the Environmental Impact in the potential integration of a CBM into Eneco's supply chain was assessed through desk research. This research aimed to provide a precise estimation of the significant environmental impacts associated with climate change and resource depletion.

The expected changes regarding these two impact categories evaluated with the use of existing Life Cycle Assessments (LCAs). An LCA is a recognized method used to assess the environmental impacts of a product or system over its entire life cycle (ISO, 2006). The following section will provide an elaboration on the selection criteria for the selected LCAs and what specific data was extracted from these LCAs.

4.3.3.2 Screening criteria of LCAs

Previously conducted LCAs were selected on the basis of predefined criteria and which aim to assess the environmental impact of a hybrid heat pump. The criteria were set in order to establish a framework for the identification of LCAs of relevance for the analysis. The criteria presented in detail in Table 3 cover aspects related to: (1) scope of the study; (2) data quality and representativeness; (3) impact assessment metric.

Table 3: The criteria considered for the screening process of existing LCAs.

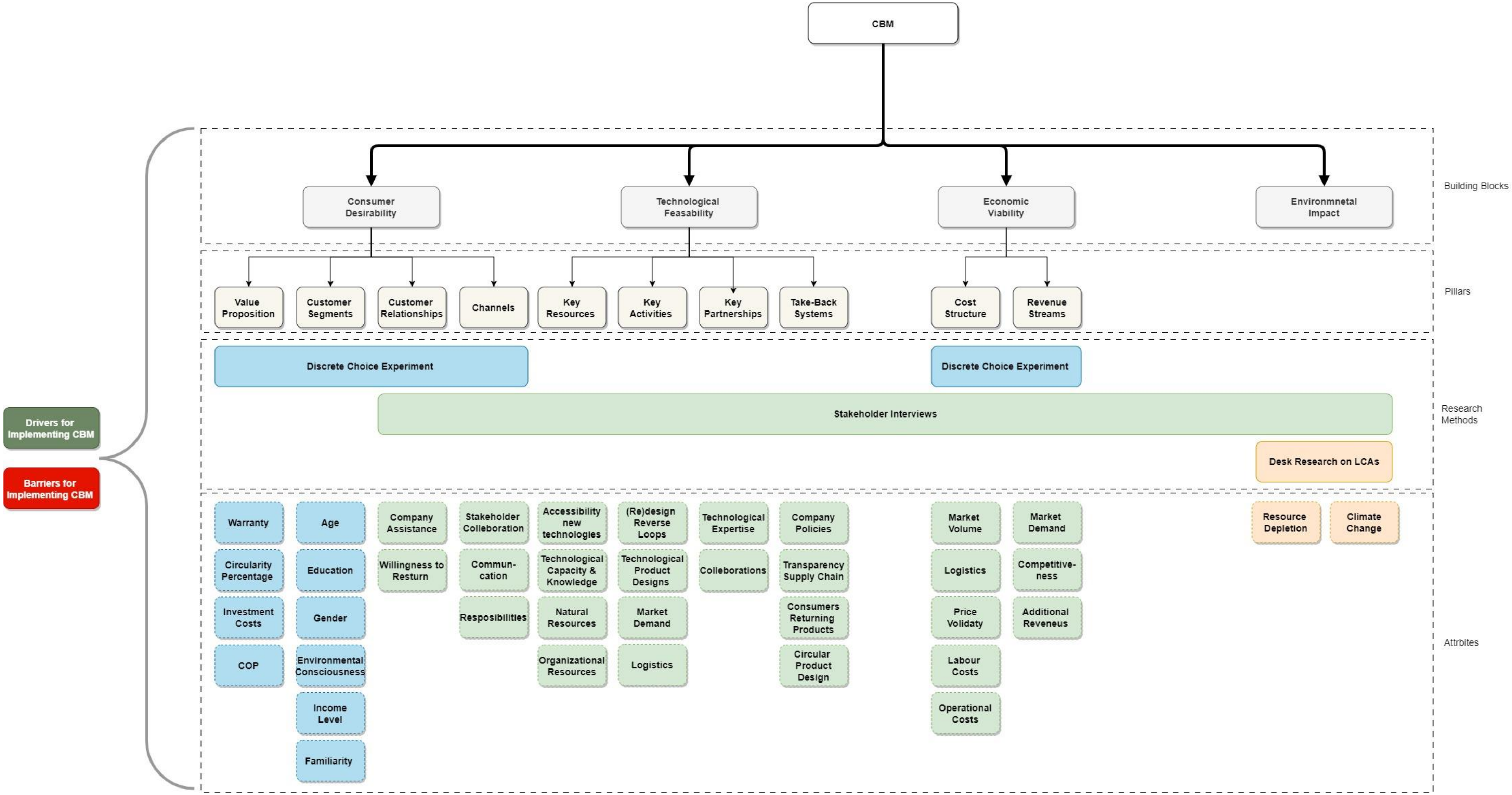
	Characteristics	Inclusion criteria
1. Scope of the study	Type of study (e.g. consequential or attributional LCA, standards, etc.)	Key assumptions of the study fulfilling ISO 14040 standards
	Product analysed	Air sourced & Hybrid heat pump
	System boundaries	End of Life phase/ disposal phase
	Assumptions and Functional unit	• Coherent scope definition for the analysis • Correct assumptions on recycling rates of materials and refrigerants
2. Data quality and representativeness	time of publication	Last 5 years
3. Impact assessment metric	Resource Depletion	In some way or from: • ADP-e (Abiotic Depletion Potential of Elements) • MDP (Metal Depletion Potential) • Kg Fe(-eq)
	Climate change	In some way or form: • Carbon footprint/ impact • GWP (Global Warming Potential) • GHG emissions • Kg CO_2-eq

4.3.3.3 Analysis of selected studies

Selected LCAs that passed the screening were analysed and used to evaluate the impact made if Eneco would implements a CBM. The current recycling percentage of materials for HPs are compared with the expected recycling/ refurbishing percentages extracted from the interview with the recycling company Refurn. With this expected impact in the disposal phase, basic calculations are made using the obtained data from the LCAs. For the specific outcomes of the interview, the data extracted from the LCA and the outcomes of the calculations, are elaborated on in Section 5.4. On the next page, a comprehensive view of the analytical approach depicts the four pillars, their building blocks, and the methods used to measure the attributes specific to this research.

The next chapter will discuss the results. The chapter has the similar structure as the four pillars of CBM with their embedded building blocks (i.e. general categories), meaning that it will start with the consumer desirability; encompassing the results from the DCE and is supplemented with the interview results when applicable. Following with the technological feasibility and economic viability; encompassing the key findings of the interviews and finally the environmental impact; encompassing the estimated impacts on Climate change and Resource Depletion.

Figure 5: Operational Model of Research Approach illustrating complexity in the methods and their connections to the building blocks and attributes.



5. Results

5.1 Consumer Desirability

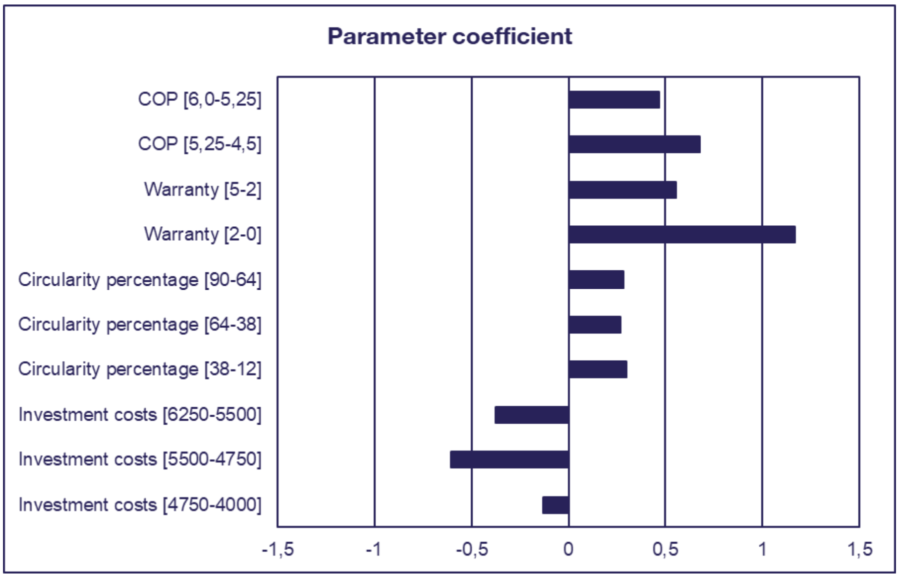
A. Value Proposition

All four attributes significantly affect a respondent's choice for an HP. Each attribute is significant with p-value <.0001 (see Table 4). This means that all attributes are relevant and influence the respondents in their decision-making between HPs. However, it is impossible to determine which attribute is the most influential using only this model. This will be analysed for the levels of the attributes in the following section.

Table 4: Main Effects of Attributes

Attribute	Logworth (-log10(p-value)	P-value
Warranty	133,090	0,00000
Investment costs	58,601	0,00000
COP	55,277	0,00000
Circularity percentage	21,375	0,00000

***Figure 6: Parameter Coefficient** show the estimated main effects for the attribute levels.*



The Parameter estimates in Figure 6 show the estimated main effects (Estimate) for the different levels of the attributes. This logistic regression model threated the attributes as ordinal, which made it possible to check the preferences between the levels.

When analysing the underlaying value placed on the specific attribute levels of HPs, it stands out that investment costs negatively influence the preference for an HP. For example, the increase from €4750 to €5500 results in the respondents being approximately 50% less inclined to purchase an HP[2]. The other increases in investment costs are still negative, but less severe.[3] In contrast, circularity percentage, warranty, and COP levels positively influence HP preference. Warranty has the largest influence on choices made, especially for the transition from 0 to 2 years[4]. COP has a similar, but less severe, effect as the warranty. A noticeable finding is that a 36% increase in circularity percentage causes a 27% rise in preference. This finding is surprising because this is the only attribute where a similar jump in level (increase of 36%) causes a similar and stable response in decision making. This means that homeowners do not interpret the circularity as a negative factor that could reduce the HP' quality, but as a positive factor that improves the sustainability of the HP. For the detailed understanding of how the attribute levels influence the choices made for HPs, see Figure 6.

5.1.1 Comparisons on the Short Term

These differences between levels by themselves, lack a perspective about the desirability of a CBM. It became interesting when comparisons are made between HPs with different levels. These comparisons enabled analysis of the conditions under which a circular HP would be more desirable compared to a regular HP. In the short-term scenario, the regular HP had the same levels as the average HP that Eneco currently sells.

The comparisons indicate that consumers desire circular HPs (which incorporates refurbished and recycled materials) with a probability of 66% over a regular HP, which is an obvious finding. However, comparison 2 shows that if the new CBM has additional costs (and accounted for in the price), a circular HP would have a lower probability of being chosen. Notably, if a higher circularity means an absence of warranty, the regular HP has a much higher probability of being chosen (Comparison 3). Thus, it is not worthwhile to sacrifice the warranty in order to achieve a higher circularity percentage could.

Table 5: Comparison 1, Lower Price + Higher CP

	Circular HP	Regular HP
Investment costs	€4750	€5500
Circularity percentage	38%	12%
Warranty	2 years	2 years
COP	4,5	4,5
Probability	**0,66**	**0,34**

Table 6: Comparison 2, Higher Price + Higher CP

	Circular HP	Regular HP
Investment costs	€6250	€5500
Circularity percentage	38%	12%
Warranty	2 years	2 years
COP	4,5	4,5
Probability	**0,47**	**0,53**

[2] The negative relationship is a logical outcome because higher costs negatively impact preferences due to financial incentives.
[3] This is quite surprising for the increase from €4000 to €4750. One would expect this increase to have the highest negative impact on HP preferability, as this is the largest relative increase. A reason could be that the cost difference between €4750 and €5500 exceeds a certain threshold and becomes more noticeable within the context of the price range. This larger perceived difference could trigger a more pronounced response.
[4] In relation to real life, this could mean that customers have doubts about the quality of the product or find the high investment cost a risk, and therefore value a guarantee of quality.

Table 7: Comparison 3, Higher CP + no Warranty

	Circular HP	Regular HP
Investment costs	€5500	€5500
Circularity percentage	64%	12%
Warranty	0 years	2 years
COP	4,5	4,5
Probability	**0,36**	**0,64**

Table 8: Comparison 4, Higher CP + no Warranty

	Circular HP	Regular HP
Investment cost	€5500	€5500
Circularity percentage	90%	12%
Warranty	2 years	2 years
COP	4,5	5,25
Probability	**0,55**	**0,45**

5.1.2 Comparison on the Long Term

In the long term, a scenario could be possible where the CBM works and the producers use a substantial amount of refurbished/ reused components, causing a lower COP (mentioned by Alklima). As shown in comparison 4, the circular HP would still have a higher probability of being chosen, indicating that for most homeowners a large increase in circularity is more important than a small increase in COP. An important side note is that lower COP may lead to higher energy consumption and emissions, potentially offsetting the benefits of circularity. But if a home generates a renewable energy surplus, such as from solar panels, this trade-off could be mitigated, aligning with Alklima's view[5]

Thus, when comparisons are made between different levels of the HP, it became evident that the potential customers prefer an increase in the circularity percentage, but only if it does not lead to a decrease in other attributes. Only in the case that the circularity percentage drastically increases, the previous argument does not hold up, in some cases a drastic increase in circularity holds greater importance than a smaller decrease of another attribute (e.g. COP in comparison 4).

B. Customer segments

The customer segments can be extracted from the DCE and from the interviews, the first part will focus on the assessment of the DCE outcomes.

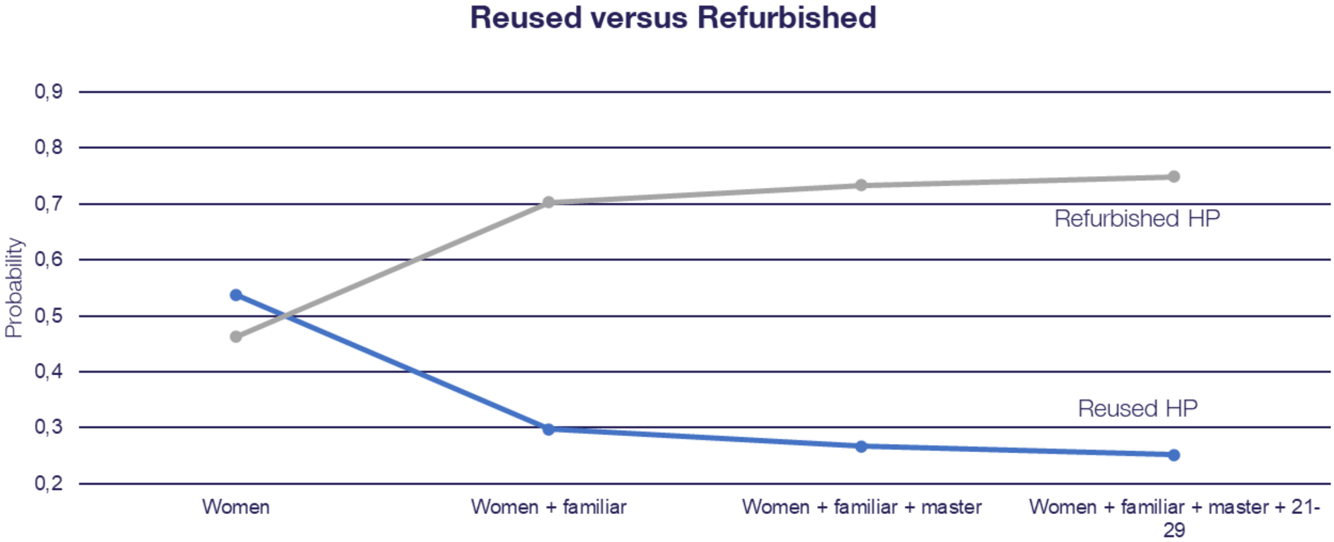
B.1 Business to consumers (B2C)

As the proposed value proposition is focused on circulating components, a comparison was made. This comparison involved an HP that has characteristics relating to a reused HP and one related to a refurbished HP. The goal was to elicit which strategy is more desirable among potential consumers. It is important to note that the characteristics were based on assumptions as real-life characteristics do not exist (yet) (see table 2).

In Figure 6, it becomes evident that the market segments for party refurbished HPs are young, have a high level of education and are familiar with HPs. This means that Eneco should target these groups as their customer segments for partly refurbished HPs.

[5] This argument is supported by Alklima but on a national scale, who mentioned “a refurbished marketplace could only be made possible as a second step if there is an energy surplus.”

Figure 7: Preference Between Reused and Refurbished Heat Pumps *demonstrating the properties of*

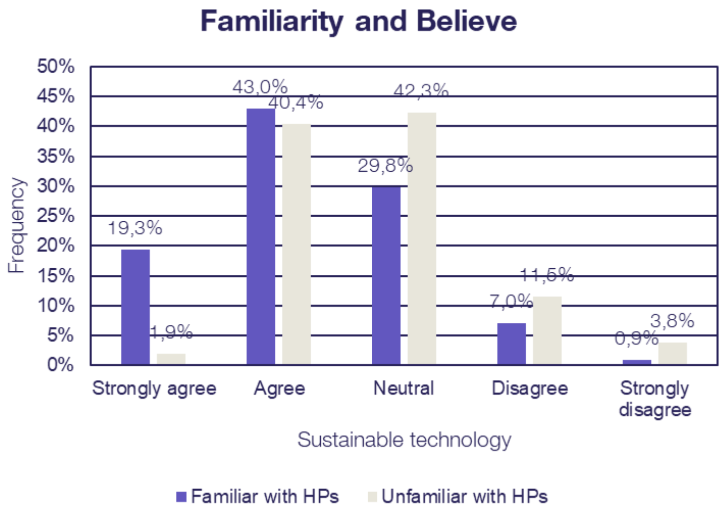


B.2 Characteristics of Sampling Group

All characteristics of respondents are shown in appendix G. What stands out is that 31.3% of respondents were unfamiliar with HPs. This was surprising, given that significant technological innovations have already been made (Producer 1), and regulations will obligate homeowners to replace their gas boiler alongside a hybrid heat pump in 2026 (Rijksoverheid, 2022). The knowledge gap became even larger with only 56.3% respondents believing that an HP can be considered a sustainable technology. This is a gap that needs to be bridged by large firms providing HPs. Especially, Eneco who want to become market leader in 2026 (Margit van Paridon, project lead heat assets). This can only be achieved if potential consumers have a better understanding of HPs.

People who are unfamiliar with HPs are largely neutral in their views about the sustainability of the HP (see Figure 8). However, still 40% of them do believe that the HP is a sustainable solution. For someone to truly believe that an HP is a sustainable solution, they need to be familiar with the technology, therefore the 40% is an unexpected and large proportion. However, the results from the DCE were still valid, because the explanation about the ‘Efficiency of energy combustion’ (or COP) at the beginning of the survey, makes it clear that an HP is energy-efficient and therefore sustainable. However, these results do impact the validity of the results, as explained in section 6.1 limitations.

Figure 8: Familiarity With Heat Pumps and Believe in Sustainable Technology



B.3 Business to business (B2B)

Additionally, from the assessment of the interviews, customer segments come forward. These are housing associations. Section K.2.1 (Drivers & Opportunities for LCA in combination with CE) explained why calculating the environmental impact of a more sustainable (i.e. circular) HP could be beneficial for housing associations in new construction projects.

C. Customer relationships

To enable this CBM, it is of importance to engage with the customer segments and convincing them of the added benefit of purchasing or leasing a partly circular HP. If a return stream of HPs is enabled via Refurn or another recycling company, they will be able to provide certificates. These certificates on the social aspects and the environmental footprint could be communicated when a customer purchases or leases a (partly) circular HP. This creates awareness among the customer segments.

Another perspective is that it became evident from the producers that customers are already asking for circularity, due to the positive influence of circularity percentage on consumer desirability in the DCE. Compiling with these customer demands could enhance Eneco's customer relationships in general. Producers mentioned that "Circularity is very high on the agenda. If you look at the questions that we also get from the end user market, is that we and the market also need to change on it and that the need is there for circularity (producer 1)". All in all, could a CBM for HP comply with some customer demands and is a clear engagement strategy needed to convince the benefits to the customers.

D. Channels

It became evident when Eneco wants to make a circular transformation, customers will only believe in it if Eneco changes their communication accordingly. Some refinement in their current channels could have a smoothening effect in building engagement with customers. Additionally, channels that are currently used for other products, such as leasing structures for gas boilers, could also be implemented to enable a CBM in the HPs system.

A refinement of the current return stream could involve the installers to explain to the consumer that the HP will be collected by another party in a specific timeframe. Although, it is not expected that a financial incentive is needed to collect their discarded system (Vincent de Graaf, Refurn). Installers could explain the benefits of the process, potentially using certificates to demonstrate the environmental and social footprint.

<u>Key findings of Desirability</u>

Comparisons between HPs suggests that an HP with a higher circularity percentage is preferred. However, this preference only holds if the regular HP shares similar characteristics as a regular HP. A change in COP, warranty or investment cost are more important than a similar change in change in circularity percentage. Therefore, it can be stated that a (partly) circular HP is preferred if it has similar characteristics to a normal HP. However, in the case that a circular HP could be offered at a lower price, a decrease in warranty or COP would have less impact, leading to a higher preference for the circular HP compared to a regular HP. Hence, the business case for a circular HP will only be favourable under specific circumstances.

Specific customer segments arose for refurbished HPs. People with a higher education, younger age, and knowledgeable of HPs have a higher preference for a refurbished HP compared to a reused HP. If

Eneco wants to comply with these segments, it must prove that the circular HP could be offered with a similar warranty and energy efficiency, this must be validated by conducting extensive reliability tests.

In the case that the reliability test show that incorporating refurbished components causes a decrease in the performance or lifespan, Eneco could still be successful by implementing a Product-as-a-Service (PSS) model. Their leasing structures for gas boilers could be altered for HPs and their 'Stadswarmte'-projects, gives Eneco the control to incorporate refurbished HPs. Moreover, it was found that 50% of the respondents have no preference between owning or leasing the model (appendix G). Meaning that with the right incentives a PSS could be desired.

5.2 Technological Feasibility

E. Key Partnerships

In this section, all partnerships elicited from the interviews will be discussed in hierarchical order, the one with the most responsibility will be explained first. Figure 9 shows the potential and proposed end-of-life supply chain, where all the key partnerships are depicted.

Refurn is a company that sees the added value of discarded electrical products, not as waste but as products or raw materials to contribute to a CE. They are already refurbishing solar panels, inverters and gas boilers (Refurn B.V., n.d), and are willing and capable of expanding these services to HPs (Vincent de Graaf).

Currently, Refurn is processing a part of Eneco's used gas boilers. This EoL supply chain could also be applied to Eneco's HPs. In this structure, gas boilers are collected through door-to-door pickup which gives Refurn the advantage of maintaining product quality and enabling quick inventory management. They undergo a testing process to determine their potential for reuse at the product or component level, with components failing to meet standards sent through different internal or external material streams to be recycled. The emphasis in refurbishing and reusing components of gas boilers is on both young and old boilers, because both have high repurposing potential:

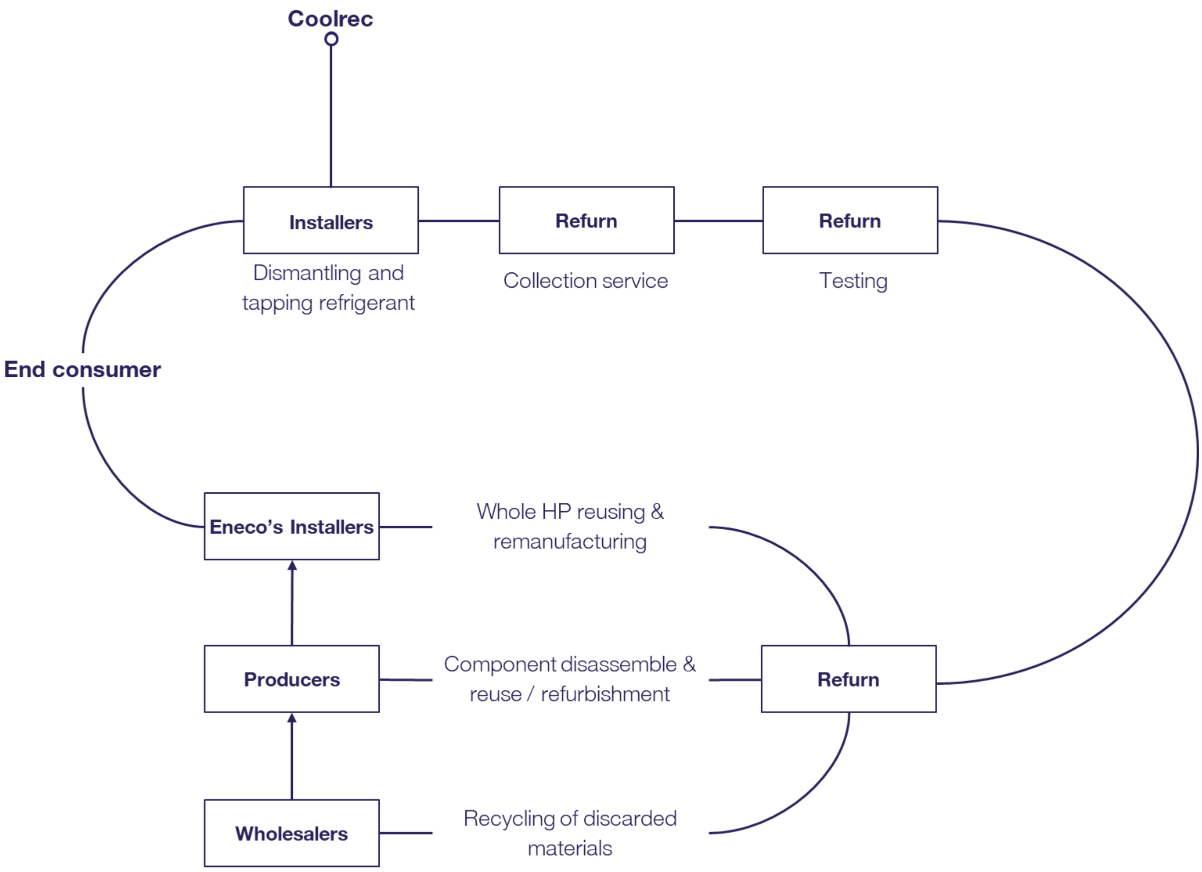
- Young boilers: because they contain a lot of usable or easy to remanufacture parts. Additionally, some components are even good enough for complete reuse.
- Old boilers: the components from EoL boilers could be utilized in maintenance to keep aging boilers running.

If it is feasible for gas boilers, and Refurn is determined to move to a similar structure for HPs, it can be stated that Refurn is the right key partner for a feasible structure for HPs. However, in this analysis, only the perspective of Refurn as a recycling company was incorporated. Although they are one of the few capable of offering such a certified EoL structure for gas boilers, perspectives from other entities like Stichting OPEN or refrigerator recyclers are needed to determine if Refurn is indeed the only feasible partner (see 6.1 Limitations).

Specialized recycling companies: Within this proposed EoL supply chain shown in Figure 9, it is evident that Refurn is not the only actor in the supply chain, some specific material streams need to be handled by specialized companies. **Coolrec** would be responsible for repurposing the refrigerants. Other partners are enlisted by Refurn who are specialized in printed circuit boards; fans; and heat exchangers (Vincent de Graaf).

Producers are another key partner. Together with installers they form the market demand for the revised components. Two of the three producers see a clear future in the use of refurbished components, and all, in some way, prefer to hand over the responsibility of the discarded products. Thus, a clear match between Refurn's capabilities and the producers was identified. However, Eneco needs to take action to get the CBM going.

***Figure 9: The Proposed End-of-Life Supply Chain** with the highest feasibility among Key Partners*



F. *Key Activities*

For the CBM to become a reality, Eneco has a clear connecting role to play. Metaphorically the role can be compared to the phrase: "What is first, the chicken or the egg?" Here, 'the chicken' is the 'market for distribution and sales,' and 'the egg' is the 'refurbished component.' Refurn will not start with refurbishing components if they do not know whether there is a clear market for them. Thus, Eneco should do research on which components the installers use for repair and which components the producers deem feasible in reincorporating into an existing or new production process.

In retrospect, this would have been a useful perspective if it was added to this thesis. However, before interviewing the producers, it was perceived as a potential possibility for them to directly receive the discarded HPs and extract the useful components themselves. Nonetheless, most producers do not desire to perform this activity by themselves, or simply do not have the capacity. Listing the market demand, therefore, reinforces Eneco's key role in the CBM.

Another necessary action is the clear administration of the Return stream. Michel states that for this system to work, the return stream needs to be documented. Michel proposes to organize the return system in the following manner:

"It's simple. If there is a work order and you are going to replace a pump (...), you know that a defective pump will come back. That defective pump needs to be registered before you can close the work order. That way, you have visibility of the return product. (...) it forces you to think about what exactly you will do with them."

If the return stream is structured in such a way, it enables a closer collaboration with Eneco's producers. For example, if multiple HPs of the same type fail prematurely, they could be sent back to the HP producer instead of Refurn. Producers could test the HPs, and potentially fix a production error, enabling longevity. Thus, creating a shared platform of the retrieved HPs could have a beneficial impact on circularity as it expands the lifecycle of the products.

Relating to the previous action, it is key to actively start sharing knowledge between the actors along the EoL supply chain. To enable a CBM, a connection between Eneco and producers needs to be established through actively sharing knowledge. For example, Eneco currently does not share the locations of the projects, while producer 1 is interested in this information.

G. Key Resources

As explained in section 3.3.2**,** Lewandowski (2016) aligns Key Resources with CE in two ways. Firstly, by implementation of circular sourcing, a method that involves obtaining materials from a closed material loop (Planing, 2015). This is the main focus of the proposed CBM, refurbishing components to be used in production or maintenance.

The second way is by immediate substitution of resources by changing to less harmful or more sustainable alternatives (El Haggar, 2010). It became clear that producers are, to some extent, engaged in this method. Take for example, Alklima, who is switching back to metal casing components to enhance recyclability and aims to minimize the use of primary resources, water, and increase the use of recycled materials.

However, some resources also challenge the CBM. Specific resources are not reusable, as producer 1 mentioned "Take for example copper, virgin copper exhibits superior quality compared to its reused counterpart. Nonetheless it could be used for the production of other products. The same goes for aluminium." Here again, it became evident that a clear vision needs to be created on which components are desired and feasible for reuse.

H. Take-Back Structure

All producers agreed, in one way or another, that the entire HP needs to be returned and transported to a single location where either material recycling or component remanufacturing can take place. It has been repeatedly highlighted that it is important for the refrigerant to "be taken back, cleaned and then can be reused" (producer 1). While the take-back structure should be a joint responsibility, Eneco has the primary responsibility, according to producer 1. The current stream of returned HP does not work (producer 2). This means that Eneco needs to re-design and implement a new return stream.

An important finding from Michel Leerlooijer and Rudolf Zwijnenberg (Appendix C) was the fact that currently customers are almost always willing to return their used products. They believe that a financial incentive is not necessary because customers "are happy to see the products go."

Key findings of Technological Feasibility

Employees from Eneco and the producers agree that responsibility for the End-of-Life (EoL) supply chain should be shared with a third party (i.e. recycling company). After analysing Michel Leerlooijer's and Rudolf Zijnenberg's interviews, it can be concluded that Refurn should be the one responsible for the EoL return stream of HPs. Refurn is able to refurbish components, recycle materials and only on rare occasions reuse a whole HP. This suggests that refurbished components can be sent back to the manufacturers for use in the production of partially refurbished HPs. In theory, the R-ladder framework by Ellen MacArthur Foundation (2016) makes a clear hierarchy between the environmental impact of refurbishment and recycling. This means that when components are possible to refurbish, they should not be recycled. However, the decision on which components should be refurbished or recycled should be made in collaboration with the producers. They state that components related to the refrigerant (such as the compressor, evaporator, and expansion vessel) as well as those related to noise production and energy efficiency are subject to constant innovation and regulatory changes. Consequently, these components could become obsolete after 10-15 years. However, these components can still be used in maintenance. Eneco should take on a leading role in the EoL supply chain, by determining the exact market demand of revised components from producers and installers. This makes it possible for Refurn to collect, extract and remanufacture the components, ultimately closing the material loop.

5.3 Economic Viability

I. Cost Structure

There were different perspectives on how the costs and revenues would compare to the current structure. Currently, the HPs are either taken to shredding companies or to scrapyards. Eneco's employees, as explained by Michel Leerlooijer, are convinced that a new circular structure will cost more than the current one. "The materials that go to the scrapyards bring Eneco a lot of money." However, Rudolf Zwijnenberg states that only Refurn is able to assess the costs and returns of the proposed structure. This is why a comparison is made with the current return structure of some of Eneco's gas boilers, which end up at Refurn. Vincent stated the following about this:

"With the revenues generated from these streams, we can afford to collect it, employ people, and even transfer a portion of the value extracted to Eneco. Some months we break even, sometimes we have leftover money, which becomes revenue for Eneco, and sometimes it costs money. But if you look at it overall, the entire collection is funded by the proceeds derived from the materials".

Thus, the expected revenues from processing materials and components of the HP are expected to at least offset the labour costs. Fortunately, the producers do not expect Eneco to be the only one who has to bear the cost of this CBM. Producer 1 emphasizes that managing the costs should be a joint effort. With the right agreements, Eneco and producers can collaborate, ultimately creating the opportunity to reduce costs as both parties share the responsibility. Producer 2 advocates a similar structure, believing that recycling costs should be shared among partners along the supply chain.

J. *Revenue Structure*

The most important question that belongs to the economic viability is “For what value are our customers really willing to pay?” (Strategyzer, 2022). This will be explained via the assessment of the DCE, the second part will elaborate on the expected additional economic revenues.

J.1 Willingness to Pay (WTP)

A popular metric used in analyses of choice models is WTP, refering to the maximum price a customer is willing to pay for specific product attributes, in comparison to the value they place on the baseline attributes of a regular HP (see comparison 1, section 5.1.1, page 33).

The new price, shown in Table 9, demonstrates the WTP for a specific attribute. In general, potential customers are willing to pay more for higher attribute levels, which is a logical result. However, there is a difference between attributes. For a higher level of circularity, respondents are willing to pay around an additional €500, while a reduction in warranty from 2 years to 0 leads to a decrease of €2200 in the amount they are willing to pay. This implies that if the CBM results in the incorporation of refurbished components into HPs, the potential customers are only willing to pay for it if there is no decrease in the warranty period of 2 years or higher. The same principle can be interpreted from the COP (see table 9).

Table 9: Willingness to Pay for Various Levels of Heat Pump Attributes, calculated in reference to the baseline levels of regular heat pumps.

Attribute	Level	Price Change	Std Error	New Price
Circularity percentage	38	**€ 508**	153	€ 6008
	64	**€ 1128**	173	€ 6628
	90	**€ 1638**	192	€ 7138
Warranty	0	**€ -2200**	176	€ 3278
	5	**€ 1069**	140	€ 6569
COP	5,25	**€ 1296**	137	€ 6796
	6,0	**€ 2170**	177	€ 7670

J.2 Revenue Structure from Qualitative Research

In this section a similar statement to Section I (Cost structure) can be retrieved. The Director of Refurn believes that the revenues from recycling the discarded materials will break even or be more substantial than the costs. “With the stream we collect, we try to cover the costs, and generally, we succeed (Vincent de Graaf, Director Refurn)." However, Eneco’s employees were still concerned that a recycling company could not compete with the prices that the scrapyard or shredding companies are able to offer. Yet, Refurn was able to debunk this concern. Vincent de Graaf made clear that in the current EoL stream, the HPs are gathered in a collection bin along with multiple different products. Often a mixed metal price is offered. Refurn is confident that, when given the chance to process the HPs collected from the consumers, they would be able to offer the same market price or even “pay out more" (Vincent de Graaf). However, this is only the case if the HPs are made with high-grade materials, which is, for the most part, still the case. This barrier is further discussed in K.1.1 Challenges & Barriers – General.

A diverse set of additional economic revenue streams can be linked to a new return stream in the proposed CBM:

- Manufacturing savings: A reduction in the need for manufacturing spare parts could lead to cost savings during the production phase (Vincent de Graaf).
- Social revenues: Refurn provides employment opportunities for people with a distance to the labour market. This can be perceived as a social return on investment (SROI), forming an indirect economic revenue stream via Corporate Social Responsibility (CSR) or in Dutch 'Maatschappelijk Verantwoord Ondernemen'(MVO).[6]
- Additional opportunities for revenues when a LCA is used for a circular HP, this is further elaborated on in section K.2.2 Opportunities & Drivers - LCA in Combination with CE.

Key Findings of (Economic) Viability

Evaluating the potential costs and revenues reveal different perspectives on how the costs and revenues compare to the current structure. While Eneco's employees initially believe that the CBM would be more expensive due to the high revenue that the materials currently yield at the shredding companies, Eneco acknowledges that only Refurn can assess the costs and returns accurately. Refurn believes they can offer a comparable or higher market price for the HPs compared to the current mixed metal price. They can finance collection, revision, and additional workforce through revenues from extracted materials. Eneco currently receives revenue from Refurn for the EoL stream of gas boilers, and a similar revenue stream can be expected for HPs (Vincent de Graaf). If it is possible to share the remaining revenues equally, a win-win scenario occurs.

Besides an economic revenue stream, the social, material and environmental returns must be considered as well. Most interviewees highlighted the environmental and social revenues that arise from the new return stream, including decreased metal depletion, CO_2 emissions, waste, and the employment of individuals with a distance to the labour market. Moreover, implementing corporate social responsibility (CSR or MVO) practices can attract more contracts and projects, leading to indirect economic revenue streams.

The most important question when assessing the economic viability is whether people are willing to pay for the proposed product. Via the DCE it can be stated that the potential consumers are willing to pay a significantly higher price for an HP with an increased circular percentage. Although there are variations in willingness to pay based on specific attributes, the consumers are willing to pay around €500 more for a circularity increase of 24%. Thus, if the employees of Eneco are correct and the new CBM proves more costly, the additional price consumers are willing to pay for a partly circular product could balance out these costs, and it could even potentially create a new revenue stream.

[6] MVO or CSR: means that a business considers the effects of their operations on people, the environment and society (EZK, 2022). As Vincent de Graaf stated "By implementing MVO, you get more contracts from municipalities, housing associations, government agencies or Rijkswaterstaat. Because MVO is increasingly being included in tenders." If Eneco can demonstrate their improved environmental and social impacts, they can retrieve more tenders and projects. Ultimately, forming an additional revenue stream.

5.4 Environmental Impact

This chapter will be structured in the following manner. First, some context from available academic literature on Life Cycle Assessments (LCAs) in relationship with HPs is discussed, along with Eneco's current end-of-life phase of HPs. This section is supplemented by the interview findings specific to the disposal of HPs or similar products. Following this, using the useful statements and numeric values from the literature, basic calculations are performed to measure the potential environmental impacts.

5.4.1 LCA and CE

LCAs have been applied to various technologies, including heating systems. The LCA from Naumann et al. (2022) prove that an HP is an environmentally friendly option for heating compared to traditional systems. However, HPs still have environmental impacts that need to be considered, including the impacts associated with manufacturing, use, and disposal of the product (Lin et al., 2021). In the end-of-life phase the landfilling of materials such as steel or copper is considered (Violante et al., 2022). Other incorporate a high recycling rate of refrigerant (90%) in combination with fluctuating recycling rates of metals and plastics (Lin et al., 2021). Given the variety of assumptions made in the disposal phase, the LCAs have diverse degrees of relevance to the Dutch HP sector. Selecting relevant LCAs within this context is crucial for accurate calculations related to material depletion and climate change (see section 4.3.3.2 Screening criteria of LCAs). It is important to note that, to the best of the researcher's knowledge, statistics on HP recycling in The Netherlands was not available. Thus, the determination of whether the assumptions made in an LCA are relevant is based on knowledge gathered from Eneco's current end-of-life stream, which may involve some uncertainty.

In Appendix G, two LCAs are discussed on why they do not fit within the screening criteria and what makes them unsuitable for accurate calculations. Before making calculations based on the transformation of the current BM to the CBM, it needs to be explained how the current BM is operated.

5.4.2 Current material stream & proposed material stream

Although a CBM has not currently been implemented for Eneco's HPs, the recycling rate cannot be assumed to be zero as the HPs are recycled through other waste streams. The average recycling rate of HPs in the Netherlands is difficult to determine due to the absence of a separate category in recycling databases, because HPs are categorized as refrigerators (Vincent de Graaf). Consequently, were the recycling rates of gas boilers used to make assumptions about the current recycling rate of HPs. Gas boilers are usually recycled by shredding companies (e.g. HKS, SIMS, Rewald) certified by WEEELABEX, meaning that they are legally obliged to reach a recycling rate of 85%. For gas boilers they reach even higher recycling rates of 90%-93% (Vincent de Graaf). The mixing of materials hinders achieving higher recycling rates.

In contrast, Refurn is able to recycle 97,43% of the gas boiler. This is between 4,43% / 7,43% higher than the current. Furthermore, they extract, reuse, and refurbish components, instead of shredding all the components, enabling utilization of components in repair and production. Due to the fact that the strategies of reusing and refurbishing are higher up the R-ladder, which save more resources, the improved recycling rate of 7,5% is taken (Figure 1; Ellen MacArthur Foundation, 2016).

The recycling rate of refrigerants was also needed to be derived. However, the recycling rate of refrigerants in HPs is non-transparent. Actors knowing possessing these numbers choose to have zero disclosure. Take producer 2 who mentioned "current numbers of recycle rates of refrigerant may not be shared with the general market."

During discussions with Vincent de Graaf the following headline was discussed “Alarm raised about recycling old central heating boilers: '95 percent ends up in the illegal circuit” stated by a chairman of Stichting Open. Vincent de Graaf (Refurn) does not agree with this statement, yet he states, “where there's smoke, there's fire." “Certainly a part of the heating systems ends up in the scrapyard as pocket money, certainly in the smaller companies.” This could result in the release of refrigerants into the atmosphere. However, the larger companies (e.g. Eneco, Veenstra) have this stream for the most part covered in their supply chain (Vincent de Graaf).

Although the return stream is currently not administered (Rudolf Zwijnenberg), this situation could potentially facilitate a supply chain in which installers opt not to send the refrigerant to a specialized recycling company. However, Vincent de Graaf explained that this non-transparency does not mean that the refrigerant is not properly dealt with, because installers are legally held responsible for what happens to the refrigerants. However, he stated that “the better the material flow to the proper processors, the more refrigerant can be extracted and regenerated or destroyed.” Thus the teir is potential for improvement in the recycling rates of refrigerants, an assumption was made that a 7.5% increase in recycling rate could be achieved, similar to the material recycling rate.

5.4.3 Environmental Impact of Climate Change

5.4.3.1 LCA from theory: Lin et al. (2021)

Lin et al. (2021) conducted a sensitivity analysis with different scenarios. One of them was used in the calculation of the environmental impact. The scenario relates to a change in the EoL structure, where 100% of the heating system is landfilled. From this scenario, Lin et al. (2021) stated that 7000 kg of CO_2-eq is additionally emitted (15.5% increase in total emissions). These numbers provided valuable information for the following calculation.

5.4.3.2 Climate Change: Calculation 1 from Theory

From the above elaborated LCA of Lin et al. (2021), it was mentioned that a 100% improvement of the recycling rate, saves 7000 kg CO_2-eq. This means that a 7,5% increase saves 518 kg CO_2 per HP. This could be compared to one person traveling around 2846 km by airplane on average[7] (CO2emissiefactoren.nl, 2022). The goal for Eneco is to be the market leader in hybrid heat pumps by 2026. That target is to produce 40.000 by 2026 (Margit van Paridon). 21,000 metric tonnes CO_2-eq[8] could be additionally saved from the expected sales from 2026 if Eneco implements the proposed CBM. This is equivalent to around 950.000 trees absorbing CO_2 annually[9] or proportional to 6.715 households going completely off the gas grid[10]. These comparisons show that implementing the proposed CBM has a substantial environmental impact.

5.4.4.3 LCA from practice: Vaillant

Vaillant was willing to share the LCA of the ‘AroTHERM Split VWL’ with the general market. Vaillant calculated the environmental benefit of properly disposing an HP after its lifetime. This “Reuse-Recovery-Recycling-potential” is calculated for multiple environmental impacts. For the GWP impact category it is shown that up to 16% of CO_2-eq could be saved this is around 553 kg CO_2-eq per HP in

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[7] 518 kg CO_2-eq (additional decrease in emission for one HP) / 0,18 (emission factor) = 2846 km by airplane by one person.

[8] 40.000 (HPs) *518 kg CO_2-eq (additional decrease in emission for one HP) = 21,000 metric tonnes CO_2 eq.

[9] Icka et al. (2016) state that an average adult tree absorbs approximately 22 kilograms of CO_2 per year. This means that the implementation of a CBM for HP for Eneco could be compared to almost a million trees a year.

[10] Average household uses 1,500 cubic meters per year (Essent, 2023) * 2,085 (emission factor of natural gas) = 3127,5 kg CO2-eq. 21.000.000 kg tonnes CO_2 eq. / 3127,5 kg CO2-eq per household = 6715 households

total. For the ADP-e impact category refers to the depletion of abiotic resources – elements, which means the elements extracted from the Earth (in kg Sb), which is around 32% and 352 kg Sb.

5.4.4.4 Climate Change: Calculation 2 from Practice

41,1 kg CO_2-eq can additionally be mitigated in the circular business model with Refurn[11]. This results in a total reduction of 1.644 metric tonnes CO_2-eq, this could be additionally saved in 2026 if Eneco implements the proposed CBM[12]. Compared to the equivalent of 526 households that completely go off the gas grid, this is still a substantial amount, but more than a factor lower than calculation 1. This difference will be addressed in the end of this chapter.

5.4.3.2 Resource Depletion: Calculation 1 from Theory

From Lin et al. (2021) sensitivity analysis it was extracted that 300 kg Fe-eq would be additionally saved from being depleted (increase of 7%). With these numbers a similar calculation can also be made for the Metal depletion (MD), resulting in an additional reduction of 22,2 kg Fe during production[13], enabling a reduction of 888 metric tonnes of material depletion annually in 2026[14].

5.4.4.5 Resource Depletion: Calculation 2 LCA from practice:

The environmental impacts are calculated with the total recycling rate is improved by 7,5%, resulting in a reduction of 26,2 kg Sb per HP[15]. This is in close similarity with the first calculation where an equivalent of 26,2 kg Fe would be additionally saved. An additional reduction of 26,2 kg Fe could be reduced for one HP[16], enabling a reduction of 1.048 metric tonnes of material depletion annually in 2026[17].

Key Findings of Environmental Impacts

The analysis revealed that current literature lacks exact numbers on recycling rates for materials and refrigerants. Although the current supply chain is non-transparent and often miscategorized, it has been effective in material recycling. Shredder companies are fast, economically viable and reasonably efficient in recycling the heating systems. However, the stream focuses on the lowest value retention for CE, namely recycling (Ellen MacArthur foundation, 2016).

Refurn's management of the stream would ensure that all refrigerant ends up at the appropriate disposal sites, thus facilitating a higher recycling rate. By focusing on refurbishing components, they could retain more material value and achieve recycling rates of 97.4%. This is estimated to lead to a reduction of 888 metric tonnes kg of materials and 21.000 metric tonnes of CO_2-eq annually, as calculated through Lin et al. (2021). When calculated with an LCA from practice, a reduction of 1.048 metric tonnes kg of materials and 1.644 metric tonnes of CO_2-eq annually is observed. Differences between the two LCAs cause uncertainties in the precise potential of CO_2 reduction. On the one hand, the academic LCA from Lin et al. (2021) uses assumptions that closely resemble the Dutch HP sector. However, the heat pump is not specifically sold by Eneco. On the other hand, does the LCA from Vaillant

[11] 553 kg CO_2-eq is the total recycling potential when it comes to the Ecotherm. 0,0743*553 kg CO_2-eq = 41,088 kg CO_2-eq can additionally be recycled
[12] 40.000 (HPs) *41,1 kg CO_2-eq (additional decrease in emission for one HP) = 1.644.000 kg CO_2 eq.
[13] If 100% is landfilled a total of 300 kg Fe eq will be depleted (Lin et al, 2021). If an improvement of 7,43% will be met, 0,074%*300 kg Fe eq = 22,2 kg Fe eq will be additionally saved.
[14] 40.000 (HPs) *22,2 kg Fe (additional decrease in emission for one HP) = 888.000 kg of materials annually.
[15] 0,0743*352 kg Sb= 26,1536 kg Sb (Sb generally stands for "substance," meaning that 26,15 kg of material can be additionally saved)
[16] If 100% is landfilled a total of 300 kg Fe eq will be depleted (Lin et al, 2021). If an improvement of 7,43% will be met, 0,074%*300 kg Fe eq = 22,2 kg Fe eq will be additionally saved.
[17] 40.000 (HPs) *26,2 kg Fe (additional decrease in emission for one HP) = 1.048.000 kg of materials annually.

not disclose all assumptions made, resulting in some uncertainty. However, the LCA can be seen as trustworthy as it complies with ISO 14025 and EN 15804; uses the Ecoinvent database; and because the acoTHERM is an HP which Eneco sells.

The precise potential carbon reduction is unclear, and future research is needed to investigate which LCA would be best suited. However, both calculation methods show that the implementation of the proposed CBM would lead to a significant reduction in climate change and resource depletion. This is believed to be a substantial amount, as it could be compared to other actions that Eneco could prioritize, such as encouraging 6700 or 500 households to completely go off the gas grid. Ultimately, this would increase the feasibility and viability for Eneco to implement the CBM.

K. Adoption Factors

The adoption factors are various organizational capabilities and external factors that support or resist the implementation of a CBM (Lewandowski, 2016). Thus, a division is made into the barriers and drivers to adopt the CBM.

K.1.1 Challenges & Barriers - General

A significant systemic barrier for CBM implementation is the financial incentives for installers to improperly dispose HPs. It is possible for them to bring the HPs to the scrapyards instead of WEEELABEX certified companies.[18] It is unknown to what extent this occurs. However, the fact that this has been indicated is a shocking result. Not only the HP producers but also employees of Eneco believe that the current return stream of gas boilers and HPs does not work properly. Within Eneco, a collective vision for a return stream is missing. Michel Leerlooijer mentioned: “We need to have a team within the Eneco organization that is responsible for the decision-making. People that ask questions and challenge the business case.” Thus, an internal working collective should be appointed.

Another factor that resists the transition to a CBM is the lack of information sharing between supply chain actors. Producers are not informed about the installation and return of HPs, making Eneco the one responsible for setting up the return stream. This lack of collaboration with installers makes Eneco blind to which components are broken down, making it impossible to know instantly whether a component could be repaired to enable a second lifecycle.

Most manufacturers lack the capacity to refurbish the EoL HPs themselves. This highlights the “need for finding the right partnership that can arrange multiple activities at once” (producer 1). Identifying specific market demands is essential, as not all materials, such as reused copper, hold the same value as their virgin counterparts. If this is communicated to Refurn, they could decide to focus on recycling of these specific components instead of reusing. Thus, it is crucial for Eneco to gather information on which components their installers and producers are willing to reincorporate.

There is a growing concern of suppliers using inferior materials in their products. This poses challenges for financing the material loop in the future due to an expected decrease in using high-grade materials. The increased reliance on plastics and lower-grade materials yields lower returns. Consequently, dismantling costs rise while returns diminish. Although this factor could resist the economic viability of the CBM, Eneco has control over this, by incorporating requirements on the quality standards of materials in the contractual agreements with HP producers.

[18] When turning in the HP to the scrapyard, the installers receive financial compensation and "they use it as Friday afternoon drinking money” (producer 1).

K.1.2 Challenges & Barriers - Refrigerant and Sound Regulation

Eneco's implementation of CBM faces significant barriers due to evolving refrigerant standards, component innovations, and noise regulations. Currently, the industry is moving towards the implementation of refrigerants with lower GWP[19] (Mik Bosman, employee Eneco). These refrigerant innovations are preventing the reuse and refurbishment of specific components. Some components are specifically designed for the refrigerant, such as the compressor, evaporator, and expander. However, it will become illegal by law to use these components with new and flammable refrigerants such as propane (Alklima).

Even basic components undergo continuous innovation and regulation, making older components obsolete. Energy efficiency is a factor which influences specific components reusability, (e.g. DC pumps[20]). When new components with a higher efficiency are becoming the standard, often the old are prohibited. Noise regulations have a similar effect of choosing recycling over reusing or refurbishing used components[21].

All in all, Eneco needs to take these challenges seriously. The first challenges were internal factors, which might be mitigated by setting up a team responsible for the CBM. The vision needs to have an embedded focus on administering the return stream and using knowledge sharing platforms between the supply chain actors. Additionally, the vision needs to be communicated to all employees within Eneco that are involved. If Eneco is willing to take action, it needs to connect the potential market demand to Refurn and mitigate risks of procuring HPs with low-grade materials. However, external factors relating to innovations and regulations are assessed as the largest barriers to the transformation towards this CBM. Eneco needs to determine whether there is sufficient demand for revised components.

K.2.1 Opportunities & Drivers - General

Implementing a CBM presents Eneco with several general drivers, based on industry trends and risk mitigation strategies. Producers already have some stimulating measures in place for circular practices, such as modular design, which facilitates repair and dismantling by preventing full replacements. Besides current actions, producers also make ambitious claims for enhancing their recyclability rate of their HPs[22]. As most HPs will be almost completely recyclable in the near future, it is an opportunity to tackle the lack of a sufficient end-of-life supply chain for reusing and refurbishing HPs.

There are some reputational risks that Eneco needs to watch out for. Mitigating these risks can be done by implementing the CBM, which makes these risks, in an indirect way, a driver for the CBM. Michel Leerlooijer's highlighted the risk of greenwashing. He noticed that Eneco requests multiple suppliers

[19] The HP market has moved from using R410 to R32 and currently aims to incorporate natural refrigerants such as butane (R600), propane (R290). Thus, the GWP is decreasing from R410 with a GWP of 2088 to R32 with a GWP of 675, with the aim to incorporate natural refrigerants such as butane (R600), propane (R290) with a GWP of 1 (Mohanraj et al., 2009).

[20] Alklima stated the example of their earlier used DC pumps (component of an HP). After using a DC pump for 15 years, upgrading to a new HP became necessary. Energy efficiency was a crucial factor, leading to the required use of newer EC pumps instead due to their higher energy efficiency. The use of outdated pumps from 15 years ago is now prohibited, resulting in environmental benefits as newer pumps consume significantly less power.

[21] Alklima explained, from a physics perspective, “larger HPs make more noise due to the larger surface of air passing through the HP.” If noise regulations become stricter and compliance with new noise standards is necessary, the casing of the HP would need to be melted down and replaced to ensure conformity with the regulations. This emphasizes the preference for recycling rather than reusing.

[22] Producer 2 says that 80% of the HP is recyclable and aims for a 90% circular HP. Mitsubishi’s HPs are 98% recyclable and they want to move towards an HP that is totally recyclable.

to meet requirements on sustainability and reusability. But in practice, Eneco never procures refurbished products. If Eneco's circular intentions are translated into actions via the proposed CBM, the risk of greenwashing diminishes.

Ilse van Andel warns of risks under the European Green Deal's reporting requirements, which could potentially reveal Eneco's lack of data on their refrigerants. If the input and output numbers of refrigerants were reported with a discrepancy, this could be harmful for Eneco's brand image.

In addition, the research analysis identified multiple additional environmental, social and economic benefits. Vincent de Graaf (Refurn) expects a significant reduction of waste, and a higher social return on investment, by providing employment to people with a distance to the labour market. Furthermore, the calculations from LCA elicit a significant reduction in CO_2 emissions and material depletion, which also forms a driver for the CBM. Taking the environmental responsibility of sold products is important during a time of global warming. Moreover, multiple regulations and governmental incentives are actively pushing for sustainable solutions in the energy and construction sector (see chapter Technological background).

K.2.2 Opportunities & Drivers - LCA in Combination with CE

This section explains how implementing an LCA incentivizes companies to make sustainable or circular product choices. Methods for evaluating the environmental performance of buildings incentivise the use of LCA calculations. The BREEAM (Building Research Establishment's Environmental Assessment Method) and MPG (MilieuPrestatie Gebouwen) are such methods. The BREEAM and MPG, are respectively an international standard applicable to various building types and a Netherlands-specific method focusing on residential buildings (BREEAM-NL, 2021; RVO, 2017). Although both have different assessment standards, a lower number is interpreted as indicating a more sustainable building (BREEAM-NL, 2021; RVO, 2017).

Producer 2 clearly states that if you have a circular HP and can incorporate the environmental benefit in the LCA calculation, that you will get financial benefits and benefits of performing the calculation up front. Through more detailed insights into the materials and their environmental impact, less points are awarded for the circular HP. Allowing for the installation of more HPs in a new building project compared to a regular HP. "This leads to increased sales, leaving more funds available to invest in LCAs." (producer 2).

Conducting the BREAAM or MPG assessments with LCAs of circular HPs can also facilitate acquiring the MIA and VAMIL, thereby "enabling tax advantages" (producer 2). The MIA (Milieu-investeringsaftrek) and VAMIL (Willekeurige afschrijving milieu-investeringen) are tax breaks for entrepreneurs who invest in environmentally friendly assets, including those in building and construction projects (Belastingdienst, 2023; EZK, 2017). The environmental assessments and tax breaks incentivize the producer to make sustainable choices and incorporate these in an LCA.

Overall, most barriers stem from internal issues, which might be resolved through knowledge sharing between Eneco's departments and supply chain actors. If actions are taken, and the specific market demand of components is researched. With these actions, it is possible that the drivers will outweigh the barriers.

6. Discussion

6.1 Limitations

While this thesis contributes valuable insights into the drivers and barriers of implementing a circular business model for heat pumps in the Dutch sector, it is important to acknowledge the studies limitations. Firstly, the study primarily employed a research approach focused on quantitative assessment for the consumer desirability. This approach facilitated the measurement and quantification of various features of a circular heat pump, as well as customer segments and revenue streams. However, qualitative insights could have provided a deeper understanding of the underlying reasoning behind consumer preferences. Although producers and employees of Eneco possessed knowledge of consumer desires, conducting interviews with consumers could have yielded more in-depth insights for the building blocks of the customer relationships and channels.

Secondly, the assessment of technological feasibility and economic viability of partnering with a third-party recycling company was exclusively focused on Refurn. This focus was affected by Eneco Employees' expectations, based on a previously established partnership for gas boilers and the presumed willingness to expand their capabilities to heat pumps. A comparison with other recycling companies, such as Stichting OPEN or refrigerator recyclers, would have provided a validation method to evaluate whether Refurn is the most feasible and viable option.

Another limitation relates to the discrete choice experiment discussed in section B.2, page 35. It is shown that 31.3% of respondents were unfamiliar with heat pumps, even after the technology was explained, still 10% disagreed with the statement that heat pumps are a sustainable technology. This can imply two things, either there are reasons to perceive a heat pump as "not sustainable", or it suggests a lack of information among respondents. This impacted the external validity, making the results less generalizable to 'potential future consumers'. However, through the data trimming process (see section 4.2.4) of filtering out individuals who incorrectly answered the controlling questions or hurried through the survey, an increase in external validity was achieved.

Lastly, the assessment of the economic viability is besides the perspective of the consumers focused on Refurn's perspective. They indicated that their revenues would offset the collection and refurbishment costs. However, it is essential to consider additional organizational costs associated with transforming Eneco's current business model into a circular business model, such as employing a new team and providing training to installers. Conducting an independent internal assessment by Eneco is recommended to comprehensively evaluate these aspects.

6.2 Reflection & Theoretical Implications

The analysis of the first pillar, Consumer Desirability, elicited specific consumer segments for a refurbished heat pump, namely educated young adults who were familiar with HPs. This key finding is consistent with the literature as it has been found that consumers' intention to buy electric vehicles is positively connected with their level of education, income, and knowledge of environmental protection (Hidrue et al., 2011).

Averina et al. (2022) found that partnerships significantly affect the technological feasibility of a CBM by creating the opportunity to utilise the specific technological expertise of others. This theoretical finding is highly consistent with the findings from the interviews, although the producers lacked the technological expertise, Refurn possessed the knowledge for recovering specific components and materials. There is a large opportunity for Eneco to utilise this expertise and close the material loop.

The analysis of Economic Viability found that consumers are willing to pay more for circularity in heat pump. While these findings appear to challenge Baxter et al. (2017), who suggest that consumers are sceptic regarding refurbished or recycled goods, further examination reveals a potential nuance. Consumers are indeed willing to pay more for circular heat pumps, but the willingness to pay is influenced by the presence of warranty and COP. In the cases where a circular heat pump had no warranty or a lower COP, the results are consistent with Baxter et al. (2017), as potential consumers show a higher preference for a regular heat pump.

The Environmental Impacts of adopting circular practices for heat pumps have been confirmed, showing a reduction in resource depletion and carbon emissions, which aligns with literature on the benefits of circular business models (Bocken et al., 2016; Ellen MacArthur Foundation, 2016). The discrepancies of the outcomes in both calculations for the potential CO_2 reduction were discussed in section 'Key Findings Environmental Impact' highlighting the need for further research on the precise measurement of climate change.

Many drivers and barriers elicited from interviews were similar from CBM literature. This study found that unclear responsibilities and lack of communication of a shared vision are barriers to implement Eneco's CBM, this is in line with Jabbour et al. (2020), who mentioned communication among departments to undermine the adoption of CBMs. Another example, design relating to refrigerants, noise reduction and energy efficiency were found to hinder the component reusability, which is in line with Adams et al. (2017) thoughts on the undermining quality of existing product design. Drivers, such as additional revenue streams (e.g. revenues from Refurn or the indirect revenue stream from CSR and tax breaks) aligns with Rizos & Bryhn (2022) believing that implementing circular economy in business operations is linked to additional opportunities for revenue streams. Since most adoption factors can be confirmed with existing theory, it may be the case that the drivers and barriers regarding feasibility, viability and environmental impact are not only context specific but they are potentially generalisable to other heat pump companies, ultimately forming a benchmark for utility companies.

A broader reflection questions whether it is worth setting up the operational activities of the CBM for a recycling rate increase from 90% to 97,5%, which could be perceived by some as low. However, this study confirms a high environmental impact in the near future and a business case projected to possess the potential for additional revenues.

Another broader reflection regards the focus of this study, which is on hybrid heat pumps, while a transition towards fully electric models is a necessary step. It is reasonable to assume that some findings could apply to all-electric heat pumps, although differences in investment costs and resource use could cause a discrepancy. Electric heat pumps consist of more materials, which offers a higher environmental impact when properly circulated. Higher investment costs for full-electric heat pumps could potentially increase the desirability for a more affordable circular heat pump.

6.3 Avenues for Future Research

Future research should investigate the underlying reasons of why consumers prefer certain features in heat pumps, especially the beliefs and attitudes relating to potential circular strategies (such as labels of 'refurbished' or 'reused'). While theory shows that the DCE captures the subjective beliefs and attitudes made during choices (Ajzen et al., 2018), future research could conduct interviews to capture the rationale behind the preferences toward circular heat pumps. Furthermore, it would be interesting to explore the transferability of the findings from Eneco's case study to other utility companies or organizations. If a circular business model could be implemented within the organizational structure and the specific supply chain of Eneco, it does not necessarily imply that a similar proposed end-of-life (Appendix I) structure would be feasible or viable for multiple utility companies in the heat pump sector.

7. Conclusion

This study attempts to answer the question: *What are the drivers and barriers for implementing a circular business model for heat pumps in the Netherlands?* By systematically exploring and evaluating the pillars needed for a successful implementation, the study provides an in-depth answer to the central question.

Consumer Desirability
It is observed that the general consumer does not have a preference between a refurbished or reused heat pump. However, people with a high-income level, high education, young age, and familiarity tend to prefer refurbished heat pumps over reused ones. It is expected that this segment is more inclined to invest in such solutions in the first place, since customers typically require a certain level of understanding before making a purchase decision. Thus, among Eneco's initial customer base, it can be concluded that heat pumps with characteristics resembling refurbished models are found to have the highest desirability. The overlap of Eneco's initial customer base for heat pumps, with the customer segments for a refurbished heat pump is a major driver for implementing the CBM, because this means that no drastic changes need to be made for the Customer Segments and (communication) Channels. Further findings reveal that the circularity percentage significantly influences decision-making, but if a higher increase in circular material uptake would negatively impact the attributes of COP and warranty, regular heat pumps will be preferred. Thus, circular heat pumps should maintain comparable COP and warranty standards, or the value of price decrease and circularity increase should outweigh any potential decrease in warranty or COP.

Technological Feasibility
The study initially assumed that designing a circular material loop via producers geographically near the Dutch market (e.g., Daikin in Belgium, Remeha in The Netherlands) would be feasible. However, the barrier became clear that they do not feel responsible for setting up this circular supply chain themselves. They either lack technological experience or the capacity to accept returned whole systems. Moreover, sending complete systems back to producers is not environmentally viable due to transport emissions. Therefore, producers and Eneco's supply chain managers, are ought to collaborate with a third party, responsible for repurposing and recycling the heat pumps. Eneco identified Refurn due to their technological know-how to establish closed-material streams. A main finding of this research is that the circular business model is technologically feasible with Refurn as key partner. Due to their established capabilities of reusing whole gas boilers, dismantling and subsequently repurposing components, and recycling materials, they showed a major opportunity to expand their capabilities to refurbish heat pumps.

Economic Viability
This research demonstrated that Refurn is prepared to expand their material streams to heat pumps which would create multiple revenue streams. It can be concluded that the economic viability of applying a circular business model to Eneco's heat pump supply chain appears promising, with potential revenues projected to outweigh costs. However, Eneco must also account for non-financial revenue streams as part of the added value. This includes environmental and social revenues that arise from the proposed return stream, such as decreased metal depletion, CO_2 emissions, waste, and the employment of individuals with a distance to the labour market. Moreover, implementing corporate social responsibility (CSR) practices could attract more projects, leading to indirect revenue streams. Additionally, the willingness of consumers to pay more for heat pumps with higher circularity indicates the possibility of an emerging new revenue stream while also attracting environmentally conscious customers.

Environmental Impact

A notable finding was that the proposed CBM could lead to significant estimated reduction in CO2 emissions and material depletion. Per heat pump, a reduction in at least 22,2 kg Fe in material depletion and 41,1 kg CO_2-eq would be achieved. This has a substantial impact if Eneco's aim of becoming a market leader succeeds. Whether the reduction of 888.000 kg of materials and 1.644.000 kg CO_2 annually justifies the required organisational transformation and efforts needs to be assessed by Eneco itself.

When these four research perspectives come together, the main research question can be answered. It can be concluded that when the elicited opportunities are seized and barriers lowered that the proposed circular business model (see Appendix I) could be successfully implemented for heat pumps in the Netherlands. The generalizable consumer desirability for refurbished heat pumps aligns with the case specific customer base of Eneco. Furthermore, a major opportunity is the precise alignment of the technological feasibility of Refurn's capability of restoring components with the desirability of the consumer segments for a refurbished heat pump. Although the viability still depends on the market demand among producers, the circular business model may still be seen as viable through the opportunities of restored components in repair or product-service systems. If the use of the revised components leads to a decrease in durability, consumers would not be willing to pay for an increase in circularity. Nonetheless, even in that case, the (partly) refurbished heat pumps could be employed in district heating projects of Eneco ('stadswarmte') or newly developed leasing structures. The substantial expected decreases in material depletion and CO_2 emissions, are a driver for the implementation of the circular business model. If the mitigated impacts could be incorporated into life cycle assessments of the refurbished heat pumps, additional revenue streams could be generated through tax breaks such as MIA or VAMIL (see section K.2.2). Sustainability assessments for construction, like BREEAM and MPG, could also contribute to financial benefits upfront. Also, the direct social benefit of providing employment opportunities for people distant from the labour market is noteworthy. The indirect benefits via corporate social responsibility further enhance the implementation of a circular business model. From the findings in section K.2.1, it can be concluded that the risks associated with a non-transparent supply chain, inappropriate disposal of heat pumps or refrigerants, and greenwashing, diminish. Ultimately, making the circular business model not only feasible, desirable, and viable, but also represents a future-proof development.

7.1 Policy Implications

This research offers valuable insights for policymakers and governments to initiate actions towards a circular economy, focusing on the opportunities and challanges Eneco encounters when adopting a circular business model. The wide range of barriers suggest the need for actions on all system levels by multiple societal actors. Looking from the macro perspective, the role of policymakers could be to lower barriers for reusing components, such as sound regulations. While limiting the sound production of heat pumps is beneficial, if it inhibits the reusability of some components, the question arises whether a reduction in sound is more significant than a potential environmental impact reduction. Currently, the economic viability of a circular business model is evaluated predominantly from a supply chain perspective. However, the Dutch government offers a 'verwijderingsbijdrage' or recycling fee for some products that need special care in the disposal phase such as cars (Ministerie van Algemene Zaken, 2023). Policymakers could give an impulse to the circulation of heat pumps by implementing a similar regulation, thereby increasing their economic viability.

7.2 Managerial Advice

Eneco's most important action is to identify the exact components their producers and installers are willing to receive back. Components related to refrigerants (compressor, evaporator, and expander), energy efficiency (e.g., pumps), and noise (e.g., casting) have a higher chance of becoming obsolete due to innovation and regulation. While the producers do see a future in reusing components, their willingness to receive some back makes this circular business model feasible. The extent of this feasibility, however, depends on the amount and types of components that they can reincorporate into new or existing production streams. Therefore, Eneco's crucial task is to investigate the specific market demand for each component. This information must be communicated to Refurn for them to start extracting these components.

To ensure an economically viable circular business model, the procurement department could incorporate specifications into contracts with producers. These specifications could relate to the recyclability rate or other circularity-related aspects of heat pump design, such as design for dismantling or modularity. Mitigating the use of low-grade materials or mixed materials in heat pumps is important, recycling them generates almost no revenue, thus disabling the revenue stream from recycling these materials.

Customers would prefer a circular heat pump provided certain conditions are met. Eneco or their producers should extensively test the lifetime, durability, and energy efficiency when setting up a circular business model. If the quality of the heat pump does not decrease, a business case will emerge.

For a successful implementation of the circular business model, internal barriers such as lack of information sharing, administration, and collective vision need to be addressed. These barriers could be effectively addressed by setting up a team within Eneco tasked with creating a shared vision. The vision needs to encompass managing the return stream and using knowledge sharing platforms among supply chain actors.

This research has provided fundamental insights into the complexity of a potential transformation to a circular business model in the Dutch heat pump sector. The research approach could form a benchmark to assess the implementation of circular practices for other companies selling sustainable technologies. It emphasizes the significant role of consumer preferences in supporting the proposed circular business model. Connecting the consumer preferences with the technological capabilities of the recycling company is a key enabling factor. Convincing its potential consumers of the substantial added sustainable impacts will facilitate a win-win situation. Eneco has the potential to facilitate this transformation by taking responsibility, connecting stakeholders via knowledge-sharing, understanding market demand, and promoting a collective vision. Doing so would facilitate a successful implementation of a circular business model, benefiting both society and future generations.

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Appendix A level balance

Levels of attributes	number of appearances	percentage of appearances
investment costs 4000	8	25%
investment costs 4750	8	25%
investment costs 5500	8	25%
investment costs 6250	8	25%
Circularity percentage 12%	8	25%
Circularity percentage 38%	8	25%
Circularity percentage 64%	8	25%
Circularity percentage 90%	8	25%
Warranty 0 years	11	34,4%
Warranty 2 years	11	34,4%
Warranty 5 years	10	30,3 %
COP 4,5	10	30,3 %
COP 5.25	11	34,4%
COP 6,0	11	34,4%

Appendix B Orthogonality

	IK4000	IK4750	IK5500	IK6250	CP12	CP38	CP64	CP90	Gar0	Gar2	Gar5	COP450	EEO525	EEO600
IK4000	1	-.306	-.333	-.361*	-.040	.000	-.131	.167	-.234	-.114	.342	.038	.000	-.040
IK4750	-.306	1	-.306	-.331	.005	.044	.086	-.131	-.031	.094	-.065	.094	-.098	.005
IK5500	-.333	-.306	1	-.361*	-.040	.000	.044	.000	.234	-.114	-.114	.038	.000	-.040
IK6250	-.361*	-.331	-.361*	1	.072	-.040	.005	-.040	.028	.133	-.160	-.160	.090	.072
CP12	-.040	.005	-.040	.072	1	-.361*	-.331	-.361*	.028	-.014	-.014	.133	-.054	-.082
CP38	.000	.044	.000	-.040	-.361*	1	-.306	-.333	-.078	.038	.038	.038	-.149	.120
CP64	-.131	.086	.044	.005	-.331	-.306	1	-.306	-.031	.094	-.065	-.065	.215	-.163
CP90	.167	-.131	.000	-.040	-.361*	-.333	-.306	1	.078	-.114	.038	-.114	.000	.120
Gar0	-.234	-.031	.234	.028	.028	-.078	-.031	.078	1	-.488**	-.488**	.080	.035	-.122
Gar2	-.114	.094	-.114	.133	-.014	.038	.094	-.114	-.488**	1	-.524**	-.108	-.017	.133
Gar5	.342	-.065	-.114	-.160	-.014	.038	-.065	.038	-.488**	-.524**	1	.030	-.017	-.014
EEO450	.038	.094	.038	-.160	.133	.038	-.065	-.114	.080	-.108	.030	1	-.561**	-.453**
EEO525	.000	-.098	.000	.090	-.054	-.149	.215	.000	.035	-.017	-.017	-.561**	1	-.485**
EEO600	-.040	.005	-.040	.072	-.082	.120	-.163	.120	-.122	.133	-.014	-.453**	-.485**	1

Appendix C Interviewees & Preliminary conversations

<u>Interviewees:</u>

Vincent de Graaf — *Director,* Refurn**:** Recycling facility of gas boilers and electric boilers
Michel Leerlooijer — *Senior Buyer Field Operations + Heat,* Eneco
Rudolf Zwijnenberg — *Interim Manager Supply Chain,* Eneco
Producer 1 — *Anonymous*
Producer 2 — *Anonymous*
Erwin Tuijtek — *Deputy Director,* Alklima, exclusive distributor of Mitsubishi Electric.

<u>Preliminary conversations:</u>

Marjon Blijleven — *Senior Procurement Manager Professional Services,* Eneco
Mik Bosman — *Senior Procurement Manager Heat Pumps,* Eneco
Margit van Paridon — *Project Lead Heat Assets*
Ilse van Andel — *Sustainability Development Officer*

Appendix D Interview guide Eneco

Take-back system

1) How does Eneco currently handle the end-of-life phase of their products?
   Follow-up: how is the take-back structure for Central heating systems structured right now?
2) What happens to the collected products once they are collected? Are they refurbished, recycled, or repurposed in any way?
3) In your opinion, what needs to change to improve the current take back structure?
4) What are the main reasons or drivers for implementing a take-back structure for Eneco's heat pumps?
   Prompt: regulatory requirements/ customer demands/ strategic advantages associated
   Follow-up: how would this be needed to communicate to the end-users?

5) Are there any challenges Eneco faces in implementing and managing the take-back structure of the supply chain? If yes, what are they, and how do you address them?
6) Can you describe the criteria or conditions under which customers or users would be willing to return products for recycling or refurbishment?
   Prompt: price / financial incentive
   Damier siminovitsh

7) Do you have any partnerships or collaborations with external entities (e.g., recycling facilities, refurbishment centers) to support your take-back operations? If yes, how do you ensure the effectiveness of these partnerships?
8) What could be the potential costs or investments do you foresee and how do they compare to the benefits from the circulairity of the HPs
   Prompt: how does this work for central heating boilers

Adoption Factors

9) Are there internal or external factors relating to organisational capabilities of the company that would affect (positively or negatively) the transformation towards a CBM for HPs?

Prompt internal:

- corporate culture
- Expertise
- transitional processes
- team motivation

Prompt external:

- Economic issues or pushes
- Technological issues or pushes
- political issues or pushes
- sociocultural issues or pushes

Appendix E Interview guide HP-producers

Technological Feasibility (Key partnerships, Key activities, Key resources, Value proposition)

Value proposition

1) How does [organization] view the business of heat pumps?
2) What is [organization] competitive advantage?
3) Could you provide your definition of circularity?
4) How important is circularity for your organization now and where is it on the agenda?

Follow up: What are your company's goals in relationship with circularity of HPs?

5) What could be the challenges for implementing a circular loop into the HPs?

Prompt:

- Refurbished
- Upcycled
- recycled material use

6) What could be the opportunities for implementing a circular loop the HP?

Prompt:

- Refurbished
- Upcycled
- recycled material use

7) Does anything need to change in the HP's design to improve the circularity at the end-of-life?

8) Prompt: to enable upgradability / refurbishment?
9) Would it be possible to make an HP (partly or fully) modular?
10) Is it technological feasible to monitor the total use per HP per household (to enable PSS)?

Key Partnerships

11) Given the goal of creating a circular economy, what changes might be needed for key partnerships with organizations in the HP value chain?

- Follow up: which key activities do these partners need to perform?

Key Activities

12) What key activities are needed to create a circular Heat pump?

Prompt:

- Distribution channels
- Customer relationships
- Revenue streams

Key resources

13) What key resources are needed to create a circular Heat pump?

Follow-up:

- Distribution Channels
- Revenue Streams

Prompt:

- physical, intellectual, human and financial resources
- Materials that allow for reusing, refurbishing, upcycling or recycling
- less raw material or energy/ toxic materials

14) Which components are first to reach their end-of-life? And which are most of the times still in workable condition?
15) Are currently or in the near future using any better performing materials ..?

Prompt: refrigerant (GWP)

Economic Viability (Cost structure & Revenue Streams)

Costs structure + Revenue structure

1) What would be the most important costs inherent to a circular structure for your HPs?

Prompt:

- Key resources
- Key activities

2) Do you believe that a circular HP will be **cheaper** than a new HP?

Prompt: approximately how much cheaper?

Prompt: upcycling vs refurbishing vs recycling

3) From a financial perspective would it be possible to use only recycled materials for an HP?
4) Could you sent me a example or actual material passport of one of your hybrid heat pumps for me to calculate the environmental benefit?

Extra questions if there is enough time (DCE)

Warranty

1) Would it be possible to give a circular HP warranty?

COP

2) Do you think that a circular HP would have a lower COP than a normal HP?

Prompt:

- Refurbished
- Upcycled
- recycled material use

Only if knowledge is present: Desirability + material passport's

5) What strategies can be employed to increase customer engagement in the design and adoption of circular heat pumps?
6) What customer needs would be satisfied by a circular HP?

Appendix F Interview guide Refurn

Take-back system

1) How do you handle the end-of-life phase of discarded products?

Follow-up: how is the take-back structure for Central heating systems structured right now?

2) What happens to the collected products once they are collected? Are they refurbished, recycled, or repurposed in any way?
3) In your opinion, what needs to change to improve the current take back structure?
4) What are the main drivers and challenges when implementing a take-back structure for Eneco's heat pumps?
5) What measures do you have in place to ensure that all collected materials are properly sorted, processed, and recycled?
6) Would you be willing to expand your recycling processes to incorporate Eneco's HPs?

7) How do you ensure the proper handling and disposal of hazardous or toxic materials that are part of the end-of-life products?

8) Would additional partnerships or collaborations with external entities be needed (local municipalities or waste management companies) to support your take-back operations? If yes, how do you ensure the effectiveness of these partnerships?
9) What could be the potential costs or investments do you foresee and how do they compare to the benefits from the circulairity of the HPs

Prompt: how does this work for central heating boilers
Prompt: in relation to the scrapyard

10) Do you have multiple collection points or only in Apeldoorn?

Expected Environmental benefit

11) What is the percentage of refrigerants that is currently recycled in the scrapyard?
12) What is the percentage of refrigerants that you are able to recycle in your process?
13) What is the percentage of materials/ metals that the scrapyard recycles?
14) What is the percentage of materials/ metals that you would be able to recycle?
15) What is the recycling rate achieved by your process for different types of materials? How does this compare to the recycling rate of scrapyards?
16) Do you track (and report) on the environmental metrics of your recycling process
17) Can you data that demonstrate the environmental benefits achieved through your recycling process?

Adoption Factors

18) Are there internal or external factors relating to organisational capabilities of the company that would affect (positively or negatively) the transformation towards a CBM for HPs?

Prompt internal:
- corporate culture
- Expertise
- transitional processes
- team motivation

Prompt external:
- Economic issues or pushes
- Technological issues or pushes
- political issues or pushes
- sociocultural issues or pushes

Appendix G: Characteristics of respondents

Table Gender

Men	Women
89	78
53,3%	46,7%

Table Age

18-20	21-29	30-39	40-49	50-59	60-69	70-older
2	8	45	27	41	32	12
1.2%	4.8%	26.9%	16.2%	24.6%	19.2%	7.2%

Table Gross monthly income

0-500	500-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-7500	7500-1000	>10000
5	5	25	30	43	28	21	4	6
3.0%	3.0%	15.0%	18.0%	25.7%	16.8%	12.6%	2.4%	3.6%

Table: Level of education

Bachelor (HBO / WO)	Basisonderwijs	Doctor, PhD	HAVO, VWO, MBO2-4	Master (HBO / WO)	VMBO, HAVO / VWO onderbouw, MBO1
42	2	4	59	39	20
25.3%	1,2%	2,4%	35.5%	23.5%	12.0%

Table type of house

Appartement/ flat	Eengezinswoning in rij	Ouderen/senioren woning	Twee onder één kap	Vrijstaande woning
17	84	1	30	35
10.2%	50,3%	0,6%	18.0%	21.0%

Table Living environment

Platteland	Stad
58	107
35.2%	64.8%

Table Familiar with HPs

Yes	No
114	54
68.8%	31.3%

Another important characteristic was assessed by the question: *To what extent do you think it is important to own the heat pump?* Although the majority (50.6%) preferred to be the owner of a heat pump and a small portion of respondents indicated a preference to lease or rent a HP. A substantial proportion had no preference, meaning that with the right incentives they might be willing to rent or lease as well. This makes it ultimately easier for a company such as Eneco to implement a circular product-as-a-service (PSS) business model.

Table Property Management

I want to own the HP	No preference	I want to lease / rent the HP
84	62	20
50.6%	37.3%	12.0%

Table Willing to buy HP in near future

Yes	No
89	78
53.3%	46.7%

Table Believe in climate change

Strongly agree	Agree	Neutral	Disagree	Strongly disagree
63	66	30	7	1
37.3%	39.5%	18.0%	4.2%	0.6%

Table believe in HP as a sustainable technology

Strongly agree	Agree	Neutral	Disagree	Strongly disagree
23	71	56	14	3
13.8%	42.5%	33.5%	8.4%	1.8%

Appendix H: two LCAs who did not meet the screening criteria after further evaluation

Johnson (2011) conducted an LCA on ASHPs, incorporating the impact of refrigerants. He concluded that the manufacturing and disposal phase accounts for ± 23% of the carbon emissions, which includes the production and disposal of the HP's hardware and the production of refrigerants (See Figure 10: total carbon impact). Johnson (2011) states that the environmental impact of the production and disposal of an HP's hardware is minimal, as the equipment (metal and plastic) accounts for 2-4% of the whole footprint. However, it is assumed that 100% of the metals are recycled and the plastic is sent to municipal waste management. The lack of real-life recycling data raises questions about the validity of this optimistic assumption.

Furthermore, the manufacturing and emitting of refrigerant (R-410) contribute to an additional 20% of carbon emissions. "The end-of-life venting was estimated at 55% of the rated charge, i.e. 45% is recovered for reuse or incineration (Johnson, 2011, p.1374)." This suggests that less than 45% of the refrigerant is reused. However, according to Vincent de Graaf, director of Refurn, the majority of refrigerants in The Netherlands are processed for recycling or incineration. This means that the assumption of less than 45% is being reused is perceived as inappropriate.

The total carbon relating to the life-cycle of one HP is not provided, preventing the possibility to make an assessment of the environmental impact of setting up the CBM using Johnson's LCA (2011). Additionally, the outdated nature of the LCA (more than 10 years old) and the perceived inaccurate assumptions of the recycling rates, creates uncertainty in the outcomes. Consequently, a second LCA from Sevindik et al, (2021) is evaluated.

Figure 10: Total Carbon Impact

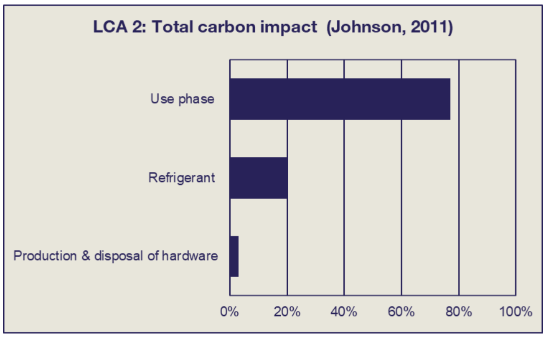
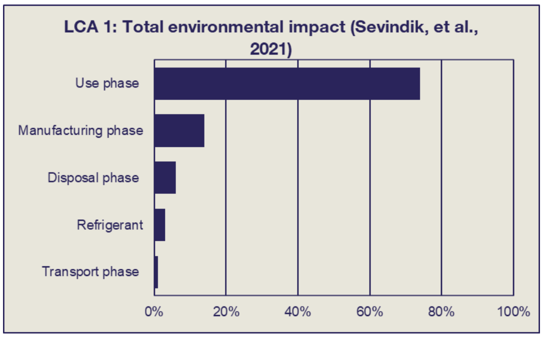


Figure 11: Total Carbon Impact



Sevindik et al, (2021) assessed the environmental impact of HPs and gas boilers in the United Kingdom, specifically focussing on the comparison between the baseline scenario and CE scenario. The assumptions made by Sevindik et al. (2021) are perceived as more plausible than those by Johnson (2011). After reviewing recycling rates in the United Kingdom and Europe, they determined that steel, copper, aluminium, and plastics were recycled at respective rates of 75%, 61%, 69%, and 32%. They posited that, after a 20% loss during decommissioning, 80% of the refrigerants would be reused. Their findings indicate that the manufacturing and disposal phases account for approximately 23% of the carbon emissions. In Figure 11, it shows that the manufacturing phase accounts for 14%, the disposal phase for 6%, and the refrigerant for 3% of the total impacts.

Besides their baseline analysis, Sevindik et al. (2021) assess the impact of three scenarios in line with the UK's government's goals. The CE scenario, assuming 100% recycling, shows the greatest reductions in environmental impacts, "with a 44% reduction for heat pumps" (Sevindik et al., 2021, p.1). This scenario has the greatest reductions in the CC (Climate Change) with an average of 75% reduction in carbon impact.

However, the specific reductions in carbon equivalent emissions could not be directly applied to Eneco's HP supply chain due to the assumptions made for the CE scenario in the year 2050. This scenario presumes not only 100% recyclability but also an energy efficiency improvement of 25%, and an assumption that the electricity mix will consist of 82% renewables. These assumptions cannot be extrapolated to Eneco's situation. Nonetheless, this study highlights the importance for the whole market to transition to a circular structure to achieve maximum environmental mitigation. Sevindik et al. (2021) further suggest that widespread use of HPs would create substantial demand for metals and minerals, making the incorporation of circular economy standards in HP manufacturing an essential solution.

To obtain a more precise estimation of the environmental impact, a third LCA from literature needs to be assessed.

Lin et al. (2021) compared the environmental impacts of hybrid heat pumps (HHPs) and condensing gas boilers. The study concluded that the HHP has lower environmental impacts compared to the condensing gas boiler system) across various impact categories.

Lin et al.'s (2021) LCA calculation showed that the end-of-life phase of the HP accounts for roughly 5% of the total environmental impact. Although precise data on recycling heating systems were lacking, assumptions were made based on a recycling rate of 90% for metals (such as steel and brass) and refrigerant (R410A). The assumed recycling rates closely aligned with those observed in Dutch shredding companies, ranging from 90% to 93% (Vincent de Graaf, director of Refurn). Since the assumptions are believed to closely represent reality, this study will be used to assess the environmental impact of setting up the CBM via a recycling company such as Refurn.

Appendix I: Proposed EoL supply chain, and argumentation

I. Proposed Supply Chain of Value Proposition

The central Building block of the CBM is the value proposition. Here, the desirability, viability and feasibility and environmental impact come together. It represents the circular business model strategy which is proposed as fitting within the perspectives of the producers, Eneco, the recycling company and the customers. The value proposition focused on refurbishing components, could be implemented in the proposed circular supply chain below, which is assessed as having the highest feasibility among the stakeholders.

After reaching the end-of-life, the HPs are disassembled from the walls of Eneco's customers by the installers. The installers need to register the defective pump before they can close the work order. This registration ends up in a database accessible to both Eneco and Refurn. The HP remains at the customer's house for less than 2 days and is picked up by the collection service of Refurn (or another recycling company). Here, the refrigerant is tapped from the system and always brought to Coolrec, specialized in recycling refrigerants and other cooling and freezing appliances from HPs (Coolrec, 2023). The HP will be brought to the Refurn's Recycling Facility at Apeldoorn. Here, the HPs are processed in a WEEELABEX certified testing lane. Multiple streams are formed. A small proportion of young HPs of specific types may have the potential to be reused or refurbished as a whole. If required, some maintenance will be done and the HPs could be repurposed. However, the focus will be on component reuse and refurbishment. Solely the components that are in demand in the market will be extracted from the devices (thus Eneco needs to communicate which components the producers or their installers are demanded). The last stream encompasses the HPs that are made from low grade materials; here only some parts are extracted (e.g. ventilator), and the rest of the HP is shredded and recycled.

After the revision phase is done, the refurbished components are stored at Refurn or Eneco (if they want to stay responsible), the producers can order the refurbished components and use them in another production stream. The recycled materials are either sent back to wholesalers, where the producers can purchase these materials to be (re)used in production, or they are directly sent to the producers.

HPs, that are either made with refurbished components or reused, are at first used by Eneco in their leasing structure and “stadswarmte” projects, these are the perfect testing areas, due to the fact that Eneco stays responsible for providing the user with a working product. The refurbished components could also be directly employed by Eneco, when their installers are repairing ‘their’ HPs.

If it could be proven via these two PSS structures that an HP with refurbished components has a similar COP and lifetime as a regular HP, then Eneco could give a warranty of 2 years (average of most HPs). The customers would prefer such an HP over a regular HP due to the fact that the circularity percentage has a positive influence on the choice made between an HP.

The next section will delve into the arguments for the choices made in designing the specific parts of the CBM’ value proposition. It is important to note that some arguments are (further) elaborated in later sections, to avoid repetition.

I.1 Material Loop

Currently, the flow of materials is not being recorded, leading to a lack of clarity regarding the proportions of HPs (and gas boilers) that are being received by scrapyards, shredding companies, or recycling facilities such as Stichting OPEN, Refurn or refrigerator recycling facilities. The interviewees from the producers and Eneco stated that currently most of the HPs end up in the Scrapyards. However, Vincent de Graaf (Director of Refurn,) stated that the installers are “legally co-responsible for what happens to the product.” This means that they could end up in scrapyards, but it is more likely that they will be recycled at shredding companies, such as HKS, SIMS or Rewald. These differing perceptions showed that the EoL supply chain is currently non-transparent, making it unclear what is happening to the discarded HPs. To reduce risk, every stage of the proposed return stream should be documented.

In the following section, the perspectives on the desired material loop that was perceived as feasible will be elaborated on to assess the common ground.

All producers believe that an improved or new circular stream should be put in operation. Producer 1 and 2 believe that the circular loop should be on the level of materials and components. It is stated "that there are a lot of materials and components in heat pumps that can be repaired and reused. For example, used in maintenance (producer 1)." They both believe that an HP can be evolved into a machine that is probably not a hundred percent reusable, but for a substantial part. Alklima is a strong believer in recycling instead of refurbishing.

Producer 1 was the only one willing to take some responsibility of receiving their discarded HPs back and revising them by themselves. However, they believe that the retrieval and recycling of the HPs system "cannot be done by ourselves, but that should be in partnership with partners like Eneco." On the one hand, they want a single actor "who can arrange everything for us or for Eneco." Meaning that it is able to take responsibility for circulating the whole HP. On the other hand, forming multiple separate partnerships would also be a possibility for this producer.

Producer 2 stated that all the HPs from all the suppliers should be, dismantled in small parts again or materials, and recycled at the same place, "then, there will be a market for it". However, they do not have the capacity to recycle the products themselves, a collaborating third party is needed. Furthermore, they are convinced that only part of the newly sold HP should be made from circular materials/ components. This would make it possible to meet the market standards for price and quality.

Alklima believes in recycling the HPs to mono materials and not in returning and refurbishing whole HPs by themselves. Their reasoning is because of the GHG emissions of transport between the customer and their production facilities in Scotland, Turkey and Japan. Therefore, they also believe in a recycling stream that combines multiple different discarded products together (also e.g. cars or phones), those have to meet certain requirements and are designed for disassembly and for recycling.

Alklima is the only one that believes in a refurbished marketplace for heat pumps as a viable second step, when an energy surplus exists in residential housing. They differentiate between "dead materials" and components that offer room for innovation:

- Piping is an example of a dead material that is highly suitable for reusing. Mitsubishi uses a piping structure that can be reused when existing piping is being replaced, without any limitations.
- Regarding the continuous innovation of HPs, Mitsubishi Electric views them as products that undergo constant improvement. The continuous innovation disabled the possibility to reuse components. Over the past two decades, HPs efficiencies have doubled, leading to significant energy cost savings and overall improved pump efficiency. While repurposing a 15-year-old HP offers circularity benefits it falls short in terms of sustainability. Also regulations force the use of more efficient components, making it impossible to reuse or refurbish components.

The common thread that became visible from the interviews is to move toward a CBM that focuses for the most part on circulating components. Also the employees of Eneco and the other producers believe in an universal and streamlined return stream, and they all point towards the same third party that should and could be responsible. Refurn is that company and is on preliminary bases perceived as capable of taking responsibility for managing the entire EoL process. Refurn is a company that supplies the services of: "collection, reuse, refurbishment, recycling and disposal of central heating boilers and electric boilers" (Refurn B.V., n.d).

After interviewing Refurn, it became clear that Eneco's employees' perception of Refurn's capability and willingness to handle the EoL process was accurate. Refurn is interested in expanding their revision process to include heat pumps. They made it very clear that they have the technological know-how; "We can drain the refrigerant, disassemble it, extract the oil from the compressor, and dismantle all the parts that are of interest." They mentioned that a lot of knowledge can be developed about the components of different types of HPs and that they would focus on reusing and refurbishing these components. Due to the fact that this aligns with the perspectives of the interviewee's of Eneco and most producers, it is chosen to design the material loop of the value proposition with Refurn as the main actor.

Refurn expresses their willingness to proceed with such a proposed return stream, as long as there is a market demand. Therefore, Eneco will need to assess the components required by themselves, their installers, and potentially the manufacturers. Subsequently, Refurn can establish this line and collaborate with other specialized parties (such as those dealing with printed circuit boards, fans, and heat exchangers) to make this circular material loop reality.

I.2 Design for circularity (modularity and disassembly)

When it comes to design, all producers were already designing their products with an end-of-life perspective in mind and were willing to move towards implementing more circular design strategies. However, their goals were slightly different; this will be explained in the section below. Modular design offers various benefits in terms of circularity, according to Huang et al. (2012) and Tukker (2015) it facilitates separation and disassembly, allowing easier reuse, repair, refurbishment, upgradability and recyclability of materials.

Producer 1 already has some parts of their HPs modular "that is especially the compressor because that is a heavy component in the heat pump." Thus, this makes it possible to separately transport the heavy component (e.g. in a stairwell of an apartment). They mention that especially the Dutch market is asking for a modular design.

Producer 2 understands that "When modules are used instead of full replacements, it can help reduce the environmental impact of the total product." They seem willing to make the required investments, but only if the following requirements are met: 1) procurement agreements need to be made with the utility companies, and 2) it needs to be possible to incorporate modularity in the LCA calculation methodologies. "While it may be more costly initially, focusing on long-term benefits and circular models, it is crucial."

Alklima (i.e. Mitsubishi Electric) prioritizes an HP design with disassembly in mind, aiming to create a product that can be fully recycled at the end of its life, which they consider the most practical approach for achieving circularity goals.

All in all, the producers are willing to either focus on a more modular design strategy or a design with disassembly in mind. If the procurement department of Eneco makes clear agreements on the expected potential recyclability rates, Refurn could reach even higher recycling rates in the future. Thus, the producers believe that Eneco needs to lay more value on the sustainability features of heat pumps. Not only should the consumers but also Eneco be willing to pay for circularity.

I.3 Product as a service

As mentioned in the Theoretical framework in section 3.5 (value Proposition), integrating products in a Product-Service System (PSS) provides benefits in terms of circularity. Through leasing, repair, maintenance and remanufacturing, it extends product lifetimes and enhances resource efficiency. A PSS promotes the take-back system because it allows firms to keep control of their products (Tukker, 2015).

As stated in the value proposition, a specific CBM that drives the use of circular HPs involves leasing structure and district heating ('stadswarmte') projects. For such PSSs, it is necessary that Eneco could monitor the usage per HP. All producers are able to monitor the usage of their HPs when applied in residential homes. In The Netherlands, smart meters are widely used in combination with an HP, enabling "excellent control over what our machine does, or can do" (Alklima). Both Alklima and producer 1 believe that Eneco could be responsible for offering the service. Alklima could provide it with or without 'performance guarantee', for new construction there are no limitations as all the details of the house are present. For renovation it becomes harder as every house has different features. Here, Eneco could step in as they are able to 'schouw' (look inside) the residential home (Alklima).

Producer 1 believes that "If you would have a leasing including replacement model, then it would be financially very interesting for Eneco, but also for the supplier." Due to the fact that this guarantees that the HP and its components can get reused and sent back to the production factory. Producer 1 already had PSS's in place for other products and is working on a similar service for HPs. They already have a pilot in place, but realized that the ownership is a large barrier. However, if homeownership changes, transferring the service to new owners could be challenging if they're not interested.

Although there are some barriers to overcome, it seems that initially focusing on at least one of these structures could provide Eneco with data on the performance of the (partly) circular HPs. If the performance keeps up with the normal standards, Eneco could move to the consumer market. This is proposed as a second step, as it was determined in the DCE that a lower COP value or lack of warranty negatively affects the choice between two HPs. Which will further be elaborated on in the next section.