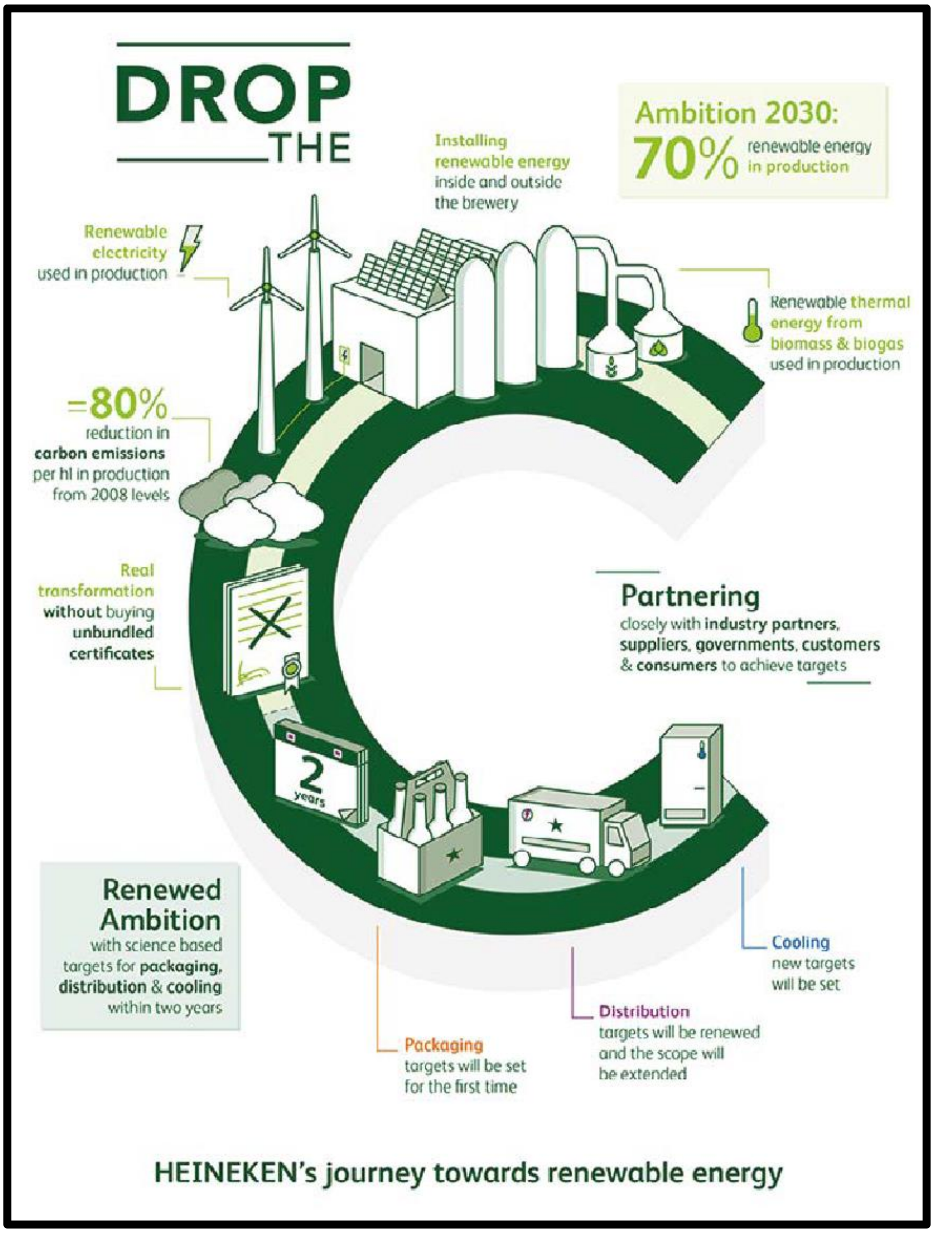
Moving the Needle

Exploring thermal savings at Heineken

by targeting on waste heat recovery systems



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Abstract

One of the rising concerns currently is global warming. As a result, there is effort at a global level to mitigate climate change, by targeting various areas. Some of the areas that need to experience transition in terms of energy consumption are big industries.

The aim of this thesis project is to make suggestions on how a large brewing organization can reach significant thermal savings globally, by focusing on waste heat recovery technologies. The structure of the project firstly includes an overview of the company and the areas of interest within a brewery. In addition, there is an analysis of the selected technologies that have the potential to move the needle towards thermal savings at Heineken. Furthermore, there is a prioritization list of the company's sites to illustrate the best possible impact of the selected technologies at a global scale. Finally, there is an overview of the findings with recommendations and the conclusion.

Table of contents

List of tables and figures

List of acronyms

UBM Utility Benchmarking Model

WHR waste heat recovery

GHGs greenhouse gases

SDGs sustainable development goals

hl Hectare litter

SUE Sustainable Utilities and Environment

CO_2 Carbon Dioxide

BAT Best Available Technology

EA Electricity actual value

TA Thermal actual value

TRL Technological Readiness Level

EU European Union

DMS Dimethyl sulfide

TPV Thermo Photovoltaic

WWTP Wastewater Treatment Plant

COP Coefficient Of Performance

t/hr Tonnes/Hour

UN United Nations

COD Chemical oxygen demand

Acknowledgement

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Last but not least I would like to thank my family and friends that made this journey more enjoyable.

Chapter 1

Introduction

1.1 Background

The last decades there is a big concern related to global warming (Luo, Sasaki and Masumoto, 2012). As a result, large industries are challenged to tackle the issue by reducing their GreenHouse Gas (GHG) emissions and improve their energy efficiency (Dedrick, 2010). Although industries face difficulties, there are ways to deal with them. A report was released called ''*A Greener Path to Competitiveness*'' related to climate mitigation, sustainable development and energy (Kechichian et al, 2016). Based on the report, Christine Egan the CEO at CLASP (organization focusing on energy efficiency) stated *"The report shows that appliance energy efficiency policies can simultaneously reduce energy use and improve competition,"* (Gex, 2016). According to Woolley, Luo and Simeone (2018), industries have two basic options to reduce their environmental impact, one is to increase the renewable production and second to minimize energy consumption. This project will focus on the second option and more specifically on thermal energy reductions. A large concern industries are experiencing is waste heat (Jouhara and Olabi, 2018). Waste heat in industries is when a significant amount of thermal energy is released into the atmosphere (Papapetrou et al., 2018). The reason for the heat loss can be due to transferring, radiation or convection from product and/or energy-intensive processes (Johnson, Choate and Davidson, 2008). In addition, to reduce energy consumption the best approach is energy efficiency, to minimize the input and maximize the output within operations (Golusǐn, Dodić & Popov, 2013). A significant element of energy efficiency is waste energy recovery (Vallack, Timmis, Robinson & Sato, 2011). Energy recovery in the case of this project is related to waste heat. Additionally, the principle of waste heat recovery (WHR) rises due to the fact of energy, in reality, cannot be consumed it just changes forms.

For applying WHR, a crucial factor is the temperature of the waste heat, which determines the type of technology used to recover thermal energy. According to Papapetrou et al. (2018), the temperatures depend on the type of industry and process, with temperature ranges from 50 °C up to 1000 °C or on some occasions even higher. For WHR, it is of major significance to separate the waste heat into different groups based on the temperature range. Hence, it can be categorized in three main parts, low temperature (less than 100°C), medium temperature (from 100°C to

400°C) and high temperature (more than 400°C). Usually, high-temperature loss originates from direct combustions, medium-temperature from exhausts and low-temperatures from sections of the process units (Jouhara et al., 2018).

For WHR a significant element is to find the most suitable technology to effectively recover wasted energy. Focusing on WHR systems can have a high saving potential in energy and cost of equipment (El-Temtamy et al, 2010).

In addition, the aim of the analysis is on a multinational entity from the field of food and beverage. The industry of the analysis mainly includes low waste heat, around 100°C (Chen and Voigt, 2020). The chosen organization is Heineken who is a global leader of the specific field. Breweries include a wide variety of processes with high-energy consumption. As a result, there is a large amount of residual heat released into the ambient environment. Regarding Heineken, the researcher will recommend strategies to move the needle towards thermal savings by targeting on WHR systems. Thus, he will make suggestions to approach WHR through the evaluation of the chosen systems and their possible impact if implemented on a global scale.

Heineken is an organisation focusing a lot on its green image which is pictured through the plan of ''Drop the C''. One of the main issues addressed in Drop the C is to reduce the CO2 consumption having a baseline of 2008 at 80% by 2030 ("The HEINEKEN Company - Age Gate", 2018). The company's plan has various ongoing projects globally. In addition, WHR is an element that has not been investigated into depth at Heineken global projects. As a result, this project, by making an analysis on WHR systems it will assist the targets set in Drop the C plan with a suggestion of alternatives as next steps by taking into account the WHR. Similarly, it is important to mention that Heineken's plan is deeply related to the Sustainable development goals set by the United Nations (UN). Heineken's plan is related to SDG 12, aiming for responsible consumption and production, but more precisely to targets 12.2 and 12.5. Target 12 focuses on efficient handling of natural resources and sustainable management by 2030 ("Sustainable Development Goals Sustainable Development Knowledge Platform'', 2015).

It is an important element of the company's scope to comply with environmental criteria for reducing its environmental footprint as shown in Drop the C. Therefore, it is observed that smaller brewing companies in some instances face difficulties on following sustainability reporting and assessment by finding it time-consuming and complex. On the other hand, Heineken as a large global entity has an annual report picturing the current situation, which allows public readers to understand the company's plans. According to Tokos, et al (2013) paying attention to sustainability is maybe time-consuming but can have positive results in other areas e.g. for reaching management targets through benchmarking.

1.2 Research Objective and research question

Research Objective

The main objective of this project is to nalyse an effective approach for Heineken saving thermal energy in its production sites all over the world. The focal point in this thesis will be thermal energy savings by the recovery and reuse of waste heat. In a second step the research provides knowledge where the highest energy savings gain can be achieved by Heineken.

Research Question

The research objective translates in the following research question:

Which heat recovery/reuse technologies are feasible to improve Heineken's energy saving performance globally, and which brewery sites should have priority in the energy saving ambitions of the company?

The question will be answered by first assessing a few technological alternatives suitable for thermal energy saving in breweries. There is a use of SWOT to assess the suitability of the technologies. Second there is analysis picturing which production sites of Heineken should have priority in implementing the selected thermal energy saving technologies. The priority selection was formed with the assistance of Heineken's utility benchmarking model (UBM).

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Analysis of Utility benchmarking model

1.3 Research Method

The research was performed during an internship at the Heineken office in Zoeterwoude. This location of the company facilitates the entire Global Production of Heineken. To answer the research question ,first there was an exploration of the available heat recovery technologies and an assessment of which ones are available for commercial application in breweries. In a second step of the project contained a general assessment of the selected technologies based on a SWOT diagram.

The third step illustrated an analysis of which Heineken production sites in the world should have priority in investing in the analysed thermal energy saving technologies, based on the criterium of reducing energy consumption per hl. The literature review used for the analysis, contacted companies offering technologies and studied the specifications of the technologies. In addition, it included interviews of people in order to collect the data needed for answering the research question.

1.4 Overview of the thesis report

The next chapter of the thesis project, introduces the company and briefly explains the brewery process. In chapter 3 the selected technologies are assessed with the help of SWOT diagrams. Chapter 4 analyses which production sites should have priority in making thermal energy saving investments. Finally chapter 5 draws conclusions, answers the research question and makes recommendations.

Chapter 2

Heineken global and operations

2.1 Background

Chapter 2 illustrates Heineken as a global organization. Additionally, it provides the reader with a clear overview of the different sections worth mentioning. The first part analysed in this chapter includes relevant information related to the company. Similarly, there is information on the global production of Heineken, such as locations and production in hl/year. Finally, the last part allows the reader to understand the basic processes of brewery and the areas of interest for later on applying the technologies of the analysis.

2.2 Company profile and operations

Heineken is a Dutch brewing organization and in 2018, owned 172 sites globally. The three breweries located in the Netherlands are Wijlre, 's-Hertogenbosch and Zoeterwoude (Sluyterman and Bouwens, 2014). In addition, until 2016 Heineken was the third largest globally, however, the two biggest brewers SABMiller and Anheuser-Busch InBev merged into one. Currently, it is the largest producer in Europe and beer is produced in more than 70 countries and has around 250 local, regional, international ciders and beers.

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Regarding the organization of the company, it divides its breweries into 4 different peers based on the annual volume produced in hl. Table 1 pictures how the company categorizes sites depending on the annual volume production. Additionally, Heineken categorizes its operations into five different parts. Each part includes regional operations and those are:1) Middle East/Asia Pacific,2) Africa, 3) The Americas, 4) Western Europe/ Central/ Eastern Europe. The coming years the company is planning to invest effort and money on the energy section of its breweries. As mentioned in chapter 1 the company raised the bar significantly, by aiming to reduce its energy consumption and thus, thermal consumption by 2030. As a result, this project needs to make suggestions on how the company can move the needle towards thermal savings. In order to make accurate recommendations it has to examine the processes within Heineken breweries, identify the thermal energy intensive areas and show where currently heat is recovered.

Table 1: Heineken breweries are categorized into four different peers depending on their annual production hl/year (One2share, 2019)

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2.3 Brewing process

There are multiple steps that need to be followed in order to reach the final product. The steps are: milling, mashing, lautering, wort boiling, wort cooling, fermentation, pasteurization and packaging (Galitsky et al., 2003). The first stage of the process of brewing is malting. According to Bokulich and Bamforth (2013) malting includes three main steps. First step is steeping, the second step germination, and the third step is kilning. In most cases for Heineken sites malting takes place ex-situ. As a result, malted barley is transferred through multiple ways depending on the location of the site and is stored into storage tanks. The second phase for making beer is called milling. This process includes rolls for reducing the size of the malted barley.

Mashing and wort separation are the two following steps. Mashing is the procedure for the extraction of different nutrients such as proteins and starch (Kok, Ye, Muller, Ow & Bi, 2018). In addition, for the wort separation mash goes to a lauter vessel or to mash filters for separating the extract from the solid particles and unwanted material.

The next step is the boiling of wort. Wort boiling takes place in the kettles and the aim of is to create evaporation of water as steam from the wort. Boiling is one of the most intensive thermal consumption processes in brewing. Traditionally, brewers used to boil wort until the evaporation rate would go to 10% or more ensuring good quality of beer and sterilization. According to Huang, Tippmann & Becker (2017) there are also other factors affecting the beer quality connected to previous processes. Similarly, if previous processes are monitored properly, a high evaporation rate percentage is not needed and it can drop significantly, resulting in less primary energy consumption for wort boiling.

The next phase is called wort cooling and aeration. This process includes the assistance of heat exchangers for dropping the temperature to be ready for fermentation and maturation. During fermentation, cool wort goes to the fermentation tanks where immature beer (green beer) will be fermented by yeast.

After fulfilling the previous steps mentioned packaging comes into place. Packaging includes a variety of materials like OW or returnable glass bottles, cans, kegs or PET bottles. The different types of packaging used also influences the type of cleaning, filling and pasteurization they need to go through. Firstly, the beer filling occurs and afterwards pasteurization follows for eliminating microbes in the beer. There are two types of pasteurizers tunnel and flash. The difference between the two types is that flash pasteurizers pasteurize only the product. Therefore, tunnel pasteurizers act on both the product and the package. According to Muster-Slawitsch, et al (2011) ''pasteurization energy demand might range from 3 to 17 MJ/hl depending if flash or tunnel pasteurization is applied''. Usually bottles and cans go through tunnel pasteurizers and kegs go through flash pasteurizers. In addition, continuous quality controls for following the quality standards follow for the products not going to post- pasteurization. Figure 1 pictures the process for making beer on a common Heineken site.

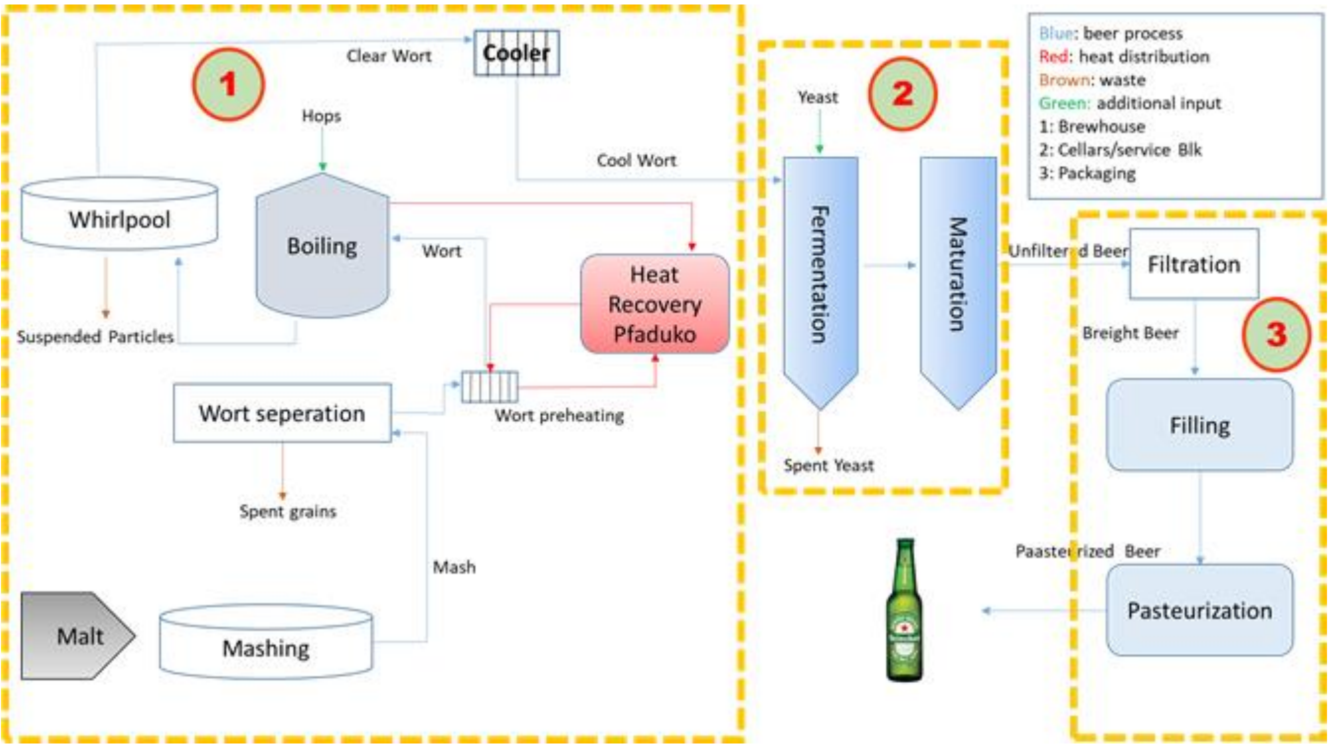

Figure 1: brewing process at Heineken breweries (author's own diagram)

2.4 WHR at Heineken breweries

Analysis of the conventional systems commonly used by Heineken for WHR.

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2.5 Overview of Heineken's structure and operations

Chapter 2 illustrated Heineken as a global company within the food and beverage industry. More specifically it showed how the company separates its production sites depending on their region and volume production. Hence, there was an analysis on the brewing process including the most thermally intensive areas of a brewery (brewhouse, packaging and utilities). Similarly, the chapter included an analysis of the WHR systems Heineken currently uses. This project will select three WHR alternative systems in order to surpass some barriers that Heineken currently faces. In addition, the new systems can have a major role by moving the needle towards thermal savings. Those are analysed in the next chapter.

Chapter 3

Analysis of alternative technological options

3.1 Background

In order to fulfil the research objective set in this project, multiple innovations need to take place for reducing Heineken's primary thermal energy usage globally. There are various areas where alternative solutions for WHR can have a high impact. Therefore, the different parameters for their application need to be examined. Chapter 3 shows a schematic overview of a brewery with the potential areas for applying WHR systems. It illustrates in a simple view, how things are placed in breweries separating it into four areas. The following step provides a technological analysis of the three selected technologies, including a detailed description of the operational part of each one of them, existing examples within the food and beverage industry or other industries. Additionally, there is a SWOT diagram to give a clear picture of the strengths/weakness and opportunities/threats each one of them possess. This chapter gives an in-depth analysis of the selected technologies including the important traits they will bring on the table.

3.2 Potential areas for recovering waste heat and selected technologies

By targeting the most intensive thermal energy consuming areas in a brewery, the researcher can illustrate where it is potential to apply the three alternatives selected. The parts of a brewery that could be used to apply the WHR systems are the packaging area, utilities and brewhouse (cellars/service Blk. is excluded). As mentioned above, the most common areas that Heineken currently recovers waste heat globally is at the brewhouse and utilities.

Figure 2 shows three main areas for applying the WHR systems of the analysis. The three main areas are brewhouse, utilities and packaging. This part also includes technologies that can have a high impact if applied in Heineken breweries globally. The maturity level of chosen alternatives is TRL8-9 (ec.europa.eu, 2015). With this maturity level they have already been proven at the food and beverage industry or in other industries. The selected systems are: 1) the chimney condenser that works as a filter at the same time, 2) WHR from cooler during wort boiling (Meurastream) and 3) the heat pump using pentane as a medium. These three systems were selected by the researcher and if are applied on a global scale they can be a game-changer for thermal savings. Regarding the TRL's the Meurastream is at TRL 9 and the other two are of TRL8. Figure 2 pictures the areas of interest for applying the three WHR technologies.

1) The chimney condenser that works also as a filter is a technology formed by Pojoulat in 2018. It is based on 10 certified patents, recovers a high amount of waste heat and does a cleanup of the pollutant content (Pojoulat, 2019).
2) The Meurastream is an innovative technology applied to recover waste heat from the coolers during wort boiling (Meura, 2016*).*
3) The heat pump using pentane as a medium was released by Mayekawa (Dusek, 2013). The interesting fact of the specific technology is that it delivers high-pressure steam covering brewery steam temperature needs.

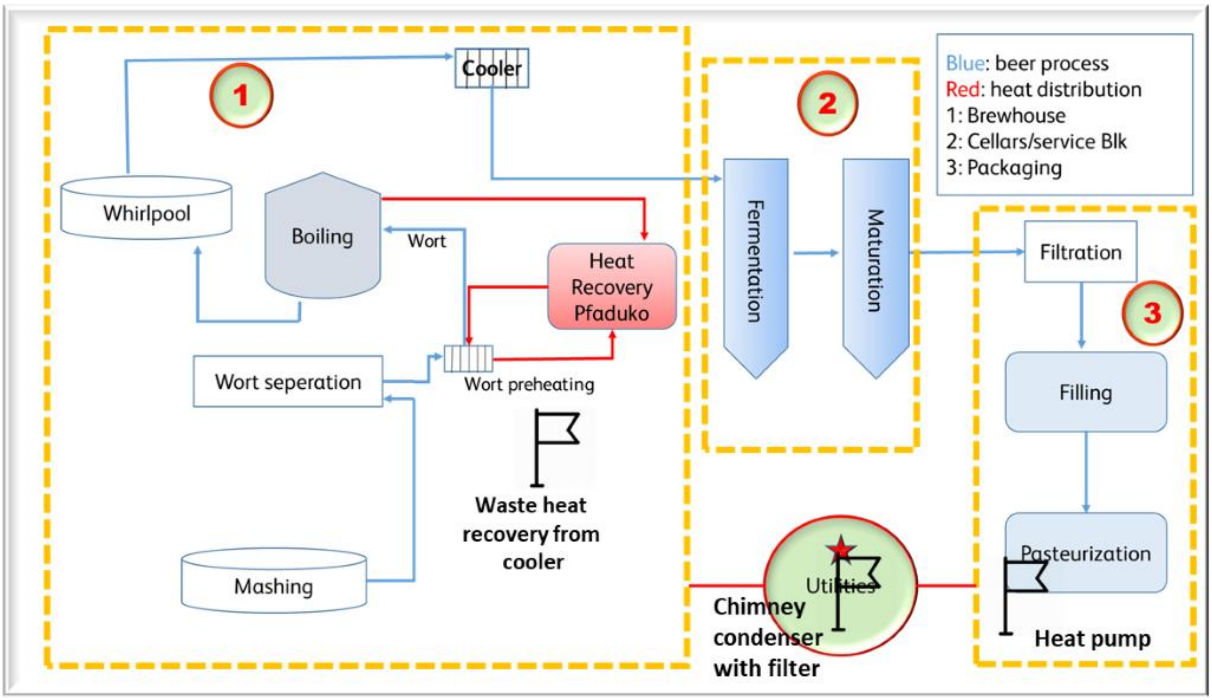

Figure 2: Overview of a brewery along with the potential areas of application for the three systems (author's own diagram).

3.3 Chimney condenser with filter from Poujoulat

3.3.1 Background

The utility area is where the boilers are placed. Boilers are responsible for producing steam and distribute it to other process areas with thermal demand. As a result, increasing the efficiency of boilers is of major importance.

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In 2018 Poujoulat released an innovative technology which deals with some of the issues currently faced. The chimney condenser with filter can recover heat with every temperature range and at the same time clean the pollutants within the flue gas (54events B.V., 2019). Additionally, the percentage of heat recovered is higher compared to the current system used.

3.3.2 Analysis of the technology

The system of this analysis is a direct heat exchanger between air and water. Furthermore, it recovers both sensible and latent heat from the flue gas. It uses a device that filters the flue gas and recovers the energy at the same time. The innovative heat exchanger from Pojoulat is called Terraosave solution, which captures and recovers the thermal energy contained in gases and exhaust fumes. One of the main technical characteristics is the square-shaped form of the heat exchanger, containing 15 cm of water on the bottom of it. Something that must be mentioned is that the efficiency of the system depends on the speed the flue gas passing by the bottom water, illustrated in figure 3. Finally, for the food & beverage industry people focus on flue gas temperatures of 90-130°C.

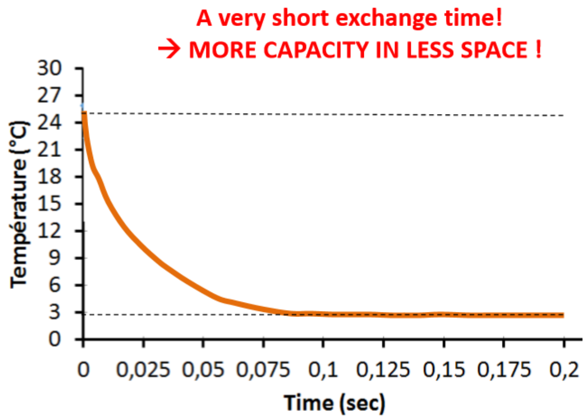

Figure 3: The efficiency is determined by the time the flue gas passes by ("Heating and Power", 2019)

The direct exchange process extracts sensible heat. What distinguishes the Terraosave heat exchanger is that in addition to sensible heat, it also extracts the latent heat, which is much greater, as shown in figure 4. In many cases, the recovered energy from a single Terraosave exchanger will be up to 2.5 times greater than the traditional plate heat exchangers. Terraosave captures and ingests exhaust fumes into the water or to another fluid commonly used for purification. Figure 4 illustrates the temperature input and temperature output. Similarly, the temperature of the flue gas will be around 130 C and the temperature released into the atmosphere 30 C. According to Van de Kamp (2019) for different temperatures, different materials are used and because it does not include any moving part it is easy to maintain. Finally, the biggest advantage provided is that it can be used with every type of fuel without the danger of corrosion ("Heating and Power", 2019).

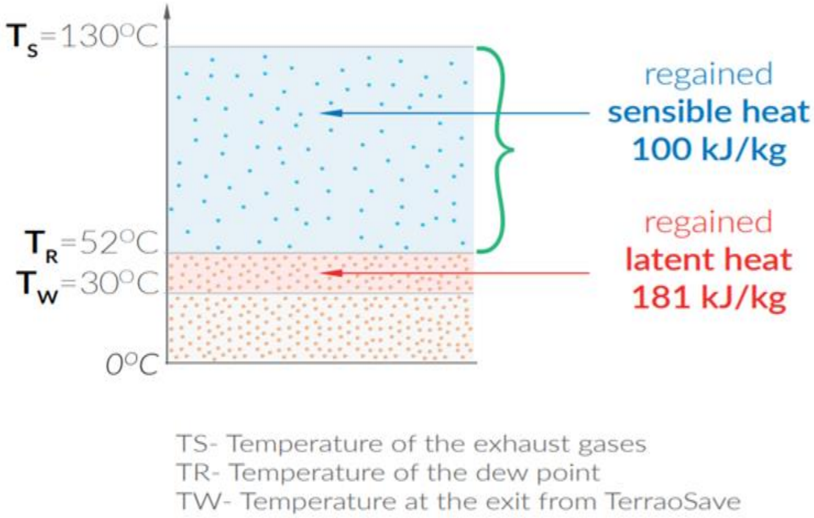

Figure 4**:** Temperature of flue gas, and temperature released to the atmosphere along with the heat recovered by the system ("Heating and Power", 2019).

3.3.3 Filtration system and existing example

A significant attribute of this chimney condenser is the capacity to highly reduce pollutants existing in the flue gas. The biggest issue present in breweries is the high concentration of NOx and SOx leading to corrosion and not complying with environmental regulations. According to the Van de Kamp (2019) all the pollutants are captured within the heat exchanger and filtered. Hence, the treated water needs to be connected with the in-situ wastewater treatment plant (WWTP) for the final treatment. The filtration system is made out of chemicals based on site-specific characteristics depending on the pollutants present. One good example of the chimney condenser with the filter applied is a combined heat and power facility, figure 5 pictures some of the characteristics of the technological operation.

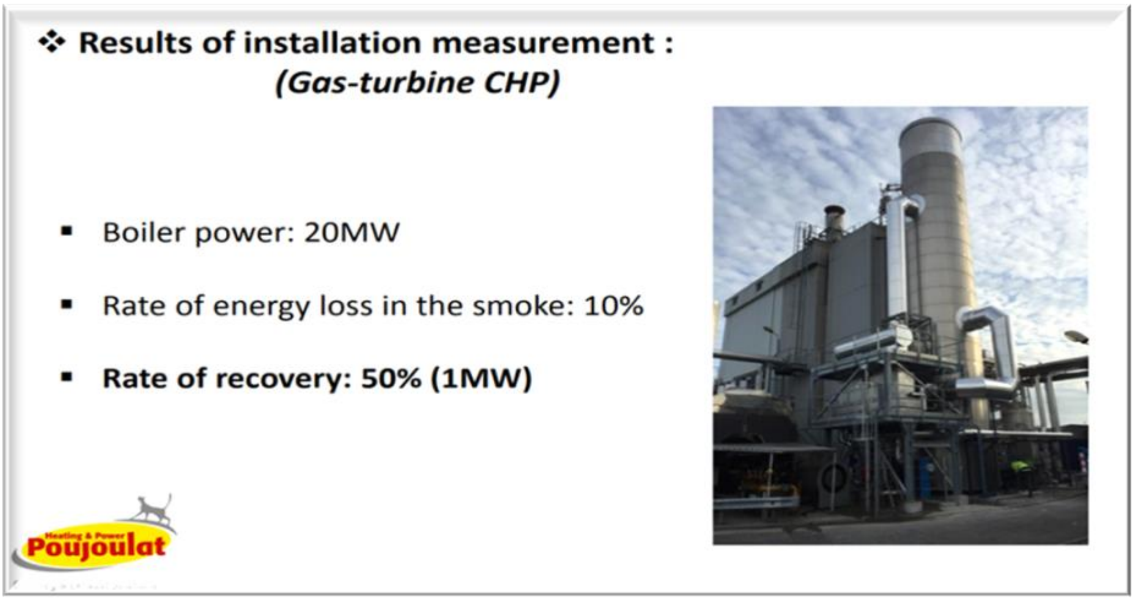

Figure 5: This is an example of a combined heat and power plant having a recovery rate from flue gas of 50% with the use of Terraosave ("Heating and Power", 2019).

3.3.4 SWOT diagram

Figure 6 shows a SWOT diagram with strengths/weaknesses and opportunities/threats of the chimney condenser with filter. Firstly, the biggest strength this technology brings on the table is its capacity to operate with every type of fuel.

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The case of the chimney condenser with a filter would surpass this issue making it attractive to all these sites. The biggest weakness presented with it is the cost (Van de Kamp, 2019). However, this cost will not be included within this project due to different prices depending on site-specific characteristics. The only information provided by the supplier referring to the price is that it costs more than an economizer, but less to an economizer with a filter combined. In this case, it is more beneficial because it has two functions into one unit (WHR and filtration system). In addition, the big opportunity presented is the high reduction of pollutants helping the brewery to deal with local environmental regulations and making the water possible for reuse. Finally, the threat that appears, is that it has not been applied in a brewery yet. Therefore, the boilers for every type of industry are similar, the main changing parameters are their size and fuel. The example presented previously illustrates a boiler size similar to the ones used within breweries making it attractive for the case of Heineken.

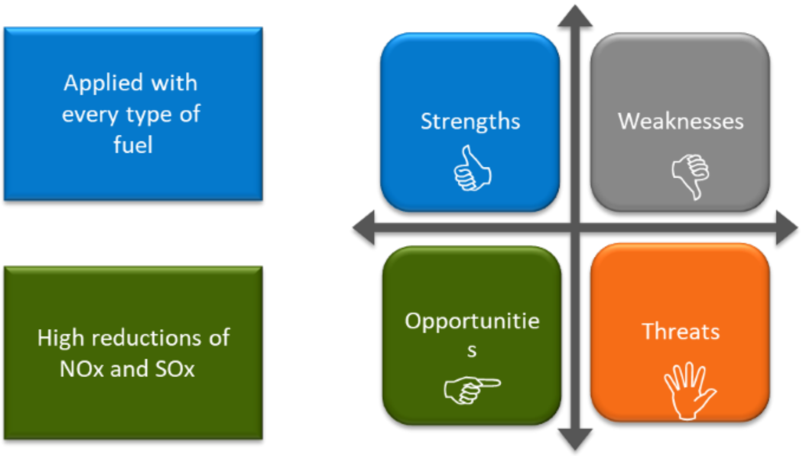

Figure 6: SWOT diagram for chimney condenser with filter from Poujoulat (author's own diagram)

3.4 Meurastream WHR from cooler during wort boiling

3.4.1 Background

Wort boiling is one of the processes with the highest thermal energy demand in the Brewhouse (Meura, 2016*).*

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Meurastream has the potential to decrease the evaporation rate to 1.5% (Meura, 2016). The specific system has already applied in a small number of Heineken sites. This analysis will illustrate why this system could be a game-changer. According to the supplier the thermal consumption is 35% less in a site that already uses WHR and 50% less to a site without WHR in the brewhouse.

3.4.2 Analysis of the technology

The analysed technology is WHR from cooler the Meurastream system. The different compartments of the system are a wort kettle, a settling tank (whirlpool), a wort stripper and cooler. The stripper is positioned in line before the cooler. As illustrated in figure 7 the other section of the system includes two water tanks, a steam booster and a heat exchanger. For the operational part, the wort coming from the holding vessel passes through a heat exchanger to enter the kettle at 99°C. The following step is the formation step that takes place in the wort kettle. During the formation step chemical reactions occur e.g. hop isomerization, formation of unwanted substances, and trub formation. Trub is the suspended solids in fresh wort (Schisler, Ruocco & Mabee, 1982). The temperature at the kettle reaches 100°C with evaporation rate of wort less than 1%, meaning that the thermal consumption is substantially less than a conventional wort boiling system. The next phase is when the mixture enters the settling tank, the trub stays at the bottom, and the clean wort enters the stripping column. In the specific case, the technology used is called the ecostripper.

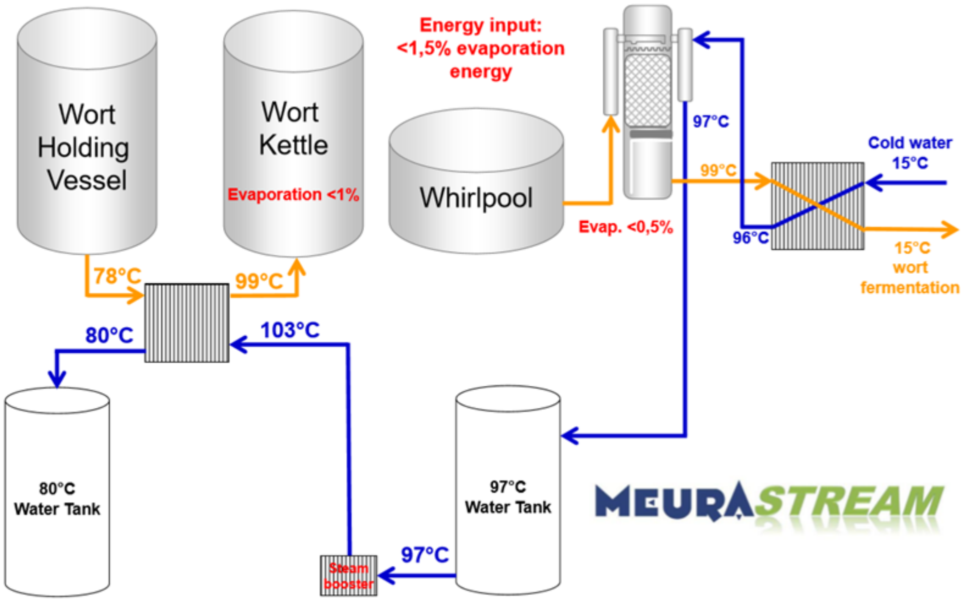

Figure 7: Schematic of WHR from cooler during wort boiling Meurastream (Meura, 2016)

3.4.3 Ecostripper

The ecostripper has an inlet on the upper part where the wort enters and goes to the distributor. The distributor and goes to the lower part of the device. To get rid of the unwanted substances (e.g. Dimethyl sulfide DMS) steam passes over the wort with low energy usage. As a result, the amount of energy used in the whole system is the equivalent of 1.5% evaporation rate of wort (Meura, 2016). Finally, the treated wort leaves the ecostripper and enters the cooler.

3.4.4 WHR from cooler

The other section of the system is what makes meurastream unique. The ecostripper has an external part taking out the stripping condensate the condensate leaves with a temperature of 97°C and enters a water tank to later on pass through a steam booster. Additionally, the condensate reaches 103°C and enters a heat exchanger. Hence, the liquid leaving the heat exchanger is 80°C and enters a tank. The heat exchanger helps to preheat the wort before entering the wort kettle (Meura, 2016).

3.4.5 Existing Examples

In terms of maturity, the Meurastream TRL is nine. The technology has already been implemented in some Heineken sites. As a result, it is proven that the technology is effective and applicable for a Heineken brewery. The sites are VBL Da Nang, CBL Cambodia and Bressivoire. All three sites have a very low thermal consumption within the brewhouse.

3.4.6 SWOT diagram

Figure 8 illustrates a SWOT diagram with strengths/weaknesses and opportunities/threats of the Meurastream. Firstly, the biggest strength that this technology brings to the table is the maturity of TRL 9 within the food and beverage sector. It has already been applied in Heineken sites, meaning that there are specialists in the company that have the knowledge on how to work with it. The difficulty that rises with the application of it is when a brewery site decides to replace previous systems with Meurastream. A brewhouse that is designed to have the conventional system for WHR has the space arranged in order to fit the existing design. However, the Meurastream as mentioned, operates with the ecostripper. According to Odogwu (2019) ‘’the ecostripper is an additional part that usually needs additional space which can be challenge, therefore through engineering there can be innovative solutions.’’ For the opportunities part due to the reduction of the amount of time during wort boiling there is capacity for more beer production leading to more profit. In addition, a big opportunity is the high reductions in thermal consumption, which is the main point of interest for this analysis. Finally, a big threat is the investment cost (1,353,000 euros), therefore depending on site annual volume production and thermal consumption the payback periods can be low.

Figure 8: Schematic with SWOT diagram of the Meurastream (author's own diagram)

3.5 Steam generation heat pump

3.5.1 Background

According to Bangerth, Tiwari, Shooshtari & Ohadi (2019) ''72% of global primary energy consumption is lost as waste heat, and 63% of these losses occur at temperatures below 100 °C''. As a result, utilizing the low waste heat, heat pumps are a very effective means. They transfer residual heat, while increasing temperature, with high efficiency and excellent performance (ehpa, 2015). They can recover residual heat and they require a small amount of energy to operate. Additionally, heat pumps can also recover energy from are ground, sea and river (Zieler, 2017). According to Chua, Chou & Yang (2010) they will have a key role for future energy efficiency improvement with respect to heat recovery. Its operating nature derives from physics, where the fluid's evaporation point decreases and boiling point increases through pressure. They consist of four main parts: the compressor, the evaporator, expansion valve and condenser as shown in figure 9. Similarly, they also use a medium fluid. In this case, the medium used is pentane. Hence, to measure heat pump efficiency the coefficient of performance (COP) is used. COP depends on the energy use ratio of the compressor (Industrial Heat Pumps, 2017)

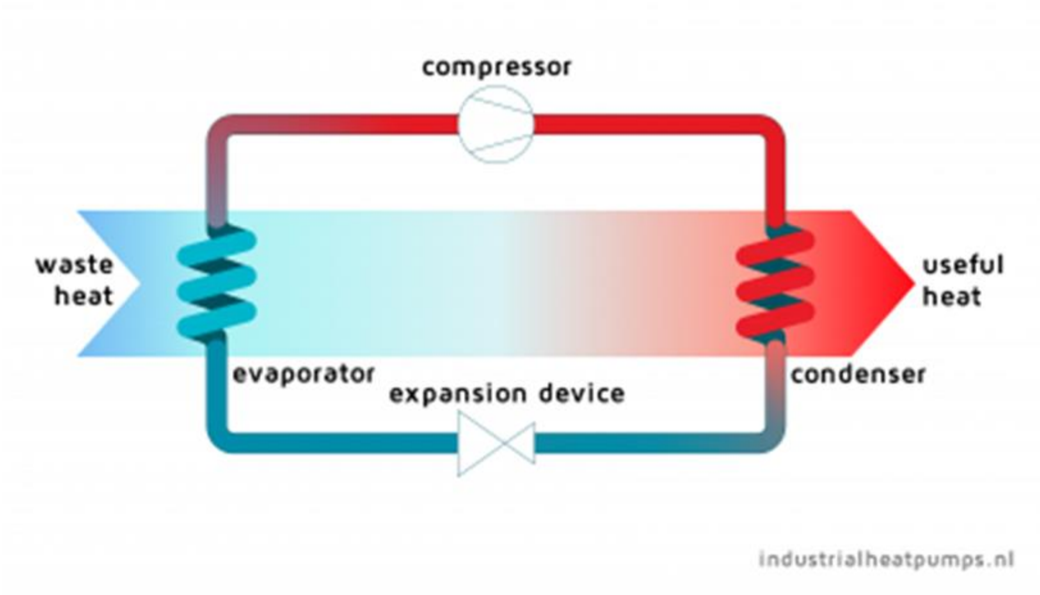

Figure 9: heat pump system has four main parts, the compressor, the evaporator, the expansion valve and condenser (Industrial Heat Pumps, 2017)

3.5.2 Analysis of the technology

The main characteristic of the heat pump analysed is that it generates steam and uses pentane as a medium. There are two main cycles related to the operational part, the cycle of water and of pentane. The specific technology in order to operate it needs to find a source of water at 85°C and the amount of water to generate steam at 2.8 t/hr. The interesting points of the specific technology is the ability to generate steam allowing the heat pump to integrate in the existing thermal system of the brewery and to reach temperatures as high as 150°C. By integrating to the existing distribution system, Heineken can save a vast amount of cost from installations. Other important aspects of the heat pump system is that has a heating capacity of 245kWh with condensing temperatures of 150°C-160°C, evaporation temperatures of 70°C-80°C and COP 3, higher COP can be achieved if the system is adjusted in optimal operation (Wemmers, 2019).

3.5.3 Pentane

The technology is used as medium pentane also called n-pentane. Its formula is C_5H_{12}, it belongs to the family of alkanes, it is colorless and it can be found in crude oils. The evaporation temperature of pentane is at 75°C. According to Kiss & Ferreira (2016), pentane and ammonia are good refrigerants with lower environmental impact compared to other ones. The pentane cycle is of major significance because it determines the temperature of the waste heat source. Figure 10 pictures the operational overview of the selected technology.

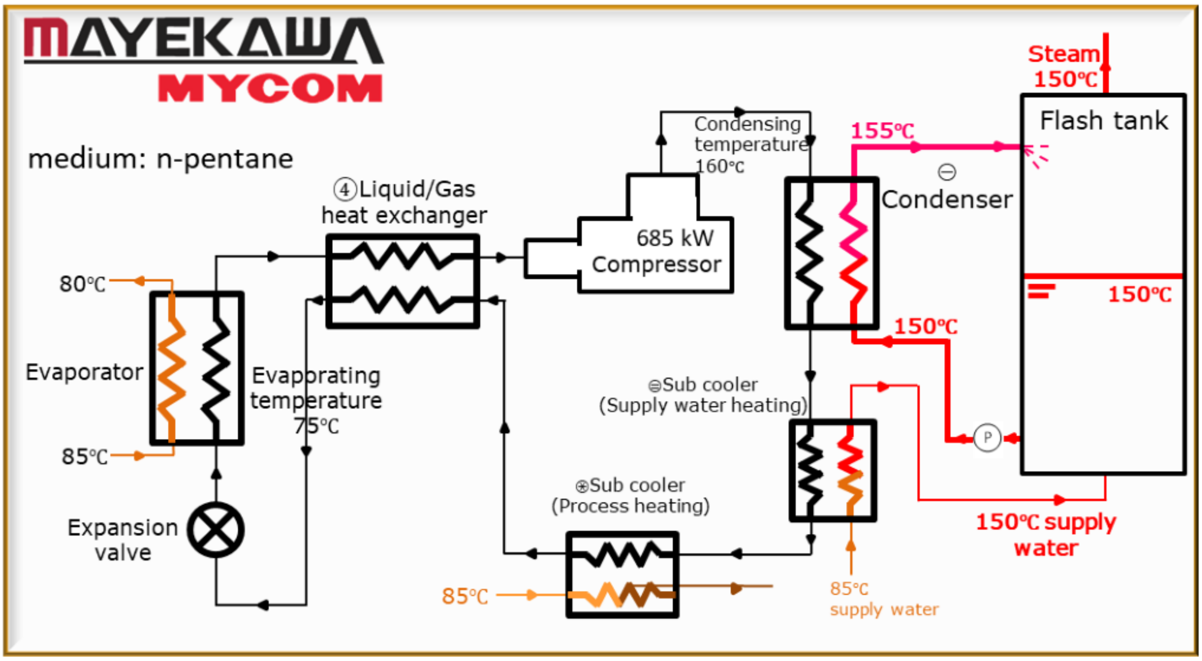

Figure 10: operational overview of heat pump using pentane as medium to generate high pressure steam (Wemmers, 2019).

3.5.4 SWOT diagram

Figure 11 illustrates a SWOT diagram with strengths/weaknesses and opportunities/threats of the heat pump using pentane. Firstly, the biggest strength that this technology brings to the table is the integration to the existing steam distribution system. The weakness that rises with the selection of breweries to apply it, because in order to be effective it needs a low electricity tariff and high heat demand. For the opportunities part it is really interesting to look at, because it has the potential to highly decrease the fuel consumption for steam generation within a site. Finally, a big threat appears with the selection of breweries to apply for it. To apply this technology it is necessary to have two main characteristics, a waste heat source of 85°C and the amount of water to produce a stream of 2.8 t/hr. It is also important to mention that the heat pump using pentane has not been applied in a brewery yet (TRL 8), therefore, it can be a game-changer in the coming years.

Figure 11: Schematic of SWOT diagram for heat pump provided by MAYEKAWA (author's own diagram)

3.6 Overview of the potential for the three WHR technologies

Chapter 3 included the analysis of the three WHR systems selected with the highest global potential. Firstly, there was an overview of the process areas in a brewery this project focusing on. Furthermore, the analysis of the three selected technologies took place. The chimney condenser showed that it can be applied with every type of fuel and can considerably reduce the pollutant percentage. Similarly, WHR from cooler during wort boiling (Meurastream) is a proven technology within Heineken, can result in a low evaporation rate and allows more final product. Finally, the heat pump's biggest strength is that it can integrate into the existing steam distribution system, which results in lower investment costs and to high thermal savings. Chapter 3 made an analysis of three systems that can be game-changers. Chapter 4 will show where Heineken should aim with these technologies in order to move the needle towards thermal savings.

Chapter 4

Where Heineken should focus to achieve high thermal savings

4.1 Background

As mentioned in Chapter 1 the company is planning to reduce the thermal energy consumption at a global level. As a result, innovations need to take place globally. Chapter 4 makes a dip dive with implementation scenarios for each of the technologies analysed in chapter 3. The different scenarios will provide evidence on if the selected WHR systems can move the needle towards thermal reductions. In addition, every scenario will provide the reader with evidence related to possible thermal reductions the technologies can provide at a global scale. Similarly, in order to examine their impact, this project will target the brewery sites that have a lot potential to improve on thermal consumption. Hence, to select these sites different criteria are set to make a priority list. The first section of chapter 4 is the priority sites of Heineken regarding thermal usage. The final section is the potential impact of the three technologies on the priority sites of Heineken. As a result, that could be a good indicator if the selected systems can be game-changers for the coming years and where should the company target first for their implementation.

4.2 Prioritization criteria

Chapter 4 includes an analysis with the priority sites of thermal consumption at global scale. There are 5 criteria taken into consideration to make a priority list. Figure 12 illustrates the prioritization criteria of the research.

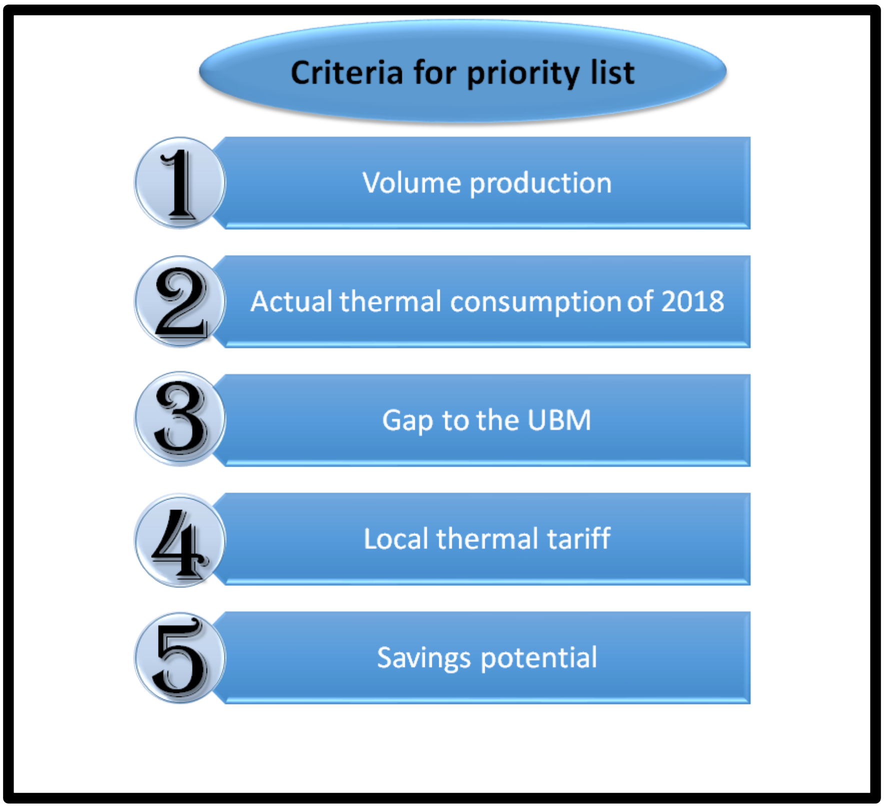

Figure 12: criteria to make a priority list in thermal consumption for Heineken (author's own diagram)

The first of the criteria is the annual volume production for 2018 in hl. This project includes breweries from peer 4, because they have the highest impact (more than 1,5 million hl/year production) at a global level. The next of the criteria is the actual thermal consumption for 2018 in MJ/hl. Hence, chapter 1 mentions the UBM, which is a tool for Heineken to set benchmarks annually regarding thermal consumption. The UBM values set for thermal are the ones the company must reach in the future in order to fulfil the energy consumption targets aimed. As a result, this analysis in order to find the priority sites, takes the actual thermal consumption of Heineken sites from peer 4 minus the benchmark values to find the gap to the UBM in MJ/hl. Thus, the sites selected were the ones with the highest gap in MJ/hl. The other criteria of importance is the thermal tariff in €/MJ and the savings potential in €. The thermal tariff in €/MJ was based on the local fuel prices of every Heineken brewery and the higher the fuel price is, the shorter payback period when people invest for new technologies. Finally, to find the savings potential for every brewery site the researcher, took the priority sites based on the previous criteria and multiplied the actual thermal value times the thermal tariff for each site, minus the UBM thermal value times the thermal tariff for each site. The savings potential in € shows sites more attractive to make investments for innovative solutions.

4.3 Priority sites

The process of the analysis included data gathering from Heineken online sources for all sites. The next step was to transfer the data into an excel spreadsheet and create a pivot table with the criteria mentioned. Each column included filters to make the selection easier. Making a list of the priority sites based on the process mentioned allowed the researcher to create tables and a bubble chart to have the priority sites in an illustrative manner. Firstly, table 2 illustrates data related to the priority sites. It includes the site name of the site, actual thermal consumption, UBM value, gap to UBM, tariff, volume production and potential savings.

Table 2: Priority sites of Heineken based on thermal consumption (author's own estimations)

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Figure 13 shows a bubble chart based on the data from table 2, to make a comparison between sites and create a clear picture of the different technological application potentials analysed later on. The sites placed towards the left side of the graph have a smaller gap to the UBM compared to the ones towards the right. The sites with the highest gap to the UBM are the ones that need to experience changes in the future in order to close the gap between the actual and the targeted value. In addition, the UBM gap and savings potential are deeply connected, because as mentioned to find the savings potential, the researcher had to multiply the actual thermal value of each site with the local tariff and UBM value with the local thermal tariff. The difference between the two estimations resulted to the savings potential for the sites examined.

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Figure 13: Bubble chart with the priority sites based on data gathered from 2018. It includes the savings potential, gap to UBM and thermal tariff (author's own diagram).

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This part includes an analysis of the priority sites within Heineken.

4.4 Impact scenario of the selected technologies on the priority sites

This section of chapter 4 pictures the possible results of the three selected technologies if applied. As mentioned in chapter 3 the only technology that has already been tested in brewery is the Meurastream. As a result, this is the only technology that has a cost for investment, allowing the researcher to estimate the payback periods. The chimney condenser and heat pump have not been applied in a brewery yet, making it impossible during the period of the project to get an estimated cost. Similarly, leading to measurement only on thermal savings for the two last systems mentioned.

4.4.1 WHR from cooler (Meurastream)

Due to the amount of data available, the analysis of the application scenarios will start with the Meurastream. Table 3 has an application scenario based on thermal data from 2018. Additionally, there are four columns of interest. The first column has the site names and the second one has the thermal savings potential in the brewhouse. The third column has the potential pay back periods. Finally, the fourth column shows the global impact compared to every Heineken site. To find the numbers presented, the column had a sum of all beer produced by Heineken in hl for 2018, divided by the consumption in brewhouse with Meurastream applied.

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Analysis of the technological impact at the priority sites based on confidential data.

Table 3: Scenario if Meurastream was applied in the priority sites by 2018, illustrating if the technology can move the needle towards thermal consumption (author's own estimations).

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4.4.2 Chimney condenser with filter and heat pump

The two technologies analysed in this part have not been applied in breweries yet. As a result, there is no focus on the investments or payback periods. The scenarios are mainly on the possible reductions of thermal consumption. In addition, the estimation is based on a hypothetical ideal environment for the technologies working on optimal conditions. As mentioned in chapter 3 in order to apply the technologies, specific site characteristics and conditions are of major significance. However, there was a limited amount of time to fulfil the project, not allowing the researcher to get access on each site specific characteristics.

For the chimney condenser some of the main characteristics needed are the content of the flue gas, an in-situ WWTP, size of the boiler and temperature of the flue gas. The scenario illustrated will be based on recovering the flue gas within the utilities and reusing the hot water for preheating the water inside the boiler. Similarly, for the heat pump it is important for the site to have a waste heat source of 85°C, available water for producing steam at 2.8t/hr and cheap electricity tariff. Hence, if the site has an annual production of around 3 million hl per year at most, the technology has the potential to cover the steam produced for the packaging area. In addition, the analysis on the thermal savings by the heat pump does not include the electricity needed for its operation.

Table 4 has five columns providing data of the two technologies if they were applied in the priority sites. The first column illustrates the priority sites names, the second and third ones show the thermal savings. Similarly, the fourth and fifth column illustrate the global impact of the technologies at a global scale compared to all Heineken sites. This is a good indicator if they can have a high impact on global thermal energy savings.

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Analysis including impact of the technologies to the priority sites.

Table 4: Scenario of heat pump and chimney condenser applied in the priority sites by 2018, illustrating if the technologies can move the needle towards thermal consumption (author's own estimations).

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As illustrated in table 3 and table 4 the three WHR systems can have a very high impact on the current situation of Heineken. They can move the needle towards thermal reductions. The biggest thermal consumption is in the brewhouse and packaging area. As a result, the Meurastream and the heat pump can be concrete solutions to increase efficiency. To conclude, the chimney condenser can also highly increase the efficiency of the boilers and avoid issues presented before. Also, it can benefit other areas such as reduction of pollutants and allowing sites comply with environmental regulations.

4.5 Overview of where should Heineken aim for thermal savings

Chapter 4 consisted of two areas of interest illustrating where Heineken needs to focus for achieving high thermal savings. The first part included the formation of a priority list with Heineken sites. The priority list was based on criteria set by the researcher to end up on where immediate action needs to take place for fulfilling the targets set by the company.

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The six sites mentioned need to experience significant changes in terms of thermal usage. The analysis included comparisons between the sites to give to the reader a clear picture of the existing situation. The second part illustrated scenarios of the potential improvements the three technologies can bring to the table site by site. To conclude, chapter 4 showed where the technologies will have the highest global impact to fulfil Heineken needs.

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

The aim of this project was to investigate which heat recovery/reuse technologies are feasible to improve Heineken's energy saving performance globally, and which brewery sites should have priority in the energy saving ambitions of the company. In order to answer the research question, the analysis included two main parts. The first part was to find which are the technologies that have the capacity to improve thermal savings performance and the second part where are the sites that Heineken needs to target for moving the needle towards thermal savings. Chapter 2, chapter 3 analysed the first part and chapter 4 analysed the second part.

Chapter 2 illustrated Heineken as a global company within the food and beverage industry. More specifically it showed the company's structure and operations. Hence, there was an analysis on the brewing process including the most thermally intensive areas of a brewery. Finally, there was an analysis of the WHR systems Heineken currently uses at a global level.

Furthermore, chapter 3 included the analysis of the three WHR systems selected with the highest global potential. Firstly, there was an overview of the process areas of interest in a brewery. In addition, the next part of the chapter provided an analysis of the three selected technologies. The analysis included four main sections, the same for every system. The first area of importance was where the technology can be applied in breweries. The second area examined was the operational principle and the characteristics they possess. The third section was an existing example within the industry or in other industries. To conclude, there was a SWOT diagram including the strengths/weaknesses and opportunities/threats that may appear.

Chapter 4 included the second main phase of the project for moving the needle towards thermal savings. The first part of chapter 4 included the formation of a priority list with Heineken sites. The priority list was based on criteria set by the researcher to end up on where immediate action needs to take place. The second part illustrated scenarios of the potential improvements the three technologies can bring on the table by focusing on the priority sites. Finally, chapter 4 showed in which sites the technologies will have the highest global impact to fulfil Heineken needs.

5.2 Recommendations

This project is an illustrative analysis on how Heineken can move the needle on thermal savings by putting attention into WHR. As a result, Chapters 3 and 4 present a good approach to the topic. The chapters examined some WHR technologies from the market providing their strengths/weaknesses and opportunities/threats. Also, they make application scenarios on the possible impact the WHR systems could have. At this point it is of high importance to provide an overview related to the WHR systems. The overview includes the biggest limitations to consider while the company fulfils the next steps.

Regarding the thermal savings in the brewhouse a good global approach for Heineken would be to apply the Meurastream. It can be a good solution for replacing the current systems applied or include it in the design of new Heineken breweries. However, one of the big limitations is the investment cost. Therefore, the company can firstly target sites with high thermal tariffs leading to shorter payback periods. As presented in chapter 4, there are three sites that the investment will have very short payback periods

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Hence, the analysis showed that for other cases if the volume produced is more than 2 million hl, the brewhouse consumption more than 20MJ/hl and the tariff is ~ 0.02 €/MJ, the payback period will be 4 years. Finally, if the technology is applied it will highly increase the environmental performance and allow more brews leading to higher beer production.

For the packaging area this project suggested the heat pump producing high pressure steam as a solution. The heat pump can have a very high impact by replacing the amount of steam produced for the packaging area if the production is at most 3 million hl/year. In addition, Heineken needs to pay attention to multiple site specific characteristics in order to make it an attractive solution for future implementation. The important parameters for selecting a site is to have a high heat demand and low electricity tariff. Another significant trait is that this solution will be beneficial depending on the electricity produced in-situ or if purchased to be certified as renewable. That is of major significance due to the high electricity consumption of the system.

Increasing the efficiency of the boilers is very significant for every brewery.

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Information on Heineken operations.

Pojoulat created a system surpassing most of the barriers faced previously. Applying the chimney condenser with filter has multiple advantages such as the 50% waste heat recovery. However, Heineken for implementing it in the future needs to consider that it has not been applied in the food and beverage industry yet leading to multiple parameters needing further investigation. For example, one of them is the chemicals existing in the filtration system leading to an additional COD within the WWTP.

To conclude, all the parameters mentioned in this project if examined properly can lead to significant thermal savings at a global level for Heineken as a multinational company.

References

54events B.V. (2019). *Biomassacentrale krijgt rookgasreiniging en warmteterugwinning - Industrial Heat & Power*. [online] Available at: https://www.industrialheatandpower.nl/nl/nieuws-item/Biomassacentrale-krijgt-rookgasreiniging-en-warmteterugwinning/ [Accessed 17 Jan. 2020].

Bangerth, S., Tiwari, R., Shooshtari, A., & Ohadi, M. (2019). Process intensification in a spinning disk absorber for absorption heat pumps. Applied Thermal Engineering, 162, 114179. doi: 10.1016/j.applthermaleng.2019.114179

Bokulich, N., & Bamforth, C. (2013). The Microbiology of Malting and Brewing. Microbiology And Molecular Biology Reviews, 77(2), 157-172. doi: 10.1128/mmbr.00060-12

Chen, X., & Voigt, T. (2020). Implementation of the Manufacturing Execution System in the Food and Beverage Industry. *Journal Of Food Engineering*, 109932. doi: 10.1016/j.jfoodeng.2020.109932

Chua, K., Chou, S., & Yang, W. (2010). Advances in heat pump systems: A review. Applied Energy, 87(12), 3611-3624. doi: 10.1016/j.apenergy.2010.06.014

Dedrick, J. (2010). Green IS: Concepts and Issues for Information Systems Research. *Communications Of The Association For Information Systems*, *27*. doi: 10.17705/1cais.02711

Dusek, J. (2013). Mayekawa develops high temperature hydrocarbon steam heat pump. Retrieved 28 January 2020, from http://www.hydrocarbons21.com/articles/mayekawa_develops_high_temperature_hydrocarbon_steam_heat_pump

Ec.europa.eu (2015). Retrieved 31 October 2019, from https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

El-Temtamy, S., Hamid, I., Gabr, E., & Sayed, A. (2010). The Use of Pinch Technology to Reduce Utility Consumption in a Natural Gas Processing Plant. Petroleum Science And Technology, 28(13), 1316-1330. doi: 10.1080/10916460902839248

Galitsky, C., Martin, N., Worrell, E. and Lehman, B. (2003). *Energy Efficiency Improvement and Cost Saving Opportunities for Breweries*. Guide for Energy and Plant Managers. ENERGY STAR.

Gex, E. (2016). Despite High Energy Needs, Industries Can Help Reduce Global Greenhouse Gas Emissions. Retrieved 11 January 2020, from https://www.worldbank.org/en/news/press-release/2016/08/31/despite-high-energy-needs-industries-can-help-reduce-global-greenhouse-gas-emissions

Golusĭn, M., Dodić, S., & Popov, S. (2013). *Sustainable energy management* (p. 243). Waltham, MA: Academic Press.

Heaing and Power-Poujoulat. (2019). Presentation, Zoeterwoude.

Hou, S., & Zhang, H. (2019). A novel solar assisted vacuum thermionic generator-absorption refrigerator cogeneration system producing electricity and cooling. Energy Conversion And Management, 187, 83-92. doi: 10.1016/j.enconman.2019.02.082

Huang, Y., Tippmann, J., & Becker, T. (2017). Kinetic studies of main wort flavor compounds and iso-α-acids during wort boiling: a review. European Food Research And Technology, 243(9), 1485-1495. doi: 10.1007/s00217-017-2858-6

Industrial Heat Pumps. (2017). Retrieved 5 November 2019, from http://industrialheatpumps.nl/en/how_it_works/cop_heat_pump/

Johnson, I., Choate, W.T., Davidson, A. (2008). *Waste Heat Recovery. Technology and Opportunities in U.S. Industry* BCS Inc: Washington, D.C.

Jouhara, H., & Olabi, A. (2018). Editorial: Industrial waste heat recovery. *Energy*, *160*, 1-2. doi: 10.1016/j.energy.2018.07.013

Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., Tassou,S. A.(2018). Waste heat recovery technologies and applications. Thermal Science and Engineering Progress, Volume 6, p.p. 268-289

Kechichian, E., Pantelias,, A., Reeves,, A., Henley, G., & Liu, J. (2016). *Policies for Climate Action in Industries and Products*. WASHINGTON: World Bank.

Kiss, A., & Ferreira, C. (2016). Heat pumps in the chemical process industry (pp. 20-100). Taylor & Francis group.

Kok, Y., Ye, L., Muller, J., Ow, D., & Bi, X. (2018). Brewing with malted barley or raw barley: what makes the difference in the processes?. Applied Microbiology And Biotechnology, 103(3), 1059-1067. doi: 10.1007/s00253-018-9537-9

LeBlanc, S. (2014). Thermoelectric generators: Linking material properties and systems engineering for waste heat recovery applications. Sustainable Materials And Technologies, 1-2, 26-35. doi: 10.1016/j.susmat.2014.11.002

Luo, J., Sasaki, W., & Masumoto, Y. (2012). Indian Ocean warming modulates Pacific climate change. *Proceedings Of The National Academy Of Sciences*, *109*(46), 18701-18706. doi: 10.1073/pnas.1210239109

Makuch, M., Kukuczka, L., Bakker, S., & Bloemen, H. (2016). Energy and Water survey Den Bosch, Netherlands. (confidential)

Mankins, J. (1995). Retrieved 31 October 2019, from https://spacese.spacegrant.org/SEModules/Technology%20Mods/Mankins_trl.pdf

Meseguer, J., Pérez-Grande, I., & Sanz-Andrés, A. (2012). Spacecraft thermal control. Cambridge: Woodhead Pub.

Meura (2016). Retrieved 1 November 2019, from http://suomenpanimomestariyhdistys.org/seminar2016/11%20Energy%20savings%20Meura.pdf

Muster-Slawitsch, B., Weiss, W., Schnitzer, H., & Brunner, C. (2011). The green brewery concept – Energy efficiency and the use of renewable energy sources in breweries. Applied Thermal Engineering, 31(13), 2123-2134. doi: 10.1016/j.applthermaleng.2011.03.033

Odogwu, E. (2019). WHR recovery in breweries [In person]. Heineken Zoeterwoude.

Olafsen, M. (2018). Optimization and Process Improvements of a High Temperature Heat Pump Using Butane as Working Fluid (Master). Norwegian University of Science and Technology.

One2share.com (2020). Retrieved 2 February 2020, from https://login.microsoftonline.com/66e853de-ece3-44dd-9d66-ee6bdf4159d4/oauth2/authorize?response_type=code&client_id=695e53f1-ea1c-4612-9a4f-ebf4ccb67a7f&scope=openid&nonce=6fd8aaae-f2a3-4994-9b0e-2c9cb7535f89&redirect_uri=https%3a%2f%2fheiport.heiway.net%2f&state=AppProxyState%3a%7b%22InvalidTokenRetry%22%3anull%2c%22IsMsofba%22%3afalse%2c%22OriginalRawUrl%22%3a%22https%3a%5c%2f%5c%2fheiport.heiway.net%5c%2f%22%2c%22RequestProfileId%22%3anull%7d%23EndOfStateParam%23&client-request-id=af9b0f23-ee34-4e98-b634-61e0ba7b28e9&sso_reload=true. (confidential)

Optimising heat recovery from industrial processes with heat pumps. (2015). Retrieved from https://www.ehpa.org/about/news/article/optimising-heat-recovery-from-industrial-processes-with-heat-pumps/

Papapetrou, M., Kosmadakis, G., Cipollina, A., La Commare, U., & Micale, G. (2018). Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country. Applied Thermal Engineering, 138, 207-216. doi: 10.1016/j.applthermaleng.2018.04.043

Parasuraman, A. (2000). Technology Readiness Index (Tri). Journal Of Service Research, 2(4), 307-320. doi: 10.1177/109467050024001

Pojoulat. (2019). 2019 10 Terraosave 2019 En Ld. Retrieved 28 January 2020, from https://en.calameo.com/books/005249585b50d53a95f1f.

Schisler, D., Ruocco, J., & Mabee, M. (1982). Wort Trub Content and Its Effects on Fermentation and Beer Flavor. Journal Of The American Society Of Brewing Chemists, 40. doi: 10.1094/asbj-40-0057

Sluyterman, K. and Bouwens, A. (2014). *Brewery, brand, and family*. Amsterdam: Boom.

Sorrell, S. (2000). Barriers to Energy Efficiency in the UK Brewing Sector. Science and Technology Policy Research (SPRU), University of Sussex

Spirax Sarco. (2011) An Explanation of Specialist Boiler Types and Other Specialist Features, Spirax Sarco, Cheltenham.

Sustainable Development Goals Sustainable Development Knowledge Platform. (2015). Retrieved 25 October 2019, from https://sustainabledevelopment.un.org/?menu=1300

The HEINEKEN Company - Age Gate. (2018). Retrieved 28 October 2019, from https://www.theheinekencompany.com/Sustainability/Focus-Areas/Reducing-CO2-Emission

Thekdi, A. and Nimbalkar, S. (2014). *Industrial Waste Heat Recovery: Potential Applications, Available Technologies and Cross Cutting R&D Opportunity*. [online] Info.ornl.gov. Available at: https://info.ornl.gov/sites/publications/files/Pub52987.pdf [Accessed 14 Jan. 2020].

Tijani, H., Spoelstra, S. and Poignand, G. (2008). Study of a thermoacoustic-Stirling engine. *The Journal of the Acoustical Society of America*, 123(5), pp.3541-3541.

Tokos, H., Pintari , ., rajnc D. (2012) An Integrated sustainability performance assessment and benchmarking of breweries, Clean Techn Environ Policy, Volume 14, p.p. 173-193

Tomescu, M., & Csatlos, C. (2012). ENERGY SAVING WORT BOILING SYSTEM IN BREWING FACTORY. In INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER AFASES. Transilvania: GENERAL AIR FORCE ACADEMY ARMED FORCES ACADEMY ROMANIA. Retrieved from: http://www.afahc.ro/ro/afases/2012/eng/4.3/Tomescu_CSatlos_Energy.pdf

Trinkenreich, B., Santos, G. and Barcellos, M. (2018). SINIS: A GQM+Strategies-based approach for identifying goals, strategies and indicators for IT services. *Information and Software Technology*, 100, pp.147-164.

Uchino, K. (2010). Advanced piezoelectric materials (pp. 1-85). Woodhead Publishing Series in Electronic and Optical Materials.

Vallack, H., Timmis, A., Robinson, K., & Sato, M. (2011). *Technology Innovation for Energy Intensive Industry in the United Kingdom*. ECN publication. Retrieved from https://publications.ecn.nl/BS/2011/ECN-O--11-047

Van de Kamp, S. (2019). Poujoulat-chimney condenser with filter [In person]. Zoeterwoude.

van Donkelaar, L., Hageman, J., Oguz, S., Noordman, T., Boom, R., & van der Goot, A. (2016). Combining unmalted barley and pearling gives good quality brewing. Journal Of The Institute Of Brewing, 122(2), 228-236. doi: 10.1002/jib.319

Wemmers, A. (2019). Steam generation heat pump-Maykawa. Presentation, Zoeterwoude

Woolley, E., Luo, Y., & Simeone, A. (2018). Industrial waste heat recovery: A systematic approach. *Sustainable Energy Technologies And Assessments*, *29*, 50-59. doi: 10.1016/j.seta.2018.07.001

Zhou, J., Pang, W., Lu, X. (2011) TPV generation of electricity by waste heat recovery from high-temperature gas using rare-earth emitters. January 2011

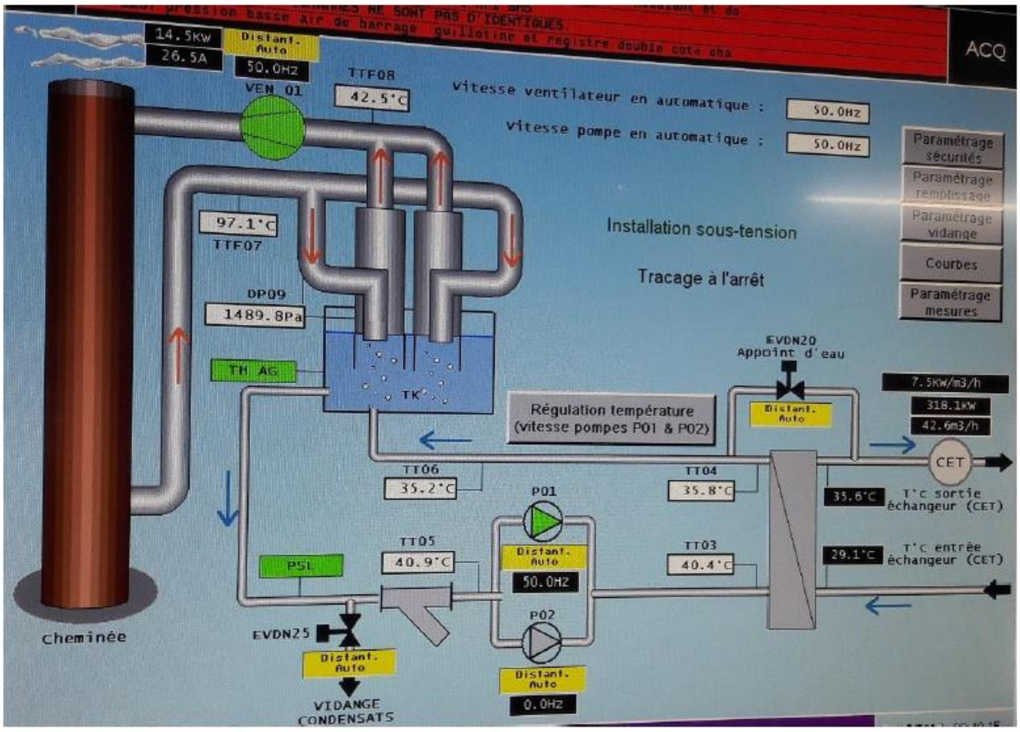
Zieler, W. (2017). Heat Pumps: The Dutch Way. IEA Heat Pump Conference – Rotterdam. Retrieved April 16, 2019 from http://hpc2017.org/wp-content/uploads/2017/05/P.2.7.3-Heat-pumps-the-Dutch-way.pdf

Appendix 1 Chimney condenser working also as filter

Key points and schematics from the meeting with Stephan Van de Kamp from Poujoulat

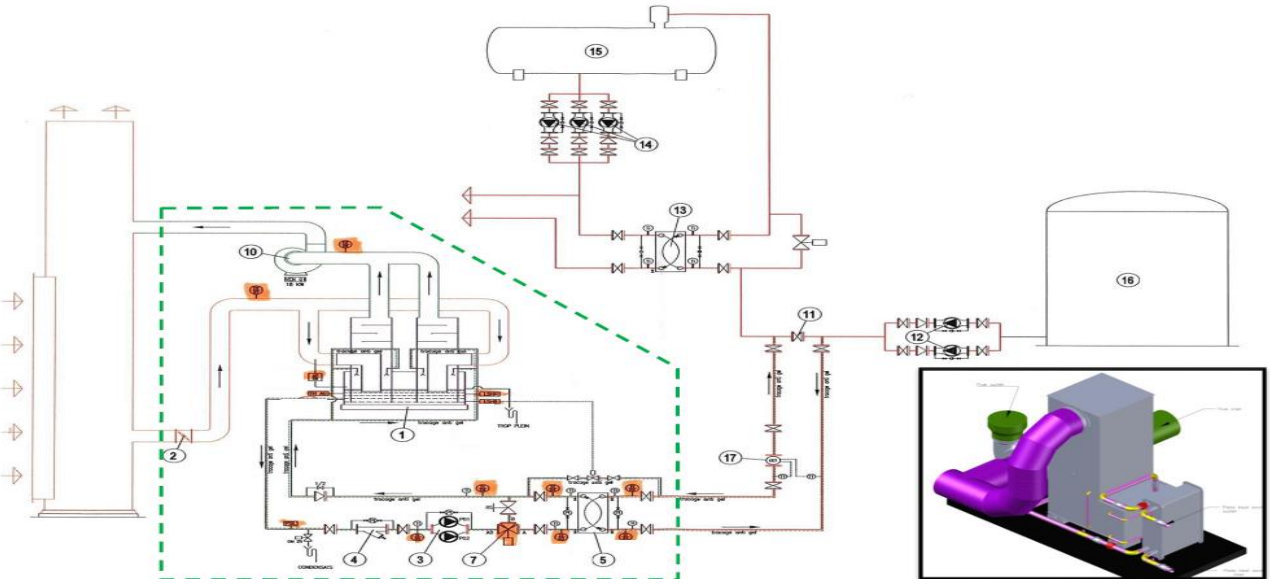
- Needs to be connected to a continues clean water flow and must be connected to a WWTP
- The responsible engineer needs to fill out a form to let them know the specifications of the brewery site that will be installed to be able to estimate the cost.
- The efficiency of flue gas recovery is determined by the speed that the flue gas passes by the terraosave.
- The structure of the device includes a gas and a water inlet. It is different to a common chimney condenser, there are 15 cm of water on the bottom part of the device. The flue gas passes by and the pollutants are captured by a big portion by chemicals within the water. The system has also a filtration system to better treat the water containing the pollutants.
- The type of pollutants contained in the flue gas need to be registered in order to prepare the appropriate filtration system.
- The combination of a filter and economizer is more expensive than this technology and works as a filter and chimney condenser together.
- It can be made by different materials e.g. by stainless steel, plastic and aluminium, etc., plastic is cheaper than steel and all materials can be used for all the fuels.
- The maintenance can be provided by the supplier and because it doesn't include moving particles it is easy to maintain just once per year.
- The existing installations include a biomass boiler in the northeast of the Netherlands
- It can be used in a primary and secondary process, can be used to preheat air and water in the boiler or into other areas.
- They give a guarantee on the efficiency
- The existing examples are 30 applications.

TERRAOSAVE
SCREEN CONTROL



Heating & Power
Poujoulat
Chimney & Exhaust Solutions

TERRAOSAVE
PROCESS DIAGRAM



Appendix 2 Meurastream

Meurastream vs Vapour condensation the case of Da Nang Heineken

MEURASTREAM VS VAPOUR CONDENSATION

The MEURASTREAM is by far exceeding the performances of the conventional vapour condensation.

With the conventional vapour condensation, the vapours from wort boiling (generally between 4% and 8% evaporation) are condensed to prepare water up to 96°C. This water is stored in a so-called stratification tank since at a certain stage water at 96°C will float to the upper part in the vessel while colder water at 76-80°C will be at the bottom. The wort of the next brew will be heated with this energy to about 92°C (and potentially further heated to 99°C with a water booster).

Although the evaporation energy is partly recovered, the vapour condensation system has some major disadvantages compared to the Meurastream:

a) The need to evaporate at least 4%

To have sufficient energy to heat up the wort, at least 4% evaporation (theoretically 3.6 to 3.8%, in reality 4%) is needed. With 100% malt brews, and thus quite a high concentration of DMS formed during boiling, this evaporation of 4% may be required. But in the case of brewing with unmalted adjuncts a lower evaporation rate is common. Thus, in many cases, a 4% evaporation is necessary not for wort quality reasons, but for the operation of the heat recovery system!

b) No solution for excess hot water

In a conventional brewhouse, with wort cooling generating water at 80-85°C, the brewhouse is making more water than it needs for its own operation. Today more and more breweries do not have other consumers for this excess hot water. Consequently, brewhouses with vapour condensation are producing too much hot water.

c) Complexity of the system – maintenance costs

In general, a vapour condensation assembly consists of 4 heat exchangers (a large vapour condensator, an other large pre-heater, a water booster and condensate cooler). In addition there are a few valves in the circuit, as well as a fan to evacuate the non-condensed vapours. To summarize: the system has a certain complexity and will require substantial investment costs (Capex), but also maintenance costs (Opex).

d) Space requirement

The heat exchanger to condense the vapours from the wort kettle is very large, certainly when a tubular exchanger is used. Also, large-diameter piping is needed to connect the chimney to the heat exchanger. Furthermore, there is the significant height of the stratification tank. In conclusion, vapour condensation technology requires more space for its implementation.

e) Energy losses

If the brewhouse is shut down over the weekend, the water at 76-80°C and 96°C is stored in the stratification tank. Over the weekend, this water will mix and the temperature will go down, which makes the system for the first 2 brews inefficient.

CASE STUDY

VBL Da Nang

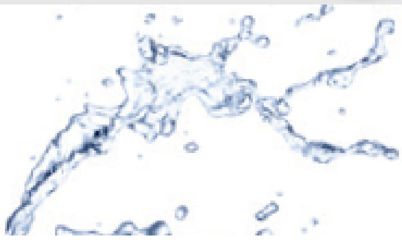
In 2014 a Meurastream was comissionned for the VBL brewery in Da Nang (Vietnam – partly owned by Heineken).

The table below shows the results before and after the installation of the **MEURASTREAM.**

	THERMAL ENERGY CONSUMPTION (MJ/HL AT 15° P)	PROCESS WATER CONSUMPTION (HL/HL AT 15° P)
Brewhouse before revamping	23.00 MJ/hl	1.50 hl/hl
Brewhouse after integration of the MeuraStream concept	11.52 MJ/hl	1.26 hl/hl

The thermal energy was reduced by 11.48 MJ/hl! With the current steam cost of 70$/T (= 0.03$/MJ), this represents a saving of 0.34$/hl. For a 2.4 million hl wort production a year, **it means 816,000 $ of annual savings in thermal energy!**

In addition, Da Nang achieved water savings of 0.24 hl/hl! Note that in case of excess production of hot water, not only is the water wasted, but also the energy it contains.



Edition 2015

Appendix 3 Heat pump using pentane

Some additional technical characteristics from Heat pump- Mayekawa

1. Investigation of steam temperature which can be generated by the present technology

- A heat pump supplying 150 °C heat (oil heating medium) using a screw compressor was developed between 2009 and 2014.

150℃ heat supply Heat Pump specifications

Item	Design condition
Refrigerant	Hydro carbon
Compressor	**Screw**
Design pressure	2.0MPaG
Heat capacity (@2950rpm)	**245kW**
COP_h	**3.0**
Heat source (wasted hot water) temperature range	70～100℃
Heat supply temperature	120～150℃

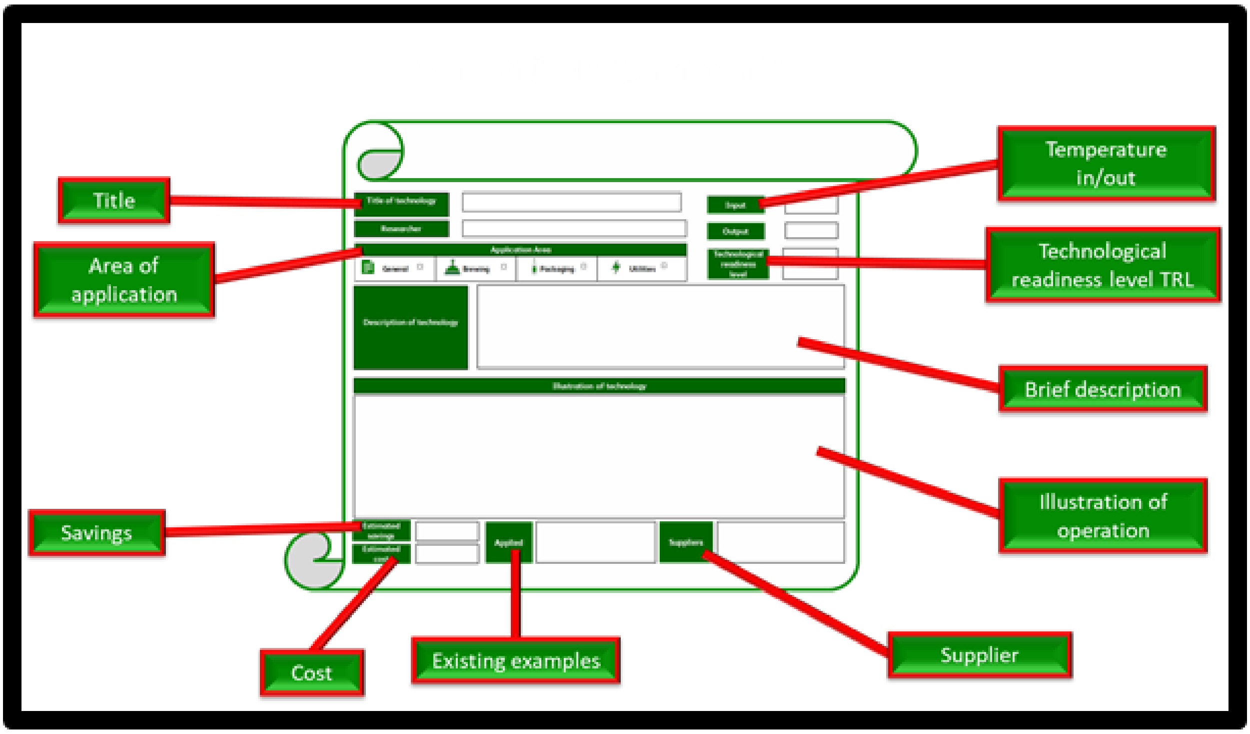
150°C heat supply HP (casing)

2

Appendix 4 Selection process for the WHR systems

Evaluation template

The evaluation template formed by the researcher is based on ten main elements. These elements illustrate if the WHR system analysed fits Heineken needs in order to move the needle referring to thermal savings at a global level. The creation of this template allowed the researcher to have the findings in an organised structure and to make clear what are the company's needs referring to WHR. According to Trinkenreich, Santos and Barcellos (2018) creating a checklist assists to define main strategies and significant indicators to achieve a goal set within a business. The elements included are the title of the examined system, the area of application in a brewery, TRL, waste heat temperature range, operational description, the illustration of operation, efficiency, cost, existing examples and name of the supplier. Figure 1 pictures an overview of the template. In addition, from the elements mentioned the ones with the highest determining value were the range of waste heat temperature, efficiency and maturity (TRL). As mentioned in chapter 1 waste heat in industries is categorized into three main categories, low, medium and high. It is of major significance to set a scope in which waste heat ranges this project is focusing on. By setting this scope the researcher makes a clear picture of which technologies will be phased out. For the food and beverage industry the available waste heat is mainly low (Thekdi and Nimbalkar, 2014). As a result, this project aims at technologies utilizing mainly low waste heat.



Technological readiness level

In order to measure the readiness level of the selected alternatives, the project uses the Technological Readiness Level (TRL) measuring system. The TRL system was originally created by NASA for systematically measuring and comparing the maturity between various types of technologies (Mankins, 1995). Furthermore, the measuring scale was later on adopted by the European Union (ec.europa.eu, 2015). The TRL measurement includes levels 1-9 and is illustrated in the figure below. The TRLs assist the reader with a checklist that can make sure the specific model fulfils the maturity level needed in an easy and understandable way, making them accessible for every Heineken brewery site globally.

Phaseouts of the technologies

The first part of the selection process was the creation of a template including different criteria to benefit the next part, which is the phaseouts to end up to the selected units. The research included 9 WHR systems. The data for this step were gathered from different suppliers, research centres and from literature. Furthermore, the process of selection included three key steps. Firstly, systems were phased out, due to low maturity levels e.g. TRLs of 1-7. The second step of phasing out included mature technologies of WHR that could not be applied in a brewery or if applied they would have a low impact. The final step was the selection of the systems with the highest global potential for thermal reductions. The 9 systems selected for the phase-out procedure were the thermoacoustic heat pump, a piezoelectric generator, thermoelectric generator, thermophotovoltaic generator (TPV), heat pipe, thermionic generator, chimney condenser with filter, WHR from cooler (Meurastream) and pentane heat pump.

Low maturity

The first phasing out of technologies was based on the maturity level they possess. In this part, the technologies were phased out because they are still under development, but in the coming years, they have the potential to highly benefit Heineken. Despite the TRL1-7 it is worth investigating them in the future. The technologies phased out due to low maturity levels were: 1) the thermoacoustic heat pump, 2) the piezoelectric generator and 3) the thermoelectric generator.

1) The first technology is the thermoacoustic heat pump's operational principle which has the generation of acoustic power by temperature differences. In addition, it pumps heat and amplifies it through a sound wave. It has a similar operation to the Stirling cycle, but without moving parts (Tijani, Spoelstra and Poignand, 2008). The main parts consist of this system are the resonator, low-temperature heat exchanger, regenerator and hot heat exchanger. The particular system is still under development with a TRL below 8.

2) Piezoelectric devices for heat recovery are made out of thin-film membranes and they work by converting ambient vibration such as oscillatory gas expansion into electricity (Uchino, 2010). There are technical challenges and disadvantages associated with these devices that limit their use for heat recovery. These disadvantages exist due to the low maturity of the technology. Therefore, there is going to be a lot of evolution regarding the technology the next 5 years according to specialists from the field.

3) Thermoelectric devices produce electricity directly from waste heat and eliminate the need for converting heat to mechanical energy, to produce electrical energy. However, their efficiency currently is low, but there are different projects taking place to increase the efficiency of the specific system (LeBlanc, 2014). It is currently immature for breweries, but in the coming years it can highly benefit Heineken. All of the systems mentioned are currently not mature enough, therefore, they are worth looking at, when they are complete and qualified to operate.

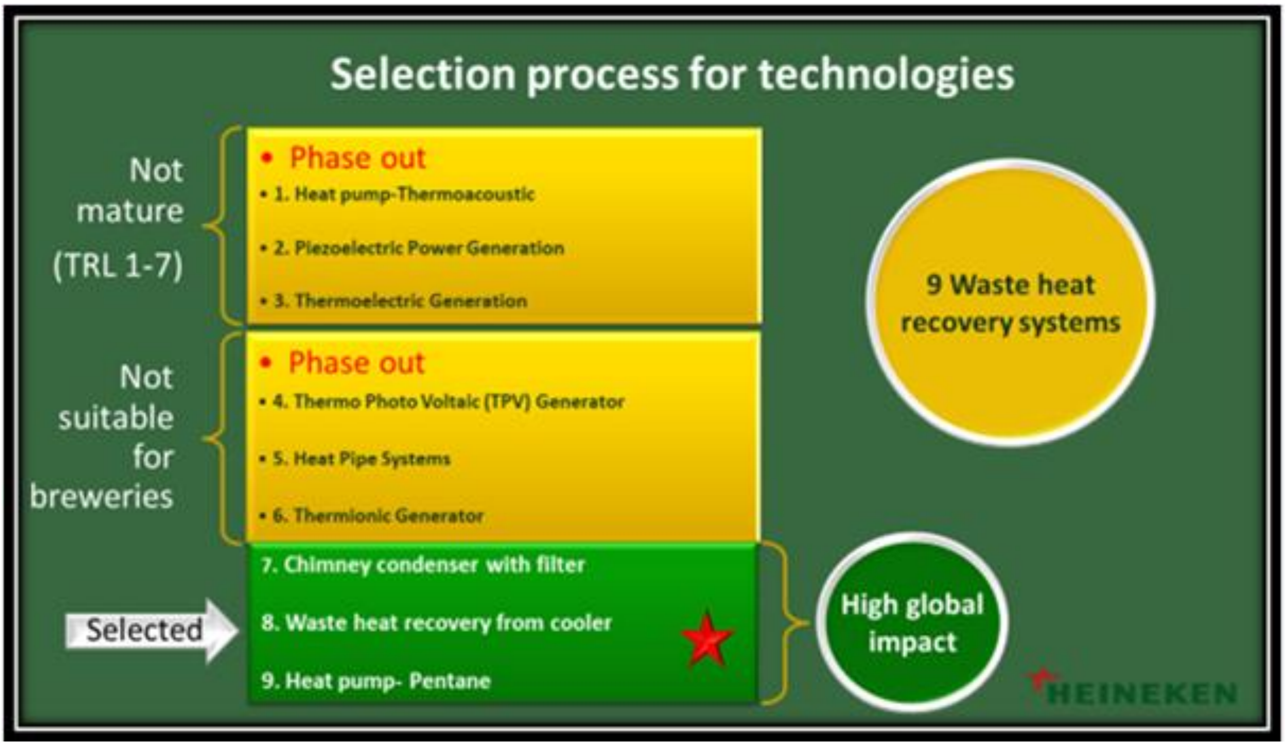
Not suitable for breweries

The technologies filtered out in this part did have at least a TRL 8. However, their application into a brewery was not possible either because of the need for medium-high temperature waste heat source or due to the low impact they would provide. Despite the phasing out in this project, they could possibly have a high impact in different industries. The systems phased out as ‘’not suitable for breweries’’ were the 1) the TPV generator, 2) the heat pipe and 3) the thermionic generator

1) The TPV generator converts radiant energy into electricity similar to solar panels. These systems are shown to potentially enable a new method of waste heat recovery and they use an emitter, a radiation filter and a Photovoltaic (PV) cell to produce electricity from a heat source (Zhou, Pang and Lou, 2011). This technology was phased out due to low efficiency making it not suitable for Heineken needs.

2) In heat pipe systems, heat is applied to one end of the pipe, it is conducted through the pipe wall and wick structure and the working fluid inside the pipe evaporates. As a result, vapour pressure is generated which drives the vapour through the adiabatic transport section to the other end of the pipe. The vapour then condenses by losing the latent heat of vaporization through the wick structure and wall of the pipe to the heat sink. The vapour flow then turns into liquid and is absorbed by the wick structure (Meseguer, Pérez-Grande and Sanz-Andrés, 2012). The system’s main use is to transfer heat with high efficiency. Therefore, it can be applied with high waste heat temperatures making it not suitable for breweries.

The next technology phased out was the thermionic generator. This technology operates with high-temperature waste heat and works by producing electric current through temperature difference between two media without the use of any moving objects (Hou and Zhang, 2019). Its operational principle includes a combination of plasma physics and surface physics. The plasma physics relation is based on how electrons are transported between the emitter and the collector. The surface physics is related to the electron current it uses and the electrode surface. Due to its low efficiency this technology was phased out as not suitable for a brewery.


Selection process for technologies
Not mature (TRL 1-7)
• Phase out
• 1. Heat pump-Thermoacoustic
• 2. Piezoelectric Power Generation
• 3. Thermoelectric Generation
Not suitable for breweries
• Phase out
• 4. Thermo Photo Voltaic (TPV) Generator
• 5. Heat Pipe Systems
• 6. Thermionic Generator
Selected
7. Chimney condenser with filter
8. Waste heat recovery from cooler
9. Heat pump- Pentane
9 Waste heat recovery systems
High global impact
HEINEKEN

Appendix 5 estimations for table 3, 4

Estimations Meurastream

- Savings in MJ/hl = Annual consumption thermal for brewhouse - brewhouse with meurastream
- Cost savings= (brewhouse actual thermal value * thermal tariff) – (brewhouse with Meurastream * thermal tariff)
- Payback period= cost for investment/cost savings with Meurastream
- Global impact= Heineken total volume 2018/ Brewhouse savings for each site with Meurastream applied

Estimations Heat pump

- Heat pump savings= Data from UBM on thermal consumption for packaging
- Global impact= sum of the annual volume production from all sites/the savings wehn heat pump applied for each site

Estimations Chimney condenser

- Chimney losses of site =Chimney losses percentage gathered from UBM * the actual thermal consumption of the site
- Savings in thermal= Chimney losses estimated/2
- Global impact= sum of the annual volume production of all sites/savings from chimney condenser of the site