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Sustainable practices in managing carbon dioxide emissions during a brewing process: a case study of HEINEKEN

Master thesis

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ABSTRACT

The brewhouse is a large energy consumer in the brewery. The paper reviews and evaluates environmental, particularly energy and CO2 emissions challenges, that breweries face during the brewing process. Taking the case of HEINEKEN, where carbon footprint takes up a huge part of their business philosophy, this paper identifies possible methods of reducing energy input during brewing process and this way lowering CO2 emissions. After an overview of the beer making process and carbon dioxide usage during brewing, methods are presented containing cleaner production, energy conservation and renewable energy application. Measures for cleaner production are based on equipment that can be introduced in the operation process. The suggested equipment for improvement such as low pressure wort boiling, vapour compression, filtration systems etc. are applied for wort boiling and mashing, since they are the main energy consumers in the brewhouse. Presented opportunities for saving and recovering energy can help to improve beer quality and reduce CO2 emissions. For the implementation of technologies in individual plants, further research is needed on economical and applicability measures. The practices for energy savings, such as continuous maintenance, monitoring, good housekeeping and replacement or improvement of inefficient equipment, introduced in this paper, can be easily incorporated into daily operations. These measures have very little or no investment, do not require specific installation knowledge and action can be taken immediately. The applicability of renewable energy sources was assessed according to several criteria including: Area requirements, Levelised cost of electricity (LCOE), Capital investment costs, CO2 emissions, Efficiency of electricity generation and Water consumption. Amongst the various renewable energy technologies, solar energy was ranked as one of the best possible options. The financial feasibility of photovoltaics in several geographic locations was evaluated using LCOE generation in order to be compared to regional electricity tariffs. The chosen locations were Singapore, Brazil and USA. The results revealed that only in Singapore the grid parity can be reached.

Keywords:

CO2 emissions, energy efficiency, conservation, recovery, renewables, solar energy, grid parity.

CONTENT

1. INTRODUCTION

Sustainability is becoming increasingly important to a wide range of corporate stakeholders such as consumers, potential investors, regulators, employees and society in general (Bringer et al., 1994). From an investors perspective it is believed that environmental, social and governance factors incorporated in their investment strategies can enhance investment value and mitigate risk. However, many profit-oriented companies still see the drive towards sustainability as a forced obligation, where government punishes them with regulations (Alfred et al, 2009).

From a consumer standpoint, growing numbers of customers prefer to purchase products from greener companies. Statistics show that more than half (55 %) of global consumers prefer to buy products and services from companies that have implemented programs in order to help the environment (Nielsen, 2014). From an employment perspective, it is becoming more difficult to attract key employees to positions in industries with high environmental risk (Epstein et al, 2001). Additionally, companies that engage in social and environmental stewardship benefit from employees who are more aware and involved (Aguilera et al, 2007). In general, it is implied that unsustainable production and consumption will degrade the ecological, social, and economic basis for tomorrow's society, while sustainability ensures that future generations will have the remedies to achieve better quality of life (Ilinitch et al., 1998; Gough, 2015).

The link between being an environmental-friendly and an economically successful company has been an essential topic of the corporate environmental management literature for some years. Some authors also assume that environmental protection causes only expenses to a company while others believe that environmental protection generally pays off and actually saves companies money (Appelbaum, 2000). There has been a wide range of empirical studies providing arguments for both sides. However, way more studies seem to be supporting the hypothesis that good environmental performance is not punished, but more beneficial in the long run. A company recklessly seeking only for profits regardless for negative effects it has on society and environment at large, cannot exist very long (Epstein et al, 2001).

The first steps companies are taking to march to sustainability usually arise in order to comply with the law (Benn, 2014). Environmental regulations vary by continent, country or region. In addition to legal standards, enterprises feel pressured to stand sure by voluntary codes, for instance the GRI table. Standards like that are more stringent than most countries laws, especially when they become applied to cross-border trade (Nidumolu, 2009).

Whenever government regulations or industry standards are of particular importance, companies overview their activities, implementing technological environmental practices and establishing policies that meet local, international standards of adequate organizations, and also diminish corporate costs (Stefan et al, 2008).

Once companies have learned to keep pace with legal requirements, they become strategically proactive about environmental issues as well. The initial purpose is usually to create a better image, but most corporations end up decreasing costs or creating new businesses too (Nidumolu et al, 2015). Becoming “green” lowers costs in a way that companies reduce their used inputs. The ambition to be more efficient extends from manufacturing facilities and offices to the supply chain (Shrivastava, 1995).

Indeed, sustainability seek is already starting to alter the competitive landscape, that will force companies to change the way they think about their production, technological procedures and business models. By treating sustainability as a goal today, early movers will develop competencies that competitors will be hard-pressed to match. This competitive advantage will stand them in good stead, because sustainability will always be an important part of development (Nidumolu et al, 2015).
The world's biggest breweries have long understood the importance of these sustainable practices, and not just because of good public relations. They realize that sustainability is also essential to a better tasting beer. Nowadays, when the beer still remains the world's most popular alcoholic beverage, the large breweries recognize their responsibility and power and have worked to support more sustainable farming practices, which in turn increase efficiencies and reduce costs (All about beer, 2015). HEINEKEN company is a good example. HEINEKEN has an ambition to become the largest sustainable brewery in the world and is therefore very open to new developments and innovations. With that in mind, the company is continuing to strive to be leader in all their business aspects (Heineken, 2015).

This Dutch brewing company's brand is the most widely spread beer brand in the world and HEINEKEN is the biggest brand in the European beer market measured in volume and value. In the beer industries, HEINEKEN accounts for 9.1 percent of the beer market share, which is the third global market share of the leading companies in 2014, based on volume sales. According to The Statistics Portal, HEINEKEN was ranked in approximately 25.5 billion U.S. dollars in beer sales. (Statista, 2014). Evidently, such a huge beer consumption impacts on the environment in many different ways. The company is a huge user of energy, consumer of water and other natural resources, atmospheric emissions, trade effluent and packaging waste.

There are many activities in the life cycle of beers and beverages which cause greenhouse gas (GHG) emissions. GHGs are, for instance, emitted during the cultivation of barley, when fertilizer is used which causes nitrous oxide gas (N2O) emissions. The use of fossil fuels, for instance during transport, brewing, cooling or the production of packaging materials, also cause GHG emissions. The three most relevant GHGs for the value chain are: carbon dioxide (e.g. from fuels), nitrous oxide (e.g. from fertilizer use) and methane (e.g. from agriculture and dumped spent grains).

Being aware of this fact the company has created a sustainability approach - "Brewing for a better world", by which the company is guided in order to accomplish their aspiration to become the world's greenest brewer.
Sustainability is one of HEINEKEN's established six key business priorities and brewing for a better world performance is integrated within company's strategy at local regional and global scales. In the annual sustainability report HEINEKEN excludes four main areas, or in their words commitments, that they are focusing on – water, carbon dioxide emissions, sourcing sustainably and responsible consumption.
In this paper the emphasis is put on carbon emission reduction which can be seen as a key measure of environmental damage.

HEINEKEN has developed a comprehensive carbon footprint model that calculates the greenhouse gas emissions of beverage production, in order to better understand the hotspots in the value chain and identify areas for improvement (Sustainability Report, 2012).
The 2011 carbon footprint was calculated for 24 Operating Companies worldwide and was published externally for the first time in HEINEKEN's sustainability report 2012. HEINEKEN made a commitment to publish and update the carbon footprint in its sustainability report every three years and the carbon footprint of 2014 (Figure 1) has been published in the 2015 Sustainability Report. As the report shows, the carbon footprint decreased from 68.4 kg CO2/hl in 2011 to 64.1 kg CO2/hl. The boundaries in the calculation include the complete life cycle of the product, from cradle-to-grave.

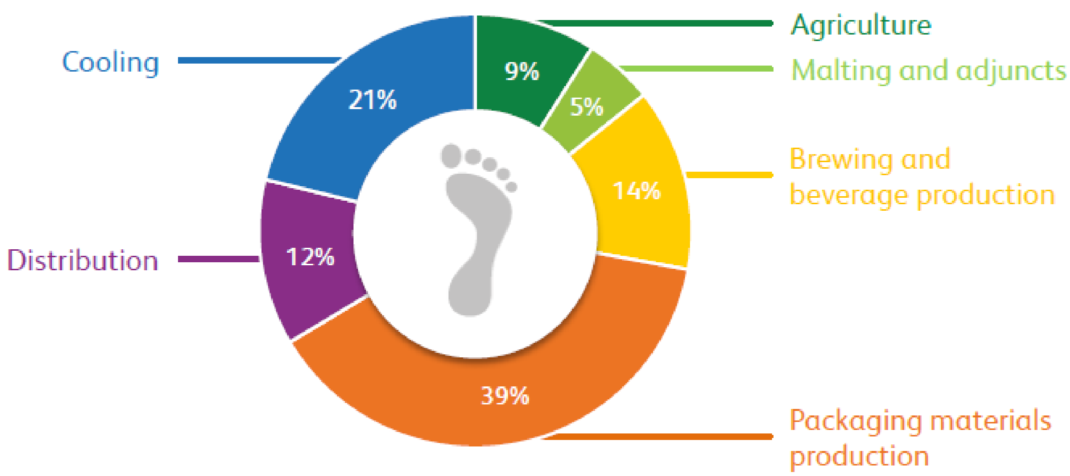

Figure 1. Breakdown of HEINEKEN NV's Carbon Footprint (64.1 kg CO2e/hl) from Barley to Bar (Sustainability Report, 2015)

HEINEKEN priorities in reducing CO2 emissions by 2020 are 40% lower emissions in production, 50% lower emissions of our fridges and 20% lower emissions of distribution in Europe and the Americas (Reducing CO2 emissions, 2015). This 40% reduction of CO2 footprint in production implies a decrease from 10,4 kg/hl to 6,4 kg/hl. This CO2 footprint has been split up into:

- an increase to 10% supply by renewable energy sources
- 30% reduction in energy use:
  - A reduction in thermal energy from 96 MJ/hl to 67 MJ/hl
  - A reduction in electrical energy from 9.2 kWh/hl to 6.4 kWh/hl.

Even though HEINEKEN set ambitions and implied actions in order to reduce carbon footprint, there is still a lot of work to be done in order to become more sustainable. With that in mind, the objectives of this research are: (i) to review and evaluate environmental challenges, in particular energy and CO2 emissions, that HEINEKEN faces during the brewing process; (ii) propose technical and energy saving and CO2 emission mitigation solutions for improvement.

To accomplish the set objectives and close the gap of knowledge the following research questions need to be answered:

1) What are the methods for reducing the carbon footprint in production in HEINEKEN?

2) How can my proposed methods for one of the main companies commitments – reducing CO2 emissions – can contribute to closing the gaps between actual results and sustainable business goals?

2. ANALYTICAL FRAMEWORK

The purpose of this research is to increase the knowledge about the strategies and actions that HEINEKEN is implementing to control their environmental impact. As the most important environmental aspect in the company, CO2 emissions were distinguished basing the choice on the context of IPCC raising issue about significant increases of greenhouse gases (Rothausen et al, 2011).

Companies have to regularly step out of their comfort zones, that's why the organization of continuous change, transformative learning, innovations are keys to business success and a sustainable society (Vermeulen et al, 2016). Benn et al. (2014), established the comprehensive model of development phases helping corporations like HEINEKEN to move towards human and ecological sustainability. They distinguished several steps that might help sustainability practices:

1. Rejection
2. Non-responsiveness
3. Compliance
4. Efficiency
5. Strategic proactivity
6. The sustaining corporation.

The first step "Rejection" describes an attitude of company's strategies towards sustainability. A company is basically oriented towards profit and disregards the destructive environmental impacts of its activities. They are oriented in resources for maintaining short-term gain.

The second step "Non-responsiveness" is unaware or ignorant of sustainability issues and keeps on functioning as "business as usual". They avoid getting in touch with reality where the action is required.

"Compliance" is the third step which focuses on reducing the risk of sanctions for failing to meet the requirements. The organization might see itself as a decent employer and corporate citizen but they are responsive to growing legal requirements for sustainable practices. They use risk minimization strategy in a sense that they accept the demands of the environment but limit their responses to what is required. Compliance provides easy access to finance, better relationship with regulations and competitive advantage.

The fourth stage is called "Efficiency". It depicts increasing awareness of the possible real advantages that might be gained introducing sustainability practices. While moving towards sustainability might have additional investments it can also lead to a huge payoff. Added value comes through saving costs, resources, elimination of waste, increased employees productivity, involvement and communication. This is the beginning of incorporating sustainability as a business goal.

"Strategic productivity" is a next level where the corporation makes sustainability as one of the firm strategies and actively pursues sustainability advantages. Transition to a carbon neutral economy is not seen as threat but as a source of business opportunities. The focus is on innovation and adding value.

The last step is "Sustaining Corporation" where an organization has strongly internalized the ideology that they are working for and are actively involved in transforming the larger economy and society towards a more sustainable world. They support communities, governments and other actors, cooperate with other organization to optimize their supply chain in order to contribute to a "greener" world. (Benn et al, 2014).

In order for HEINEKEN to reach the last phase of sustainability steps there will be technical system suggestions used. Grubler et al (1999) stated that technological choices have long-term impact on the characteristics of industrial societies and the natural environment (Grubler et al, 1999). In this paper, technologies and innovations become overviewed in order to determine the extent to which valid prescriptions can be identified for the corporation into the strategic management process. The technological innovation approach includes the internal and external environmental technologies that are relevant to the organization, which can be both equipment as well as processes.

Thomas Hughes observed that technology development cannot be focused in engineering knowledge alone without wider range heterogeneous aspects (Bijker et al, 2012). Keeping that in mind, in order to develop accurate solutions of CO2 emissions and energy efficiency implementation in HEINEKEN, the researcher applies financial-technical aspects, in particular cost-benefit analysis (Smith et al, 2007). Cost-benefit analysis provides a framework for identifying and comparing the costs and benefits (measured in monetary values) of a proposed project. These particular attributes may have an important bearing on how the financial sector of organization impacts technical environmental innovations and vice versa.

3. METHODS

The methodical approach of this research includes both qualitative and quantitative methods and interpretive perspectives are incorporated in order to best link methods to the research questions. Firstly, all the available quantitative and qualitative data regarding CO2 emissions in the company were processed. The aim of the data collection process is comprehensively, to get acquainted with the sustainable development and associated implementation processes in the company. In order to improve the understanding on the focused topics, the secondary data was obtained from interviews and supporting documentation such as scientific literature, company's website, and sustainability reports. The interviewees were selected regarding their deep knowledge on the companys sustainability processes and practices, mainly focusing on energy efficiency and CO2 emissions (Petrini, 2009). The data was analyzed and summarized in order to develop preliminary findings which gave a better

understanding of the processes HEINEKEN underwent to move towards one of their business goals. Additionally, to gain a holistic and contextualized concept of how HEINEKEN approaches sustainable development and its implementation, there has been a lot of going back and forth during the analysis between the literature and the collected data. (Maon et al, 2009).
Quantitative methods were employed to collect, validate and analyse data from internal reports placed in the internal companys database. Those documents presents carbon footprint for HEINEKEN NV calculations that also conduces to Sustainability Report 2015.
To get better knowledge about CO2 emissions in the production unit and the brewing process itself, there was an acquaintance with the Zoeterwoude Brewery arranged, helping to get more familiar with the carbon dioxide usage, collection and recovery during the brewing process in the company and where the carbon dioxide is being produced or emitted. In regards to that, the current challenges for CO2 emission reduction and energy efficiency were critically reviewed and there were suggestions, using literature research, provided to reduce the impact of brewing operations on the environment (Maon et al, 2009; Olaijre et al, 2012). Energy efficiency for HEINEKEN in a short term has a higher priority, because the reduction percentage (30%) is higher. In a longer term, once the energy efficiency is optimized to maximum, the whole technique of reducing CO2 emissions should be changed. For this reason the focus in the paper was more on renewable energy application. There were searched out ways for reducing CO2 emissions in the company by evaluating all other possible renewable energies that could be implemented in the company.

Additionally, a cost-benefit analysis regarding CO2 emissions was made. Cost- benefit analysis is one of the most important tools for profit - oriented companies. Economic analysis can play an important role in the climate debate. UNFCCC states that “policies and measures to deal with climate change should be cost-effective so as to insure global benefits at the lowest possible costs” (Manne, 2000). In order to estimate if produced energy from the renewables will achieve “grid parity”, a comparison of the relative cost of energy produced by different energy-generating sources was made. This is called a levelised cost of electricity (LCOE). The author developed a mathematical model for solar electricity costs. The model helps to assess the economic lifetime energy cost and lifetime energy production that is applied to a renewable energy technology. The equations were embellished taking into account not only system costs, but also factors such as incentives, operations, maintenance, or different variations of annual energy production. LCOE is a method that allows a comparison of energy costs produced by different means. The LCOE model was established for solar PV, because it is the one of the fastest growing energy sources and is rapidly expanding into residential areas, with governments offering incentive programs to make “green” energy a more economically viable option (Solar Energy Industries Association, 2016). It is a high chance interested parties can implement the technology due to the rapid decrease of the prices for PV systems in recent years and subsidies granted from some countries. (Moro, 2013). The LCOE Calculator is a MS Excel based Tool where all the data related to technology is entered. The LCOE method is a simple way to compare technology choice in different locations, providing an assessment of the cost of the energy-generating system including all the costs over its lifetime in Euros per kWh.

Finally, in the discussion part, the limitations of the research are presented. That is a confrontation of broad assumptions like cost, or production units, as well as suggested technology applicability to specific breweries. In this section, there were pros and cons depicted regarding the established methods and assessed discrepancy of sustainable solutions (Andreoli et al, 2000).

4. PRODUCTION OF BEER

In the brewing process HEINEKEN uses barley, hops, yeast and water (Heineken Brewing, 2015). The first step in the beer production process, that is indicated in the figure 2, is preparation of malt and cleaning it from the large impurities. Afterwards, the malt *milling* starts. It is the process when the malt is crushed to break up the grain kernels in order to extract fermentable sugars. The crushed malt is called *grist*. Mixture of milled malt, water and gelatinized adjunct (starch that is not malted) is known as *mash*. The objective of mashing is to obtain a mash which would yield appropriate *sweet wort* a liquid rich in materials dissolved from the malt and any adjuncts that were used. A mash should be held at a chosen temperature (in hot water at 72-81°C) to allow natural enzymes in the malt to break down malt's starch into sugars (sweet wort). At the end of the mashing process sweet wort has to be separated from the spent grains. (Lawrence, 2003). Mashing can be two different types – *infusion* or *decoction*. Basically the main difference between these two methods is in the way the heat is applied to the mash. Decoction type takes longer, especially if the decoction mashing process is repeated several times and usually it has richer taste. During the infusion mashing, hot water of 71-82°C is carried out in the insulated mashing tuns in order to increase wort extraction efficiency. It stays like this between 30 minutes to two hours and a half, until the wort is withdrawn from the mash. The advantage of the system is that it can be easily controlled and automated, but is possibly less efficient then decoction (Willaert, 2007). In decoction mashing, three vessels are being used - a mash mixing vessel, a mash cooker and a lauter tun. A portion of the mashing mixture is pumped to a mash cooker, heated to boiling point and then re-entered into the mash mixing vessel. This process is repeated several times. This way, wort temperature increases every time and part of the mash gets evaporated. This process has a higher energy demand requiring around 11 MJ/hl then infusion mashing requiring 8.5 MJ/hl of fuel. The mash after all of this is transferred to a lauter tun for wort separation (Worrel, 2002). The extracted spent grain, is usually reused as an animal feed.

The next step is when clarified wort moves from the lauter tun to a brewing kettle where the wort is heated up for boiling. This step is called *wort boiling* and it involves wort boiling and evaporation (from 4 to 12% evaporation rate). The process continues for a recipe-determined time (approximately 1-1.5 hours) (Galitsky, 2001). It is the most fuel-intensive step of the brewing process. The wort has to be boiled before using it as a nutrient for alcoholic fermentation by yeast cells (Willaert, 2007). The boiling sterilizes the wort, stops enzyme activity, strips volatile compounds, and ensures protein from malt reaction that forms flakes. The wort gets concentrated through evaporation, and its color develops by caramelization. During the wort boiling hops are added. Hop female flowers are being used, which gives beer its characteristic bitter taste and improves its storability (Heineken, 2015). Once the hops add flavor, aroma and bitterness to the brew, they are being removed. The clarification of boiled wort can be done with the help of *whirlpool*, *sedimentation* or *filtration.* Whirlpool is one of the most economical methods to remove the hop debris. In this cylindrical vessel, the wort is pumped tangiantelly, which forms whirlpool motion. This causes hop debris to settle at the centre of the vessel bottom in a cone shape. Afterwards the clarified wort is decanted off and is ready to be cooled. These systems can be liquid or dry (Galitsky, 2001). Atmospheric cooling systems practice air stripping columns and liquid cooling uses plate heat exchangers. Plate heat exchangers can be two types: either single-stage (using chilled water) either multiple-stage (using glycol and ambient water). The wort is around 96-99°C when it enters heat exchanger. It exits when is cooled down to 8°C (Worrell, 2002). Once the wort is cooled, it is being transferred from the heat exchanger to the fermentation tank. During the transfer the sterile air is dissolved into the wort and the *fermentation* process can start properly (EasyBrau, 2015). Yeast is being added to the oxygenated wort in the fermentation vessels. During the fermentation process the yeast is converted to the carbohydrates in the wort to produce alcohol and carbon dioxide (carbonation process starts). The process generates significant heat but in a closed fermenter, CO2 is recovered and reused later. The temperature is being controlled by ice water circuit that goes around the cooling jacket of the vessel. Fermentation takes several days depending on the desired beer taste and yeast strain. After the first fermentation process, the yeast is being removed and the "young" beer is pumped to the aging tank and being stored there (some brewing methods require second fermentation, where fresh yeasted wort or sugar is added in order to start second stage of fermentation (Willaert, 2007). If second fermentation takes place, the yeast is removed once again). In the aging tank the beer is stored, cooled and kept there for a certain period. The goal to store the beer in *storage tank* is to improve its taste, clarity, and help to keep it longer. The goal to store the beer in *storage tank* is to improve its taste, clarity, and help to keep it longer.

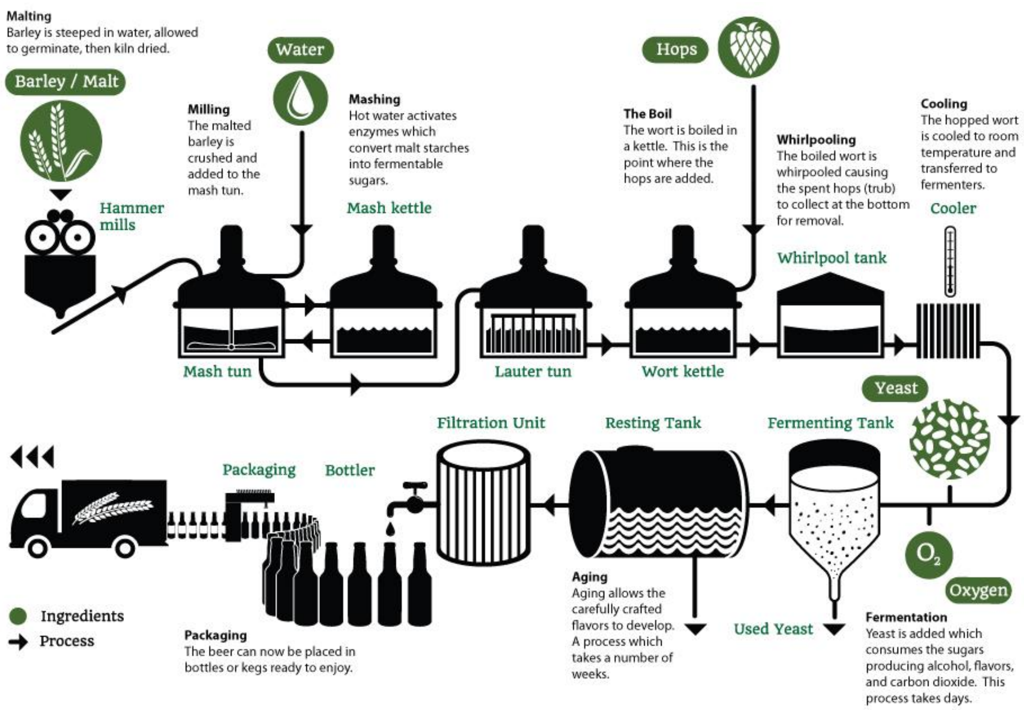

Figure 2. Brewing process (Chromacademy, 2016)

Afterwards, the beer must be cleared from all the remaining proteins and suspended yeast particles. The beer has to go through the *filtration* process – a centrifuge (rapidly spinning plates). Here protein, hop debris, yeast and other solids are spined out to the edges leaving beer in the middle. Finally, the *pasteurization* starts – beer cleaning from all the remaining bacteria before bottling (Worrell, 2002). Here the beer is heated up to 60°C killing all the bacterial contamination and then rapidly cooled, after which bright and clear beer is filled into bottles, cans or kegs. Filling and bottling of a beer is an automatic process to ensure completely hygienic conditions (Heineken Brewing, 2015).

5. CARBON DIOXIDE

HEINEKEN divides its CO_2 emissions from brewing and beverage production into upstream, on-site and downstream.

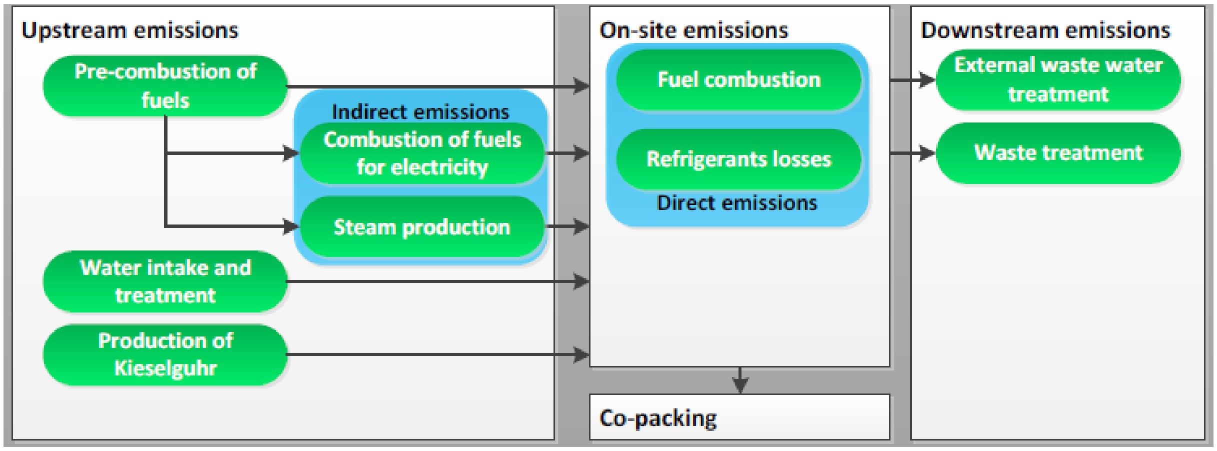

Figure 3. Overview of the beverage production generating emissions (Carbon Footprint, 2015)

As figure 3 indicates, emissions are generated upstream during the production of electricity, on-site by burning natural gas or diesel and downstream related to waste and waste water issues. Upstream emissions can be reduced by using cleaner sources of energy like wind, hydro or solar energy. On-site emissions can be reduced by using energy more efficiently. Downstream emissions consist of emissions generated after the brewing process, such as emissions for the treatment of waste water by third parties and emissions from spent grain, surplus yeast, can become zero if waste streams would be fully recycled (Hiller, 2015).

One of the primary Greenhouse gas emissions is CO_2. CO_2 is a crucial compound to all forms of life on earth and is also very important in beer because CO_2 is produced during fermentation, with about the same weight of alcohol.
The harmful effects of oxygen (foreign gas) on beer are well known. It is important to move beer around a brewery under an inert atmosphere. The inert gas usually used for this purpose is carbon dioxide (CO_2). This helps to keep dissolved oxygen down to the lowest levels possible. The levels targeted by brewers are around 0.02 mg/l or preferably even lower. Apart from excluding oxygen, CO_2 is also used to give the product "sparkle" by dissolving CO_2 in the beer and maintaining these levels by pressurising vessels. It is also used for beer dispense. CO_2 is naturally present in beer because it is produced during the fermentation, together with about an equal weight of alcohol.
CO_2 has two main uses in the brewing process:

- Adjusting the carbonation level
- Removing and preventing foreign gas uptake

Adjusting carbonation level

CO_2 is dosed into beer during the filtration process to reduce the presence of foreign gas in the beer. At the same time, CO_2 is used as the counter pressure to suppress the release of dissolved CO_2 in the beer during the transportation. CO_2 is usually injected into a pipeline under pressure just before a plate heat exchanger. This has two advantages:

1) The beer pressure is high as it enters the heat exchanger. This helps the gas to dissolve
2) The large surface area and turbulence in the heat exchanger help to disperse the gas.

Another aspect of moving beer under CO_2 is that the carbonation level is maintained and not lost to the atmosphere. This saves some of the need to re-carbonate beers later in the process. Every time beer is moved, the dispatch and receiving tanks need to be top pressured with CO_2. There is also a big demand for CO_2 in packaging operations. Small packages such as bottles and cans are open to the air as they enter the filler and this air is removed using CO_2.

Foreign gas exclusion

1) Fermentation

Fermenters generate an enormous amount of CO_2. Any air present will quickly be swept out at the start. Breweries using closed vessels keep a backpressure on the vessel while fermenting. This pressure may also be maintained when the vessel is being emptied; so additional CO_2 is fed back into the vessel. CO_2 is denser than air, so the gas does not disperse easily when the vessel is emptied. If the vessel is emptied at ambient pressure, there is a blanket that protects the beer and prevents air from getting in.

2) Lagering or storage tanks.

A top pressure of CO_2 is usually kept on cold storage tanks to prevent beer oxidation. This presents a problem when caustic detergents are used for cleaning.
This problem can be overcome in another way by venting the tank first and letting the CO_2 out by displacing it with air which wastes the gas. To recreate an inert atmosphere the tank has to be filled with water after cleaning and then empty this water with CO_2 displacing it. The vessel is then refilled with beer. This is very time consuming and wastes a lot of water. An alternative is to use acid or neutral detergents while maintaining the CO_2 atmosphere. However, the cleaning action of these detergents is not as good as caustic.

3) Filtration

Most filters have buffer tanks before and after the filter, and the level in these tanks will go up and down. CO_2 has be used as the top pressure gas in these tanks and gas will be vented every time the tanks are filled.

4) Deaerated Water Production

Diluting water in the filtration area has to be stripped of oxygen and carbonated before being used to adjust the strength of the beer.

5) Bright Beer Tanks

Bright beer tanks for filtered beer are kept under pressure of CO2 in order to keep the carbonation level and keep out oxygen. Whenever a tank is refilled, CO2 is either vented to atmosphere or recovered for subsequent reuse. Bright beer tanks are often cleaned with acid detergents rather than caustic. This avoids CO2 being absorbed by the detergent. Bright beer tanks are not dirty and an acid detergent is usually effective. Most tanks are cleaned at atmospheric pressure, so the tanks need to be vented before cleaning, which wastes gas.

6) Keg plant

CO2 is used in considerable amounts during the keg (small returnable barrel created especially for storage of beverages) filling process. In the step just before filling, steam is removed out of the kegs using CO2. The keg is also pressurised at this point, then filled with beer. The amount of gas used during kegging should be in the range 0.5 to 0.8 kg of CO2 for each hl of beer.

7) Bottling

Bottle fillers use significant amounts of CO2 because air in the bottles need to be removed before filling with beer. Most bottle fillers use what is called double evacuation. This involves sucking air out of the bottle then pressuring with CO2. This process is repeated to remove yet more air. The mixture of evacuated air and CO2 is vented to waste. If the filler bowl pressure is carefully controlled then gas usage can be reduced slightly.

8) Canning

Canning uses more CO2 than bottling, but the amounts can vary depending on the line design and operation. To remove air from cans is not as simple. The cans cannot be evacuated to pull air out otherwise they would collapse. Instead, pressurised CO2 from the filler bowl is blown through the cans to displace the air. This gas mixture is vented. The cans are then pressurised before filling, then released. More gas is used as these released cans are conveyed to the seamer, or closing machine. The cans usually pass through another machine which blows CO2 onto the top of the filled can to remove any air bubbles floating on the beer surface.

CARBON DIOXIDE COLLECTION AND RECOVERY

CO2 is a natural product of fermentation and it can be collected from the fermenting cellars. It is then processed and used in the various parts of the plant that were mentioned above. Fermentation CO2 contains a number of fermentation by-products and other volatiles, e.g. ethanol, acetaldehyde, hydrogen sulphide (H2S), and dimethlysulphide (DMS). The purity has to be at least 99.5% to start collection. Because of this limitation, a brewery producing 1 million hectoliters per year will make around 4000 tonnes of gas. It is now possible to purify and convert all this gas to liquid CO2.

There are several stages in the production of CO_2:

1) Collection
2) Compression
3) Deodorising
4) Drying
5) Liquefaction and storage

Collection

1) Foam catchers

In the foam catcher, excess foam is removed as this foam might hinder the normal operation of the CO_2 scrubber. The gas coming from fermenters is quite likely to contain some beer foam and other suspended droplets of liquid. This liquid must be separated from the gas. Getting this foam or mist out of the gas stream is achieved by using a series of small separation vessels. These vessels have a small water spray device that is activated if foam is detected. The purpose of the foam catcher is to prevent foam or, sometimes even, wort and yeast from contaminating the various components of the CO_2 recovery system.

2) Ballons

After the prevention of foam, CO_2 now is led towards the scrubber and compressors. As the supply of raw CO_2 from the fermenting cellar to the CO_2 plant may be intermittent, a gas balloon is used to smooth out the flow of CO_2 gas. This method also prevents the compressors from switching on and off too frequently.

3) Scrubbers

Gas still needs to be cleaned before compression, because CO_2 will contain a lot of volatile material from the fermentation. These compounds have to be removed in a gas scrubber. Fresh water is sprayed down the machine and meets the gas passing upwards. This washing system removes almost all the volatile compounds.

Compression

Once the gas has been largely cleaned, it can be compressed. This is the first stage in producing liquid CO_2. Compressors are used to avoid any risk of contamination. As the gas is compressed, it heats up exponentially. It must be cooled down at each stage of compression to bring it back close to ambient temperature. As a result, most of the residual water vapour in the gas will condense out.

Deodorising

The washing process described above removes nearly all the fermentation impurities. The small amounts of hydrogen sulphide (H2S), and dimethlysulphide (DMS) that are left behind are still too much, so they must be removed. They need to be taken out before the gas is cooled and liquefied. If not, they will dissolve in the liquid CO2 and not come out again.
The best way of taking these impurities out is to pass the gas through a deodoriser. These devices are made from activated carbon. The carbon takes the trace contaminants out of the gas stream, but eventually becomes saturated. It can be regenerated by heating with steam or hot air.

Drying

The purified CO2 gas has to be dried because:

- Humid CO2 is a source of contamination as it permits growth of algae and bacteria
- Humid CO2 is corrosive
- Water vapour can cause serious process problems

Although the gas is now pure and clean, it still has traces of water vapour in it. The moisture content of a gas is directly related to temperature and water can still exist as a vapour when it reaches its freezing point. It is necessary to get this water out otherwise ice will form in the liquid CO2 storage tank or in other parts of the plant. The driers are regenerated by dropping the pressure and heating, sometimes as high as 200°C., using electric heaters.

Liquefaction and storage

The stage where the CO2 is clean has been reached already, now it is dry and ready to be liquefied. It is then put into storage for subsequent use. Like most gases, CO2 can be liquefied by applying both pressure and cooling. CO2 flows from the condenser into a liquid storage tank by gravity. It is good practice to design with two CO2 storage tanks. One for receiving and the other for delivered gas. (Kunze et al, 2004, Lewis et al, 2012, Tejani , 2016).

6. CO2 EMISSIONS

The role of carbon dioxide is absolutely essential for beer production. All the processes regarding carbon dioxide recovery from the fermentation described above help to avoid having to purchase all the gas that brewery requires from outside manufacturers this way reducing demand on resources.

Even though, CO2 is collected and recovered during the fermentation process, which reduces the energy usage, there are other processes in the brewing that are high energy consumers.

The biggest and real source of carbon dioxide emissions in the brewing industry is the combustion of fossil fuels – either at the brewery itself or in the generation of the electricity supplied. There is, therefore, a need for continuing improvement in the efficiency with which fossil fuels are used, whether through the use of electricity or through the combustion of fuel at the brewery.

7. ENERGY EFFICIENCY

The production of the beer is rather energy consuming (Figure 4 shows a breakdown of energy consumption). Carbon footprint target for HEINEKEN Company is a development of a sustainable process with energy efficiency to achieve savings in fuel and energy costs. (Scheller, 2008). Energy-efficient technologies can have benefits for brewery besides energy and CO2 emission reduction. Majority of energy efficiency equipment can lead to beer quality improvement, increased production and higher efficiency. All of them can lead not only to productivity gains but it is also important for overall company's environmental strategy (Muigai, 2013). The reduction of the energy consumption is leading to a corresponding reduction of the costs and of the pollution created by carbon dioxide and other greenhouse gases. According to the Kyoto Protocol, measures have to be taken to reduce this kind of pollution. The highest heat consumption is normally taking place in the brew-house.

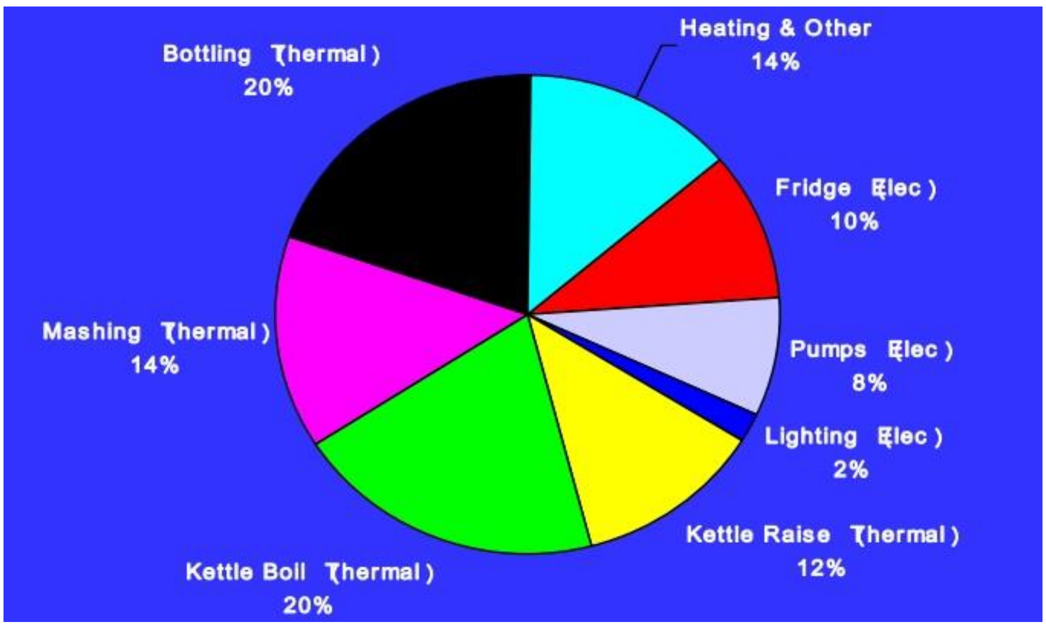

Figure 4. Energy usage of brewing company (Briggs, 2004)

As the figure 4 depicts, mashing and wort boiling, aside from the bottling which is not the part on beer production, consume most of energy.

CLEANER PRODUCTION

Wort boiling

Wort boiling is the longest and essential part of the brewing process for sterilization, protein coagulation, alpha acid extraction and volatile evaporation. When the wort is boiling, approximately 6-10% of water is evaporated. Usually steam is emitted to the air, this way losing energy and causing unpleasant smell. Optimizing this process by recovering heat during wort boiling can help to save a large amount of energy that is wasted as steam (Kichula, 2008).

The simplest solution would be to use this steam to produce hot water which can be used for various procedures such as office heating, kettle cleaning, cleaning operations etc. However, In HEINEKEN, as in a lot of other breweries, hot water is produced also during the wort cooling (Kapturauskas, 2007) .This way the surplus of hot water is formed, but there are other options for heat recovery from steam: (Scheller, 2008).

1) ENERGY SAVING WITH VAPOUR CONDENSER

The evaporated water mass during boiling process has a high energy content so the wort should be pre-heated by recovered hot water as much as possible. Wort can be heated up by recovered heat from the vapour condenser. It works in combination with an energy storage system, which can also be a two-tank —one tank cab used for containing the hot water (around 97°C) and the other one for used hot water (around 80°C) (Willaert et al, 2004).

For wort preheating during transfer from the wort collection tank to the wort kettle, the hot water is circulated through a heat exchanger. A single-layer plate heat exchanger used as a vapour condenser is combined with a heat storage tank in which the wort is heated up by the energy recovered from the vapour of each brew. This recovered energy is stored in the heat storage tank and used for lautered wort before boiling (lautering is the method most brewers use to separate the sweet wort from the mash) (Willaert et al, 2004). The vapour flows in at the top of every second plate, and the condensed water runs out at the bottom (Tomescu et al, 2012). The recovered thermal energy temperature increases from 72 to 95°C and is sufficient to preheat the lautered wort, during transfer from the wort tank to the wort kettle. This way, pre-heating needs approximately a quarter of the energy input that would have been needed to heat it up directly from lautering temperature to boiling point. (Dornbusch, 2009).

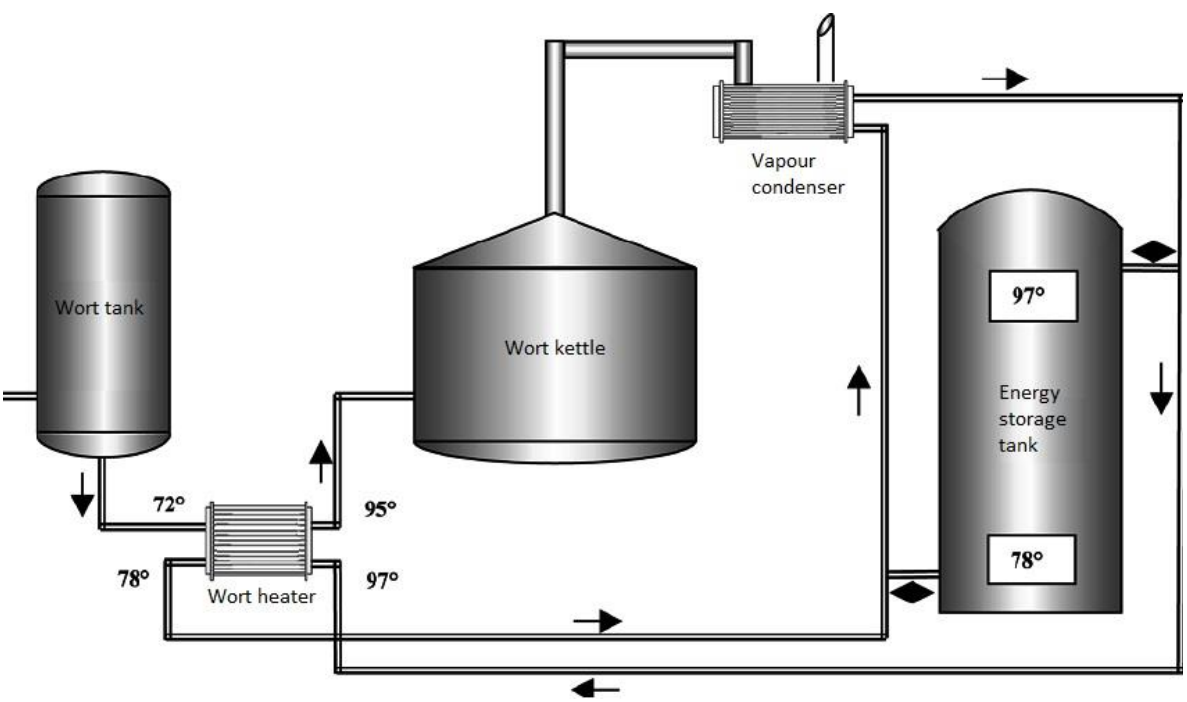

Figure 5. Wort tank with vapour condenser used for energy recovery during wort boiling (Edited from: Willaert et al, 2004)

The figure 5 illustrates operational principal of vapour condenser.

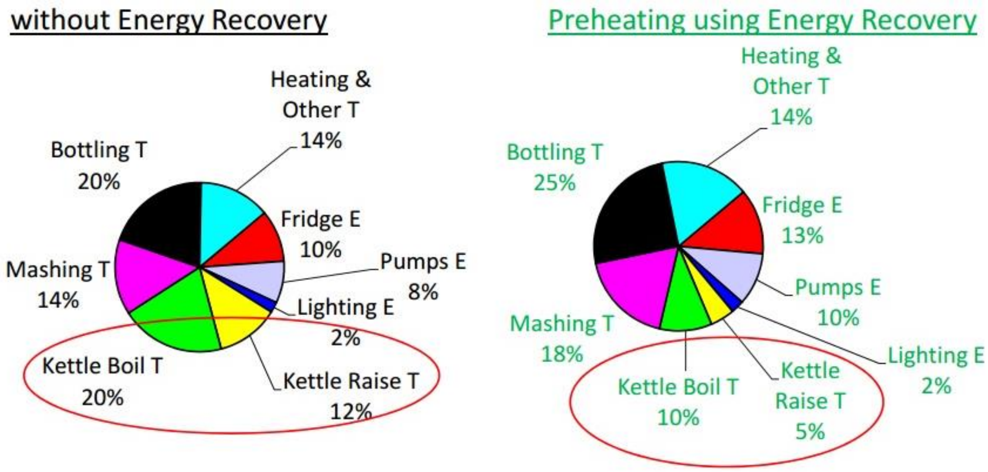

Figure 6. Differences between conventional wort boiling and boiling with wort preheating (Briggs, 2004)

The figure 6 indicates the differences in energy reduction between the conventional wort boiling and heat recovery using a vapour condenser. As the figure depicts, when the heat is recovered, the energy input is twice as much lower when comparing to conventional wort boiling.

The advantages of the system are:

- Moderate cost;
- Not complicated system with few moving parts and no high temperature or pressure

However, there is a disadvantage:

- Space for energy storage tank required.

2) MECHANICAL VAPOUR COMPRESSION (MVC):

During the atmospheric boiling, the produced vapour is about 100°C. When using a mechanical compressor, the vapour gets compressed to an over 0.3–0.4 bar pressure. The compressor helps to increase the temperature of the steam and then it can be used for heating purposes (Willaert et al, 2004). The wort heating starts with the fresh steam supply from a boiler to the wort copper. The steam from the copper is compressed and it achieves a condensation temperature of 102-106°C. As a result of fresh steam compression the temperature increases and then it can be used again directly for heating the wort. (Tomescu et al, 2012).

Basically, the main purpose of vapour compression is to balance out the loss that is arising. The system operates when it is free of air. That is why automatic air removal valves have to be installed at the lowest point of the system and the vacuum prevention system is needed for the cooper in order to prevent air drawing in. The fresh steam is essential while using vapour compression, because the heat of evaporation is used to heat up the wort and there is almost no excess hot water (Willaert et al, 2004).

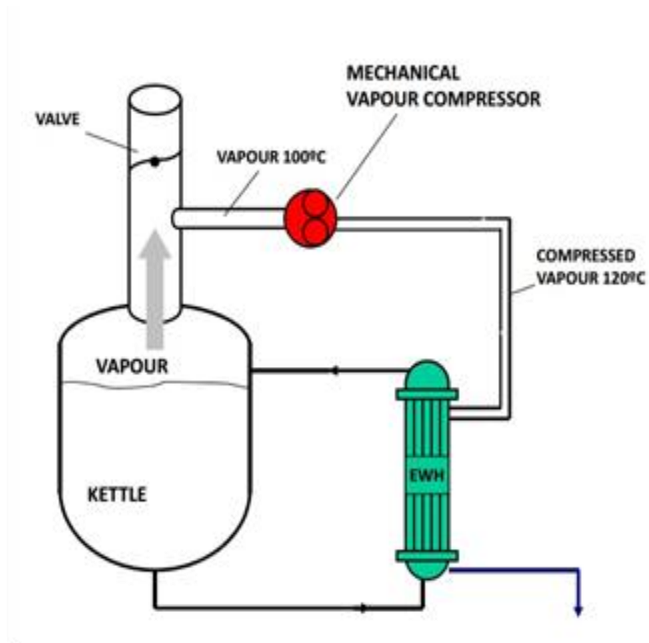

Figure 7. MVR – Mechanical vapour compression used for energy savings during wort boiling (Briggs, 2014)

Figure 7 depicts operational principal of Mechanical vapour compression.

The advantages of the system are:

- Direct recycling of boil energy;
- Much more energy can be recovered with the mechanical vapour compression, compared to the thermal vapour compression;

However, the system has drawbacks that contain:

- All the vapours are directly pointed to the boiling process. This way, the lautered wort cannot be preheated if mechanical vapour compression is working;
- The plant engineering is complicated ;
- High maintenance;
- Noise production;
- Peak electricity demands may occur because of the power used by the MVC.

The installation of a vapor compression system helps to reduce heat demand during wort boiling, but the disadvantage of a mechanical recompression system is its high electrical power consumption. In order to lower the power consumption it is recommended to introduce a wort kettle with internal boiler and energy storage tank (Scheller, 2008).

3) THERMAL VAPOUR COMPRESSION (TVM)

During the thermal vapour compression (Figure 8) process, a part of the vapour is soaked up by a steam jet pump and compressed to an 0.1–0.4 bar overpressure. The steam jet pump consists of a head and a jet through which fresh steam passes from a boiler with an at least 8 and up to 18 bar of overpressure. Due to the increased velocity of the fresh steam it is transformed into a pressure energy. Another left part - 30-35% of the vapor is condensed in the kettle and can be used as hot water to preheat the lauter wort (Willaert et al, 2004).

The advantages of the system are:

- Lower investment costs then mechanical vapour compression;
- No peaks in the electricity consumption as in MVC;
- One steam jet compressor is sufficient for whole plant;
- Can be combined with hot energy storage to increase recovery;
- Low maintenance;

However, the system has its own drawbacks as well:

- High steam pressure (might need the pipework);
- Increased production of hot water
- Requires space.

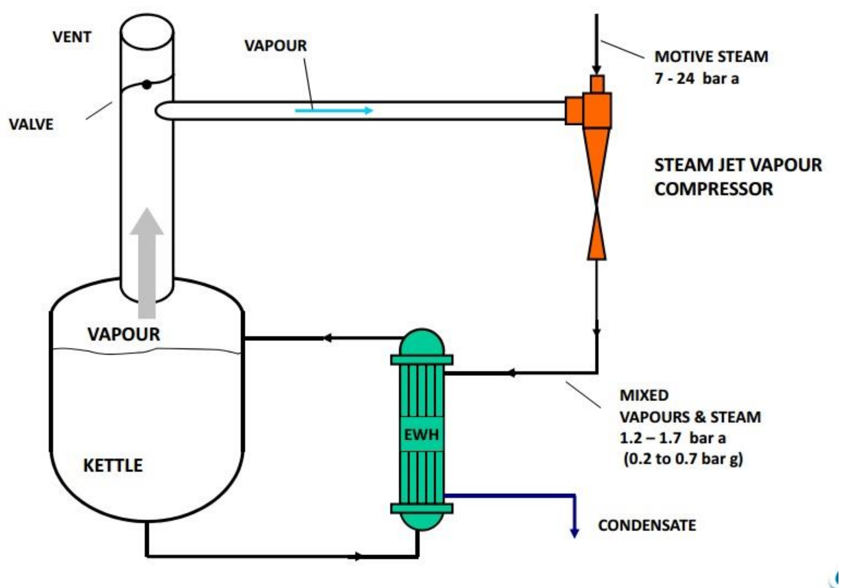

Figure 8. TVC- Thermal vapour compression used for energy savings during wort boiling (Briggs, 2014)

Thermal vapour compression is a less expensive option than mechanical vapour compression (Sturm et al, 2013). Energy cost savings per brew (100 hl and 10% evaporation) while using vapour compression instead of conventional boiling are quite high, although the introduction of TVC is only logic, when the hot water produced can also be used (Tomescu et al, 2012).

4) LOW PRESSURE WORT BOILING

Low pressure boiling was designed to increase the evaporation rate of undesired components and decrease the energy costs. During the conventional boiling process the evaporation rate exceeds up to 10% and, but during low pressure boiling is decreases to 6-7%. Over the years, this technology has been further developed into a dynamic low pressure boiling where the evaporation may be achieved 4-5% total. This system operational principle is that the pressure in copper is increased up to 1.17 bar (around 104°C) and then is lowered to 1.05 bar (around 101°C). Each time the pressure is released, a huge amount of small bubbles appears throughout the wort that transfers the unwanted volatiles to the surface (Briggs et al, 2004). In the process, the evaporation of 4.5-4.8% is obtained which is enough to reduce the volatiles. The vapor produced can be used for production of hot water and the recovered energy can be stored in a hot water storage tank (Karaghouli, 2013).

Wort boiling and heating are performed using an internal boiler. A homogeneous boiling temperature in the kettle is usually hard because of the design of the wort kettle, like inadequate heating surfaces on the bottom or shell. This way the heat transfer is insufficient to reduce all volatiles. Installation of internal boiler ensures continuous circulation. It can reach up to 30 times per hour and promotes a homogenous temperature throughout the whole kettle (Muigai, 2013).

This technology has been commercialized by the company Huppman. The figure 9 indicates technology operational principle. Their Jetstar internal boiler combined with dynamic low-pressure boiling has proven to have significant results (Scheller, 2008).

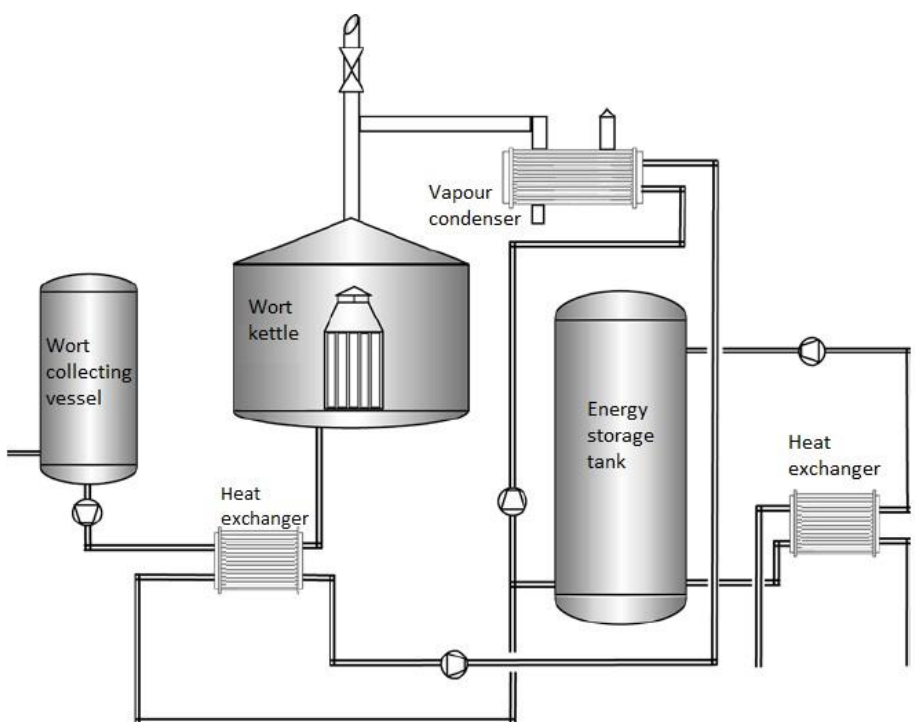

Figure 9. Dynamic low pressure boiling with energy recuperation systems for wort boiling and energy efficiency improvement (Edited from: Hackensellner 2001)

The recommended installation of wort boiling at low pressure and 4-5% evaporation when comparing to conventional wort boiling under atmospheric conditions without an energy storage system and with 7.5% total evaporation saves up to 5.6 kWh/bbl (4.7 kWh/hL) of energy (Scheller, 2008).

5) COMBINED WORT BOILING WITH FILM STRIPPING (MERLIN)

The main reasons why evaporation during wort boiling is required are to achieve the specific wort gravity at the end of boiling and eliminate undesired aroma compounds. Not long ago, the company Anton Steinecker presented a new boiling system, named ''Merlin''. Merlin wort boiling system is an external wort boiling system. The system contains two vessels: a wort holding vessel (whirlpool) and a steam heated cone container (Merlin). The latter is a vessel containing a conical heating system (Buttrick, 2006). The principle is that wort from the whirlpool is being pumped into a heated cone as it is showing in figure 10. The cone is fed with the fresh steam 0.6- 1.5 bar overpressure, with a steam temperature of 110°C (Willaert, 2007). Because of the thin layer of wort, it allows gentle boiling with a rapid elimination of undesired aroma substances. Then the wort is pumped from the whirlpool across the heated surface and this procedure is repeated 4-6 until the end of the boiling cycle (Weinzierl, 2000). The undesired compounds deposit at the bottom of whirlpool when the process is completed and the wort holding vessel whirlpool is used purely as a whirlpool (as a settling tank where solid particles are separated from the wort). From the whirlpool the wort is pumped to the heat exchanger (Sinha, 2007).

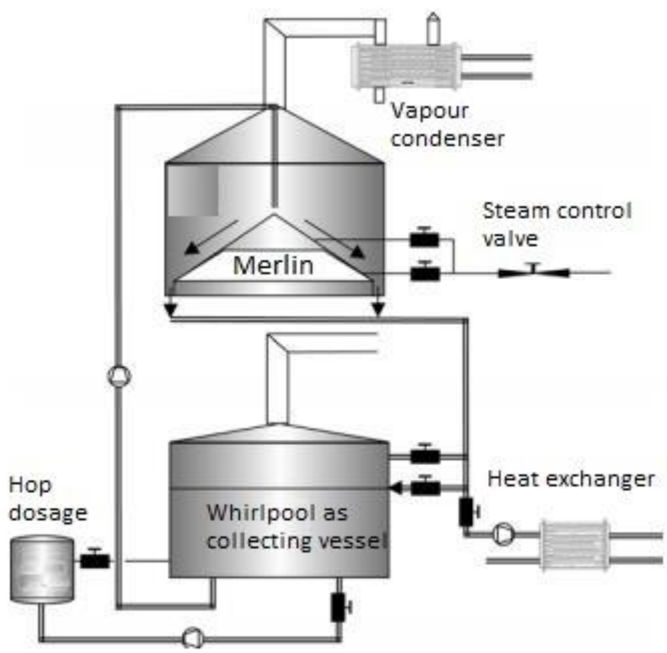

Figure 10. Merlin wort boiling system with whirlpool and energy storage system (Edited from: Miedaner, 2001)

The system is able to produce good quality worts with 4% evaporation in 40 minutes. Steinecker claims that the Merlin system reduces fuel consumption up to 65-75%. Additionally, system improves product quality, reduces caramelization and fobbing (expansion of gas in beer) ,provides more brews between cleanings and performs better vessel utilization (Buttrick, 2006).

Mashing

In the brew house, mashing and wort boiling are the main heat consumers (Scheller, 2008). As the Figure 4. Brewery energy usage depicts, mashing takes up to 14% of energy while producing beer. Hereby, there are some suggestions to increase energy efficiency during mashing process.

1) EQUITHERM SYSTEM

During the wort cooling, heat is removed from the wort. This high temperature energy can be reused for the mashing process (Ormrod, 1986). Krones Steinecker developed a system that captures the surplus heat from brewing process and recovers it during wort cooling (Worrell, 2003). Once the heat is removed from the wort, it is temporarily placed in the energy storage tank. Then the recuperated energy is injected into the mashing operations.

A mash vessel, depicted in the Figure 11 and indicated as a ShekesBeer Ecoplus, is supported with a "pillow plate" design. This specific design creates a high heat transfer and that allows the mash to be heated using only hot water. A pillow plate exchanger heats throughout the entire surface and allows high heat transfer because of the applied counter flow principle. (Krones, 2014).

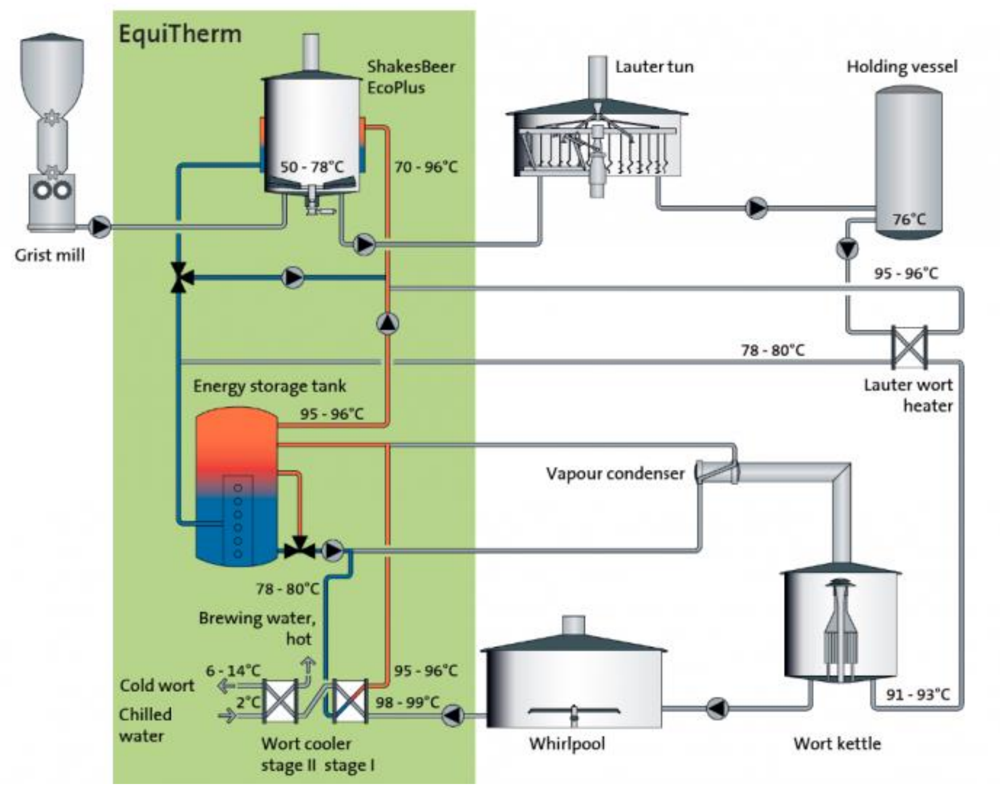

Figure 11. EquiTherm energy recovery system allowing the surplus heat formed during the brewing process to be recovered and reused for the mashing process (Krones, 2014)

The system is universal and can be used for all mashing methods. As Steinecker claims, there can be more than 25% of primary energy savings achieved during the brewing process. Comparing to the conventional processes, reductions in the heat consumption of more than 30% can be achieved and in electricity over 20% with reference to cold wort. The system also improves mashing quality because the medium temperature of the water from the energy storage tank is 96°C and it ensures gentle heating on the enzymes during the process (Rajendran, 2015; Krones, 2014).

2) FILTRATION SYSTEMS

Mash filters use less water, energy, and raw materials than conventional lauter tun system. They improve efficiency, productivity of the brewing process which leads to better energy efficiency. A company Philippe Meura has developed a modern generation mash filter - Meura 2001. The system is designed to a mash "press" and grains get squeezed at the end of filtration removing all the remaining wort. This Membrane Mash Filter is made from inflatable rubber membrane with polypropylene chambers which can squeeze the mash against a cloth (Hermegnies, 2006).

The filter has a huge surface area with a thin filter bed (few millimeters thick) filled with filter plates. The steps of the filtration process are showing in the figure 12. In the beginning the mash enters the filter from the mash conversion vessel through the polypropylene chambers (Sinha, 2007). Once the filter is full and the bed starts to form on the cloths, the clear wort starts running to the wort kettle. After filtration around 80% of soluble sugars can be recuperated. When all the mash is transferred, the filter bed is being precompressed. Then the heavy wort is being forced through the bed, next the membrane pressure is released and the water is pumped through the mash inlet. When the dewatering is over, the membrane is mechanically compressed at high pressure and the grains are squeezed dry (O'Rourke, 2003).

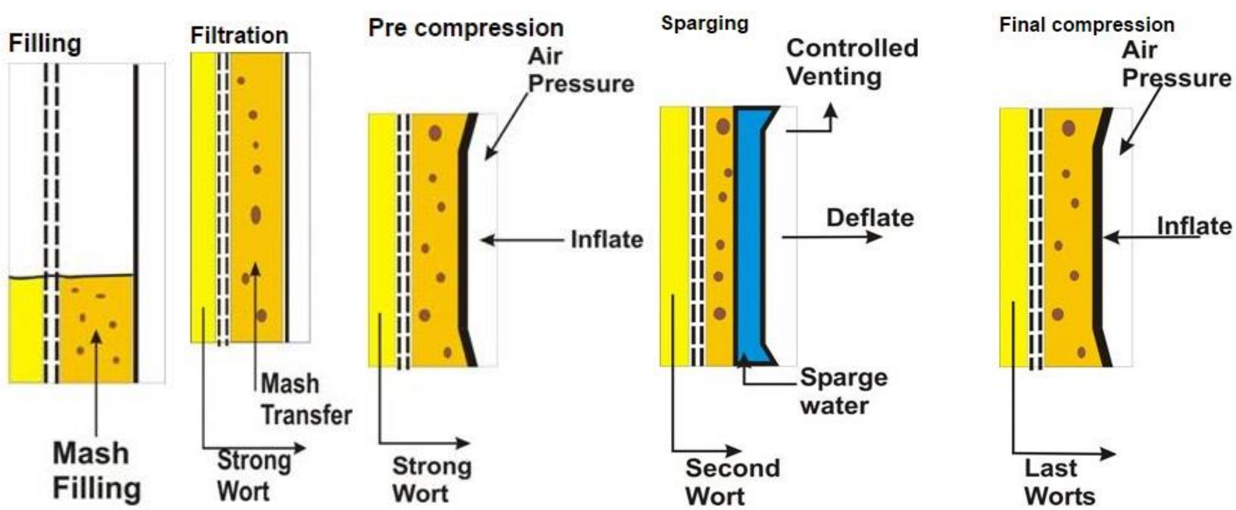

Figure 12. Meura thin-bed mash filtration technology equipped with membrane allows the mashing process to be much more efficient (Edited from: Molson Coors)

After the process the spent grains (the leftovers of malt and adjuncts after the mashing) are 30% dry material and can be cleaned up and reused.

Lauter tun and mash filters produce high quality wort. Mash filters give a better extract recovery, drier spent grains, use less water which makes them more efficient (Briggs et al, 2004). Furthermore, the brewing water volume is reduced by 20% when comparing with lauter tun. The saved water is being used for post fermentation which saves a large amount of energy since the water doesn't need to be heated. However, the lauter tun has its advantages as well. It is less expensive and requires less maintenance (Andrews, 2011).

ENERGY CONSERVATION

There is a wide range of technical options available in order to reduce the CO2 emissions. For the beer production they include energy conservation, energy saving measures, strategic measures, renewable energy options, etc. (Blok, 1993).

The initial investments of renewable resources and equipment are very high, that is why energy conservation is gaining significant importance in energy intensive brewing process. Programs like energy audit seem like good primary solution - inexpensive investment, and imperative tool for analyzing and controlling demand/supply state. Energy audit identifies and quantifies energy usage in the brew house. The main goal of an energy audit is to sustain a suitable balance between energy that is required and the energy that is actually utilized. Usually the process typically contains analyzing historical and present data of energy consumption, making a comparison of actual consumption to the ordinary consumption in similar breweries, checking the capacity of the machines and overall efficiency of the equipment. It also reviews fuel storage and management, makes an analysis for energy saving incentives and reviews the need for new energy saving techniques (Kini, 2011).

One of the energy audit steps is the energy conservation strategy which can be seen as the simplest primary solution towards lower energy consumption. It doesn't require any expenses (at least they are not substantial) and actions for improvement can be taken immediately, so it is a fast answer to energy reduction. Below one can find a suggested list for energy conservation in the brewery. In order to reduce energy consumption the following conservation criteria, based on electricity, thermal energy and fuel terms, can be implemented (Xhagolli, 2014):

1) Continuous maintenance:

    - Checkup if all processes are running according to design;
    - Checkup of manuals given by suppliers;
    - Checkup of all installations, improve or increase insulation on lines, pipes, refrigeration systems, bottle washers, pasteurizers etc. There has to be a sufficient level of insulation in order to minimize heat loss and save energy;
    - Check and minimize losses of beer. The more beer is produced with the same energy, the lower specific energy usage is required;
    - Checkup of outside temperature – temperature control of central heating;

2) Monitoring and good housekeeping:

- When possible shifting from high to low tariff hours;
- Switching off the lights that are not in use;
- Switch off ventilation where possible;
- Switching off heating or air conditioning when its not necessary;
- Reducing steam pressure in boiler reduce gasses and increases boilers efficiency;
- Regular cleaning of the machines;
- Preventative maintenance to reduce leakages (Xhagolli, 2014);
- Installation of computerized controllers for better regulation;
- Fossil fuel switch to biofuels or natural gas;
- Involving all employees in energy saving and conservation practices;

3) Replacement Investments:

- Optimize Clean In Place (CIP) systems (Effective spraying devices, using enzymes instead of traditional caustic products, use surplus water and heat);
- Increasing number of plates of the heat exchanger. It will give lower cool load and higher heat recovery;
- Installation of automatic switches;
- Improving efficiency of the lamps and using LED lightning where possible - straightforward and inexpensive to save energy (Sorrell, 2006);
- Installation of economizers.

In the energy world the most important energy efficiency, reduction or conservation opportunities that can be installed in the brewery are energy tracking programs. The energy management programs, like the above mentioned energy conservation solutions, are good practices that can significantly lower energy consumption and cost. Combining them with the heat recovery equipment and renewable energy technologies long-term reductions in kWh usage and costs will be achieved. (Weisser, 2007).

8. RENEWABLE ENERGY

HEINEKEN established a target for 2020 on CO_2 emissions: to reduce CO_2 emissions (kg/hl) by 40 %. Their strategy is 30 percent reduction in thermal and electrical energy use (energy efficiency) and 10 percent reduction by applying renewable energy sources (Tejani, 2016).

Renewables are abundant, sustainable technologies generating energy from natural resources (Bilgen, 2004). In this paper the emphasis of renewable energy technologies is put on the CO_2 emissions reduction during brewing process (Kini, 2011). Renewable energy comes in various different forms and there is no one solution that would fit all Operating Companies. When considering the best fitted renewable technology, all available possibilities should be considered. The following renewable energy technologies can be considered for HEINEKEN as potentially most suitable options:

1) Solar thermal
2) Biomass
3) Tidal Power
4) Wind Onshore
5) Geothermal energy
6) Solar PV.

These specific technologies were chosen, according to the Operating Companies manufacturing turnovers, geographical locations, climate and technology availability in the country. The technologies were evaluated according to the criteria:

1. *Area requirements*

This requirement is important criteria to consider how much of the land the renewable energy is going to need. While the renewable energy is installed in a particular area, that plot might be used for other purposes which might result in economical losses. The land use is hard to estimate because this criteria is highly depended on the size of technology and geographical conditions (Troldborg, 2014). The criteria is expressed in km^2/TWh.

2. *Levelised cost of electricity*

When considering the renewable technologies it is necessary to assess the investment costs, operation and maintenance (O&M) costs, produced electricity costs per energy produced. That is a term of Levelised cost of electricity (LCOE). It is expressed in EUR/kWh.

3. *Capital investment costs*

This criteria is already included in the LCOE calculation. However the initial investment cost alone is emphasized in this paper, in order to consider if the size of the price is affordable for the company to purchase it directly. It is also expressed in EUR/kWh.

4. CO2 emissions

It is very important to estimate the CO2 emissions released to the air because of renewable technology system, especially considering that CO2 emission reduction is the main purpose of installing renewables. Here they are estimated for the full operational life cycle, including manufacturing and the operation itself. The criteria is expressed as grams of CO2eq.

5. Efficiency of electricity generation

The criteria refers to using less energy input with a purpose to deliver the same service. There is a solid relation between energy efficiency and environmental impact, because normally the same services producing less pollution and resource utilization are linked with enhanced energy efficiency. The units used are %.

6. Water consumption

Water consumption here is referend as water that was “lost” outside the plant area, during the electricity generation. The criteria is very useful for understanding the impact of energy technology operations on the water sector. It is important to note, that here water withdrawal (the water that can be returned to the water source and reused) is not taken into account. The criteria is expressed in kg per kWh.

All mentioned criteria were selected comprising technical, environmental and economic aspects. This way it shows a very clear quantitative comparison with regards to renewable technology. Also, each description of technology gives an overview of the operational principle and specifications of technology that distinguishes it among others. The description provides advantages and disadvantages of each technology as well.

SOLAR THERMAL

Solar thermal energy generator creates heat by concentrating the light from the sun, then that heat runs the heat engine, which turns the generator to make electricity. Solar Thermal systems use thermal energy that is absorbed by concentrated sunlight and use it to heat up liquid, usually water or gas. They are working on the engines (like gas turbines, steam engines) that can be quite efficient, around 30% - 40%, and can produce 10's to 100's of MW of power (Solar Thermal Energy, 2008). Thermal energy can be stored in storage tanks and be used when it is needed without interfering from undesirable environmental conditions like during night or cloudy days. That makes technology very attractive because it doesn’t have any limitations towards time of the day (Jager, 2014). An estimation of land use for the solar thermal electricity is 11.5 km2/TWh (Clarke, 2016). An investment cost for concentrating solar thermal (CSP) plants International Energy Agency (IEA) currently estimates between USD 4,200-8,500 per kW (3730-7550 EUR/kW) (Concentrating Solar Power, 2013).

In concentrating solar thermal plants that use steam cycles (all CSP except solar dish), water is used to produce steam to turn the turbines and generators (Concentrating Solar Power, 2013). Once the steam has done its job, it has to be cooled down and condensed into water so that the cycle can start again (Carter, 2009). Most of the systems around the world use wet-recirculating technologies, where cooling requires 2-3 m3 of water per MWh (2-3 kg/KWh) (Concentrating Solar Power, 2013). This water consumption factor should be carefully considered before implementing technology into water scarce areas. Dry-cooling technology can reduce water consumption by around 90 percent. However, it is way less effective when the temperatures reach above 40°C degrees (Larson, 2007). The estimated CO2 emissions range 36-91 g CO2eq/kWh.

There are four major types of concentrating solar power (CSP) plant system technologies: Parabolic troughs, Solar towers, Solar dish, and Fresnel reflectors, all of which can be integrated with thermal storage (Kuravi et al, 2013).

1. The *parabolic mirror trough* tracks sun path throughout the day. It uses a mirror in the shape of a parabolic cylinder to reflect and concentrate sun radiations towards a receiver. The receiver absorbs the incoming radiations and transforms them into thermal energy (Xiao, 2007). Thermal energy is being collected by a fluid like synthetic oil, which can reach approximately 700°C. The fluid is circulating within the receiver tube. Oil transfers heat into producing steam and this way starts turbine and generator (World Nuclear Association, 2016). The current levelised cost of electricity (LCOE) for parabolic trough plants ranges from USD 200/MWh (0,18 EUR/kWh) to 330 USD/MWh (0,27 EUR/kWh) depending on the location, energy storage etc. Efficiency of electricity generation 10-15% (Concentrating Solar Power, 2013).
2. The *solar or power tower* is a set of flat mirrors tracking the sun and focusing on heat at the top of a tower, heating water to make steam for a turbine. LCOE for solar Towers range ST plants range in 220-280 USD/MWh (0,2 EUR/kWh to 0,25 EUR/kWh). Efficiency of electricity generation 8-10% (Concentrating Solar Power, 2013).
3. *Solar dish* is parabolic dish-shaped concentrator which reflects sunlight into a receiver that is located at the focal point of dish (Concentrating Solar Power, 2013). Its efficiency of electricity generation exceeds 16–18%. Even though, the efficiency is the highest of all CSP technologies, currently, solar dish and Fresnel reflector are the least mature. The solar dish doesn´t use any water nor steam except for a tiny amount to clean the concentrators.
4. *Fresnel reflectors* are similar to parabolic troughs, but are simpler and have a lower cost. Linear fresnel reflectors track the sunlight and the focus sunlight onto a receiver positioned above the reflectors. This way the receivers can generate steam directly. Efficiency of electricity generation 8-10% (Muller et al, 2004).

Overall the technology is quite expensive and requires much space, although it does have low operating costs. The biggest advantage is utilization of thermal storage to better match supply with demand (Edenhofer et al, 2011).

BIOMASS

Biomass energy is any source of energy produced from non-fossil biological materials (Field et al, 2008). The modern biomass usage stands out from the traditional biomass energy by its conversion into energy carriers, like electricity or liquid fuels (Hoogwijk et al, 2005). Biomass feedstock can be converted into bioenergy through thermochemical and biochemical conversion processes (Capareda, 2011).

Biochemical conversion processes:

1. *Anaerobic digestion* – natural breakdown of organic materials into microorganisms, in the absence of oxygen. Process happens in a vessel (anaerobic digester) and produces biogas (methane and carbon dioxide). Waste water treatment plants and livestock manures are the most suitable materials for anaerobic digestion. Here the biogas blower can be used to pump the gas to a boiler in a brewhouse.
2. *Ethanol fermentation* - Ethyl alcohol production of fermentation of yeasts with a wide range of materials that contain sugar. If a material is a starchy, the starch has to be converted into fermentable sugars before yeast fermentation. Yeasts perform the conversion to energy (producing ethanol and CO_2) in the absence of oxygen (Capareda, 2011).

Thermochemical conversion processes:

1. *Pyrolysis*- heating of biomass in the absence of oxygen. Since no oxygen is present the material does not combust, but the organic materials transform into three products: liquid which is bio-oil, solid which is bio-char and gaseous. (Bridgwater, 2012). Vapors and char are generated through decomposition and bio-oils are used as a source of energy e.g. fuel in combustion boiler or as a transportation fuel (Jameel et al, 2010).
2. *Gasification* – a complete biomass breakdown into combustible gas and volatiles and ash in the presence of any external oxidizing agent so that the output gas still has combustion potential. Gasification is a continuity of pyrolysis. Here, the carbon char that would remain from pyrolysis is converted to syngas through the reactions with oxygen, steam and hydrogen in high temperatures. Gaseous products can be used for heating or electricity production (Thermal Gasification of Biomass, 2013).
3. *Combustion* – Burning of fuel to produce direct energy. Boiler used for biomass combustion transfers the produced heat into steam. Then it can be used for producing electricity, heat or mechanical energy.

Biomass energy production and impacts are very relying on specific feedstock that is used and the technology that is applied to extract the energy (Troldborg et al, 2014). However, in order to sustain a manageable number of renewable energy sources, it was decided to consider different technologies and feedstocks as one. The land use intensity for bio energy can vary from 286 to 890 km^2/TWh (from ethanol made from sugar cane to biodiesel made from soy) (Korres et al, 2013). Grams of CO_2 emissions per kWh for biomass is approximately 100 (Troldborg et al, 2014). Capital investment costs alone can vary greatly depending on the country and technology. Anaerobic digestion capital costs are in between 2570 and 6100 USD/kWh (2285 – 5423 EUR/kWh), when co-firing (type of combustion) requires an investment of only 400 to 600 USD/kWh (356 -533 EUR/kWh). The estimation of levelised cost of electricity as well varies greatly from 0.04-0.29 (0.04-0.23 EUR/kWh) (Biomass for Power generation, 2012).

The efficiency is also very dependent on the technology that is used. The traditional industrial combustion process typically allows energy conversion efficiencies around 15% and some of the modern gasification technologies provide 55% energy efficiencies (Kalt et al, 2011).
Water consumption is also very dependent on the locations and feedstock. In order to keep the manageable number, the average number of water footprint of various locations (the Netherlands, US, Brazil and Zimbabwe) is taken into account, which reaches 71,25 m3/GJ (64,12 kg/kWh / the number was calculated taken the density of a wood chips, which is the most used fuel) (Gerbens-Leenes et al, 2009).
Biomass is a relatively inexpensive resource compared to other renewables. It is also a very mature technology that is able to produce reliable energy and a useful way to manage waste disposal. Nevertheless, it uses a lot of water resources and land which could be used for food production. It as well uses a lot of wood, which can lead to deforestation and wood burning can increase particulate carbon emissions (Ellabban et al, 2014).

TIDAL POWER

Tidal power is a form of hydropower that coverts the energy of tides into electricity. There are two types of methods for generating electricity from the tides:

1. *Tidal range devices*, which utilise the potential energy generated by the difference in water level between high tide and low tides. The energy turns the turbine (or compresses air) and this way creates electricity.
2. *Tidal stream devices*, which utilise the flowing water energy in tidal streams and this way generates electricity directly. They are often considered to be equivalent to wind energy, since in both methods the energy is taken out from a moving fluid (Roberts et al, 2016). They are much slower than wind, but generate similar outputs of energy, because the density of seawater is much higher than air.

The development of commercial arrays of tidal current technologies is still in the demonstration phase, so levelised costs of electricity (LCOE) is in the range of 0.25-0.47 EUR/kWh (Tidal energy technology, 2014). Capital investment costs vary widely and the lack of commercial scale usage makes it hard to evaluate the true costs, also the immaturity of the technology influences high prices. Capital investment costs vary from 6.73 to 16.05 USDm/MW (6730 – 16050 EUR/kWh) (World Energy Perspective, 2013). Tidal technologies are still in undergoing development stage, so the cost are estimated to decrease with deployment (Ellabban et al, 2014). Tidal energy has an efficiency ratio of approximately 80% in terms of converting the potential energy of the water into electricity (Harnessing Energy from the Oceans, 2014).
Tidal power land requirements have been estimated based on the power generation per sea-floor area unit which was calculated to be around 30 km2/TWh. The technology is estimated to have 25 CO2eq/kWh (Troldborg et al, 2014). Tidal energy technologies are not very mature, but show a great potential for generating large amounts of electricity (Rourke, 2010). The main advantage over other renewables is predictability even for longer time span of a number of years, and energy can be generated at day and night (Tidal energy technology, 2014). However, the huge construction costs of tidal technologies restrict their development. Other current matters restricting the development are installation, maintenance, electricity transmission and environmental impacts. Construction and installation is challenging, giving only few minutes of slack time between tides (Roberts et al, 2016).

Maintenance will need easy access to turbines and that requires a ship. Besides the frequency and difficulty of the maintenance is not established. Tidal power plants need to be constructed close to land, but even then in some cases electricity transmission to the shore over longer distances can be required. Electricity transmission is another issue and in some cases transmission to shore over longer distances may be required. The effects of tidal power plants on the environment are not completely determined yet, but they are believed to be negligible. (Rourke, 2010).

WIND ONSHORE

Onshore wind turbines are located on the land and they harness energy from moving air to generate electricity. Turbines are operating on a simple principle. Energy in the wind is turning three blades around a rotor, which is connected to the main shaft and it spins a generator to produce electricity. The turbines are ascended on a tower in order to capture more energy. The higher above ground wind turbines are placed, the faster and less turbulent wind they can catch (Wind Power, 2012).

In order to generate electricity from the wind, the kinetic energy of moving air has to be converted to mechanical energy and afterwards to electrical. That's why it is a challenge for the industries to design a cost effective wind turbine and power plants next to it, to perform this conversion (Blaabjerg, 2014). The capital investment costs of wind mills are currently in range of 1700-2450 USD/kW (1518- 2190 EUR/kW) and the LCOE is calculated to be 0.07 USD/kWh (0.06 EUR/ kWh) (Wind Power, 2012). Furthermore, onshore wind holds a significant cost reduction potential. It is projected that by 2025, that energy cost will be even lower, followed by the measures taken to increase energy yield and reduce project costs (Solar and wind cost reduction potential to 2025, 2016). A total estimation of land use for wind power is 72 km2/TWh (Evans et al, 2009). Although, the wind mills can also be integrated into agricultural land, which reduces their share of the land area required (Troldborg, 2014). The carbon footprint of Wind turbines is 25 g CO_2eq/kWh. Here, the most of the CO_2 emissions are a result of electricity used during manufacturing. The efficiency of wind energy is estimated to be between 24 and 54%. This big fluctuation appears because different locations have different quality of wind resources. Onshore wind turbines use very little water only for operations and maintenance which is 1 kg/kWh (Evans et al, 2009).

Wind onshore is proven to be a reliable renewable technology that uses very little water. One of the biggest advantages is that it's relatively cheap. As mentioned before, the technology can be built in agriculture lands. If that is not a possibility, wind farms would take up big amounts of land. Unfortunately, they also are quite loud, even 500 meters from the source they still make noise of 50dB. That is a problem if wind turbines are built in residential areas. It also has (visual) impact on landscapes and species, such as birds and bats, which can be caught up in the spinning blades (Pedersen et al, 2009). Obviously, wind turbines require constant and significant amounts of wind, so the location, in regards to wind quality, has to be carefully evaluated before introducing this technology (Ellabban, 2014).

GEOTHERMAL

Geothermal energy uses the heat from beneath the earth's surface to generate electricity. Nowadays, a common way to capture energy from geothermal sources is to tap into naturally occurring "hydrothermal convection" systems. Here, the water that is naturally heated up to 200C by the rocks. The water becomes denser than normal water temperature, so is forced to be brought beneath the earth's surface and trapped in cavities. This way the steam or hot water can be captured and used to drive electric generators (UCSUSA, 2014). Geothermal power plants can provide electricity at industrial scale. Industries can drill their own holes in order to more effectively capture the steam (Troldborg, 2014). Geothermal power plants pull hot geothermal fluids, use it, and then return it to the underground reservoirs so they can be naturally reheated for reuse (UCSUSA, 2014).

The most common electrical generating plants are flash and binary technologies.

1. A *flash power* plant uses a mixture of water and steam. They are the most common and use water with temperatures higher than 182°C. The water from a well is pumped to a steam separator where it is flashed into steam and water. Then water can return back to the geothermal reservoir through injection wells, or cycled for other processes such as heat input to a binary system in a direct-use application. Remaining steam drives a turbine and generates electricity. Afterwards, the steam is cooled down to liquid form (usually condensed in a direct contact condenser, or heat exchanger type condenser) and then reinjected into the geothermal reservoir as well (Demeo et al, 1997). If the temperatures are very high, the water can go through the double flash cycle which produces 15-25% additional power than a single flash condensing cycle from the same resource (Dipippo, 2015).

2. A *binary power* plant functions as a closed loop system and can be used for moderate – temperature resource where temperatures are as low as 74C. The plant uses the heat of the hot water to boil a secondary working fluid, an organic compound that boils at a lower temperature then water, such as isobutene or ammonia. The secondary fluid is vaporized in a heat exchanger and the force of the expanding vapor is used to turn a turbine. Power plant cooling system is used for condensing the vaporized secondary fluid back into liquid. The fluid afterwards is injected back to the underground reservoirs, so is the hot water from the geothermal resource. The water and the working fluid are kept in separate closed loops without making any contact with atmosphere and that is why the power plant manes nearly zero air emissions (Franco et al, 2009).

In general greenhouse gas emissions are very much related to technology choices. The waste gases can be 90% of CO_2 by weight, and by directly releasing them, the amount of emissions will be big. However, as mentioned before, the binary systems work in a closed loop and don't emit CO_2. The overall estimation of emissions, taking into account a major part of all technologies available, is 170 g CO_2eq/kWh (Strezov, 2009). The LCOE is assessed to be 0.07 USD/kWh (0.06 EUR/kWh). The total initial investment is considered to be in a range of 2000 USD/kWh to 6000 USD/kWh (1790 EUR/kWh – 5380

EUR/kWh), whereas the cost of drilling and reinjection of wells takes up around 50% of the total cost (Kanoglu et al, 2009).

Geothermal power plants have quite small area requirements, since the major components are located underground. However, the subsidence (downward sinking of the land) above the geothermal reservoir can be increased due to the lower reservoir temperature, which occurs when the hot water changes to vapour and absorbs huge amounts of heat (Bromley et al, 2015). That is why the land use indicator takes into account whole geothermal field. Area requirement then is in a range of 18–74 km2/TWh. The underground reservoir, subsequent extraction of the energy and injection operations the can also cause seismicity (a micro earthquake) which constantly have to be monitored (Majer et al, 2007). The electricity generation is 10-20% efficient. Such a low efficiency of power generated to energy is because of the relatively low temperatures of the geothermal resources. Binary cycle plant electricity efficiency can be even lower since they use lower temperatures (Kanoglu et al, 1999). Geothermal power uses large amounts of water for cooling. Also, some water that was pumped from the reservoir gets lost as steam, so not all of it is reinjected. The usage of secondary fluid, rather than fresh water, reduces the water footprint. Depending on the technology that is used, water consumption of geothermal energy can require 12–300 kg/kWh (Macknick et al, 2011).

Overall the main advantage of this technology is the unlimited supply of energy. They can be built underground and integrated in agricultural areas or so, which decrease the land use. However, the sites are very location-specific. Also, they have a water consumption aspect and surface instability (Ellabban et al, 2014).

SOLAR PV

Photovoltaic are semiconductor devices that convert sunlight directly into electricity. Traditionally, cells are made out of silicon, are flat and usually more efficient in terms of the potential energy converted to electricity. However, new generation solar cells can be thin film, made of semiconductor materials or plastic lenses or even mirrors (Tyagi et al, 2012). Solar cells are designed with positive and negative layers that are able to create an electric field. So, when the semiconductor material is exposed to light, photons of the sunlight are absorbed by the cell and their energy causes significant number of electrons to get free. Flow of electrons creates electricity. This is called photovoltaic effect (Upadhyay et al, 2014).

PV can be used for on-grid and for off-grid applications. Grid-connected solar PV operates in parallel with electric utility grid. They are usually used in urban areas, where access to electric grid exists. Whenever the output of photovoltaic system is lower than on-site electric loads, the power is generated from electric utility grid. Off grid systems are designed to work independently from electric utility grid. It is especially useful in places where the utility grid does not exist. This way, they have to be connected with some kind of energy storage unit in order to have electricity by night or on cloudy days, when solar PV is not able to provide energy. The off grid system also can be designed to be connected with other renewable energy, for example wind generator. This is called a PV hybrid system (Masters, 2013).

Over the past decades PV systems strongly improved their performance and reduced costs. Recent assessments of lifecycle emissions from the solar PV showed that it emits approximately 17– 39 g CO_2eq/kWh (Fthenakis, 2015). Photovoltaic occupy around 28–64 km2/TWh of area. However, they can be located on the roof tops which reduce their footprint for land use (Strezov, 2009). The efficiency of the solar modules can range from 9-40%. The 40 percent being the concentrating solar cells. Efficiency of the cell can be improved by pilling up multiple layers of semiconductors which absorb different ranges of solar spectrum (Tyagi et al, 2013). The silicon type photovoltaic, that are most reliable and commonly used type, now exceeds 25% (Pandey et al, 2016). Water consumption occurs during the production of solar PV, but there are low requirements for operations and maintenance – approximately 10 kg per kWh of electricity generation (Strezov, 2009).

The main advantage of the system is that the cost is on a fast reducing track and is expected to continue reducing for the next years. Another financial pro is that the operations and maintenance costs are considered low. At least lower compared to other renewable technologies. However, the energy output is difficult to predict. The location has to be very carefully considered and even then, unexpected cloudy or rainy weather makes the technology less reliable. For a continuous energy supply, there has to be a storage unit installed, which increases investment cost. Recently, rapid cost declines are enabling PV plants to become very economically competitive for off -grid installations and on-grid applications. That is mainly why PV systems are rapidly expanding in many countries (Edenhofer et al, 2013). The most competitive projects can have a installations cost as low as 1300 USD/kW and the upper cost range can reach 5400 USD/kW (1170 EUR/kWh – 4850 EUR/kWh) (Renewable power generation costs, 2015).

The choice of solar PV technology for installation is often based on a trade-off between investment cost, module efficiency and electricity tariffs. Recently, most of the PV technologies in many countries have been driven by promotion policies, including federal investment tax credits and other incentives in order to help develop of markets in key countries and improve economics of PV investments (Abdmouleh et al, 2015). PV power plants already reached LCOE of 78 EUR/MWh to EUR 142/MWh (0.07 EUR/kWh - 0.14 EUR/kWh). As capital costs decrease, performance ratios rise, and the application of PV systems expands towards sunny skies. Solar PV is now a mature technology, but unlike most mature technologies, its costs will continue to decrease and the range of countries will continue to narrow (Technology Roadmap, 2014).

SUSTAINABILITY RANKING

The selected renewable energy technologies were ranked according to specific suitability criteria. The results are summarized and presented in the figure 13.

Criteria	Solar thermal	Biomass	Tidal Power	Wind onshore	Geothermal	Solar PV
Area requirements(km2/TWh)	11.5	286 - 890	30	72	18–74	28–64
LCOE (EUR/kWh)	0.18-0.27	0.04-0.23	0.25-0.47	0.06	0.06	0.07-0.14
Capital investment costs (EUR/kWh)	3730-7550	356-5423	6730 -16050	1518- 2190	1790– 5380	1170 – 4850
CO2 emissions (g CO2eq/kWh)	36-91	100	25	25	170	17– 39
Efficiency of electricity generation (%)	8-18	15-55	80	24-54	10-20	9-40
Water consumption(kg/kWh)	0-3	64,12	0	1	12–300	10

Figure 13. Renewable energy sustainability ranking

The results presented in the figure 13 show, that tidal power takes up the smallest amount of area. However, solar PV, if implemented on the roof, or wind power, if integrated in agricultural lands, can have zero area requirements. The lowest prices of levelised cost are wind onshore, geothermal and solar PV. They are mature technologies whose supply chain has been already established. Biomass is one of the oldest renewable technologies and is very mature as well, but its broad diversity of technology options cause big fluctuations in prices. The biggest output of EUR/kWh has tidal power. It is still developing, and naturally its initial investment cost is the highest. The lowest investment cost has solar PV. It also has little CO2 emissions. Tidal power works in a similar style as wind power and coincidentally produce same amount of CO2. The most efficient technology is tidal. It is the most predictable renewable energy and can reach up to 85% efficiency if the difference between lowest and highest tides is around 7 meters (Hafemeister, 2014). Even if this condition is not met, tidal power is still way more efficient than any other energy technology. Tidal power has also the lowest water footprint. Once this technology is fully developed, it can outrange other technologies by providing a continuous and predictable output. Nonetheless, currently, according to the ranking, wind onshore and solar PV technologies seem to take over.

9. LEVELISED COST OF ELECTRICITY (LCOE)

HEINEKEN, as a green company is interested in renewable energy applications. Solar PV currently is the cheapest and has the biggest amounts of incentives around the world supporting the technology. Solar energy, as a mature and rapidly expanding technology, is becoming a very attractive solution for raising stakeholders interests and reducing CO2 emissions. In order to check if the system can reach the grid parity there was a model developed for checking a financial payback in certain locations.

LCOE of more mature renewable power technologies –such as biomass or geothermal have been largely stable since 2010. When considering an investment for Solar PV installation, the life cycle cost of producing electric power has to be accessed. LCOE is a static measure of cost, which can provide an estimation and useful insight, but in order to define the true cost, it requires a more detailed system model. In this paper, calculation of LCOE for solar PV considers the cost of the energy generating system and the energy generated over its lifetime and the output is provided in EUR/kWh (Branker et al, 2011). The model reflects multiple factors: initial investment price including incentives and subsidies (if available, like Investment tax credit or other incentives), production over lifetime, system degradation, residual value and discount rate.

A total life cycle cost of the Solar PV system comprises all the present costs and benefits and ones in the future, all brought back to the present value. The calculation starts from time being equal to zero in order to include the project cost at the beginning of the first year, which is not discounted and the system energy output is not degraded (Branker et al, 2011). LCOE calculates the constant price of electricity for which the net present value (NPV) equals to zero (LCOE, 2015).

$$NPV = \sum_{t=0}^{25} \frac{1}{(1+r)^t} * (Benefits_t - Costs_t) = 0,$$

Where:

$$Benefits_t = Production_t * LCOE,$$

Then:

$$\sum_{t=0}^{25} \frac{1}{(1+r)^t} * (Production_t * LCOE) - \sum_{t=0}^{25} \frac{1}{(1+r)^t} * (Costs_t) = 0,$$

Rearranging

$$LCOE = \frac{\sum_{t=0}^{25} \frac{1}{(1+r)^t} * (Costs_t)}{\sum_{t=0}^{25} \frac{1}{(1+r)^t} * (Production_t)}$$

Finally, the net costs include cash outflows like the initial investment, cash flows such as governments incentives, operation and maintenance costs and residual value (Branker et al, 2011).

Time- A solar PV module usually has a 25 manufacturer warranty which means that the power output is the most efficient in this time. In the calculations the lifetime of solar system was considered to be 25 years (Tyagi et al, 2013).

Discount rate – It reflects current rates of money used for constructing new PV projects. The discount rate puts a value of time preference on money, which varies by location, circumstances and time period considered. Private sector usually favours higher discount rates in order to maximize short term profit (Branker et al, 2011).

Initial investment – Direct purchase of a Solar PV. It is expressed in EUR and is calculated by multiplying system cost in EUR/W with system size. The cost of a PV system depends on its size and other factors, like geographical location, supporting structure for mounting, and PV module type (NREL, 2014).

Incentives- Incentives provided from government. For example, Investment Tax Credits. They have been implemented in several jurisdictions around the world to support solar energy. In the United States, for example, the credit is equal to 30% for the direct purchase of the solar system.

Operations and Maintenance (O&M)- Total (fixed and variable) cost of operations and maintenance of the system. This is expressed in EUR/kWh/year. The figure 14 shows the prices depending on the system size.

Technology Type	Fixed O&M (USD/kWh/year)	Fixed O&M (EUR/kWh/year)
PV <10 kW	21	18,85
PV 10–100 kW	19	17,06
PV 100–1,000 kW	19	17,06
PV 1–10 MW	16	14,36

Figure 14. Fixed operations and maintenance costs (Distributed Generation Renewable Energy Estimate of Costs, 2016. Retrieved from http://www.nrel.gov/analysis/tech_lcoe_re_cost_est.html)

The price was converted to Euros and the total E&M cost over equipment life time was a sum of O&M Cost (EUR/kW) multiplied by System Size (kW);

Residual value – The value of the system at the end of a project's life. It ensures that the system continues producing at the its greatest capacity throughout its lifetime. If the system is well maintained, its residual value can be still quite significant after the end of system lifetime. It is expressed in EUR.

The production denominator includes the first year production and the annual degradation over time:

System degradation – An accurate quantification of power decline over its life time. It is calculated by subtracting annual degradation rate from 1. It reduces the energy with time and is expressed in %. The solar cell performance rate degrades depending on lots of variables such as type of solar cell, electricity production level , location or climate. The degradation rate is generally treated as a single value in the calculations despite the mentioned facts, because even within a single PV system, individual panels can degrade with considerably different rates (Darling et al, 2011). Current literature reports a degradation rate of less than 1%. The Thin film model degradation rates have improved significantly, but they are still closer to 1%/year than to the 0,5%/year (Jordan et al, 2013).

So,

$$LCOE = \frac{\sum_{t=0}^{25}\frac{1}{(1+r)^t}*(II + O\&M - Incentives - RV)}{\sum_{t=0}^{25}\frac{1}{(1+r)^t}*(Production_t*(1-d)^t)},$$

Where:

r- Discount rate;

t- Time (years over projects lifetime);

II – Initial investment;

RV- Residual value;

d – Annual degradation.

Solar PV industries offer a range of options to finance projects. Already around 70% of the solar system projects introduced today are done with a PPA (Purchase Power Agreement). The basic principle is that energy provider and the brewery sign an agreement to install the solar equipment and supply power to the customer. It is usually supplied for a very low capital investment of a brewery or no investment at all. It may be required to use customers property, where the electricity can be generated, at a fixed price over the agreed upon period of time (Chen, 2016). The LCOE by direct purchase solar PV output is compared to Power Purchase Agreement (PPA) output to estimate which way is more profitable for the company. PPA can provide solar system with no upfront investment but does include an escalator (McAllister, 2012). PPA outcome is expressed in EUR/kwh and is calculated:

$$PPA = Production_t * PPA\ rate * (1+E)_t;$$

Here:

PPA rate – Fixed rate per kWh;

E – Escalator.

PPA rate – It is an electricity rate that was agreed upon with the client as the basis for a Power Purchase Agreement. It is a fixed rate which is normally lower than the local utility's retail rate (Feldman, 2014).The rate is expressed EUR /kWh.

Escalator - It is an indicator on the future utility energy prices which foresees that the energy generated by solar PV will be more expensive (McAllister, 2012). The escalator rate is fixed and the customer paid price increases at a predetermined rate, usually between 2% - 5%.

LCOE CALCULATIONS

LCOE can be used to compare Solar PV projects in different Operating Companies with different market prices in different locations. In order to reach grid parity, the system output has to be higher than the local electricity cost. This way the project is profitable for the company. In the paper, several Operating Companies are compared: HEINEKEN USA, placed in New York City, HEINEKEN Brasil placed in Brazil and HEINEKEN Asia Pacific located in Singapore. These countries were chosen to make a good comparison because all of them are in different continental zones, which results in different production units of solar systems as well as system costs variations. Furthermore, unlike Singapore and Brazil, USA simulates solar energy with financial subsidies, which is interesting to compare how the outcome differs if the price of the system decreases significantly. Brazil (in 2018 will be 7 perating companies) and Singapore (has three Operating Companies) have big turnovers in regards to manufacturing.

The annual production rate indicates the total solar energy output generated (in kWh) annually according to the installed capacity. The generated electricity from photovoltaics is very location-dependent. To accurately depict geographical attributes, annual yield (kWh/kW) of the system is estimated based on the actual performance of a sample of PV systems found in the literature of these three Operating Companies. The production rate also differs according to the technology (Doshi et al, 2013). In this paper the production rate is estimated taken into account the most common solar PV technologies such as thin film and crystalline silicon systems and leaving out multijunction devices such as concentrating solar cells. The efficiency of the silicon and thin film devices can vary up to 5% bias, so the output from these systems do not deviate that much, whereas multijunctional cells have much higher efficiencies (Parida et al, 2011).

The present value of the cash flows is calculated by means of a discount rate which was chosen to be 6% and applied for all Operating Companies (Hernández-Moro et al, 2013). Another invariable measure in these calculations is annual degradation factor. This is chosen to be 1%. It was decided not to account for residual value of the system, because it very dependent on technology, size of the system and is usually determined by the supplier before starting to use the system. Proper monitoring and maintenance of the solar energy systems can ensure residual value being quite significant. However, when the performance is not being recorded and the system is not properly taken care of, both physically and financially, the residual value after systems lifetime may be very low. That is why it is very hard to estimate residual value in the LCOE calculations.

Power Purchase Agreement (PPA) is sold to a customer at a specified tariff established by a provider. PPA rates were collected from several case studies found in literature. However, as mentioned before, the Power Purchase Agreement (PPA) rate depends on provider, so it can vary accordingly. The price offered by PPA is usually indexed at a discount to the grid electricity prices with the escalation rate (Energy studies institute, 2015). The escalation rate is chosen to be 2% in all calculations.

The LCOE analysis in this paper doesn’t include taxes, interest payments, transfers or inflation with respect to solar PV electricity generation.

HEINEKEN USA

The average amount of solar electric energy produced is 59387 kWh/year. It is managed by a 50kW size solar system in New York city climate (Salasovich et al, 2013).The system of 50 kW-DC is modelled at USD 2.79 USD/W (2.48 EUR/W) (NREL, 2016).

The calculations take into account also Investment Tax Credit (ITC). It is an incentive of 30 percent federal tax credit for not only residential but also commercial investments in in solar energy. It is equal to 30% discount of the initial investment that is payed for solar property. In 2020 ITC rate will drop down to 26% and in 2023 it will remain only 10%. There are many other local subsidies in New York City, but they will not be taken into account because they are either for residential systems, minor grants, or tax incentives that would make a very small difference in the output.

National Renewable Energy Laboratory made a Power Purchase Agreement Checklist where there are examples of PPA terms in USA depicted. The estimated PPA price for 50 kW model for 25 years agreement was 0.152 USD/kWh (0.136 EUR/kWh) (Salasovich et al, 2013).

According to all the variables, Solar PV system will have an output of 0.142 EUR/kWh if purchasing the system directly and 0.172 EUR/kWh if leasing via PPA. Commercial electricity tariff in New York City is 15.12 dollar cents per kilowatthour (0.135 EUR/kWh) (Electric Power Monthly, 2016). Comparing the results, we can conclude that Solar LCOE will not reach grid parity in NY when buying directly. If choosing PPA, the price has to be negotiated.

HEINEKEN BRASIL

As mentioned before the production rate is very location dependent. Brazil is a 8.5 mln km2 size and the climate slightly varies per location. HEINEKEN Brasil is located in San Paulo, south-east of Brazil. Here the annual yield for commercial 30 kW PV system is estimated to be 49.056 kWh (Azzaoui, 2013).

Solar cells in Brazil have almost 30% higher price then the international price levels. That is because they are currently only being imported and transportation and installation costs are high (PV Energy in Brazil, 2015). The initial financial investment for this system was evaluated to be around 188.047 BRL (Azzaoui, 2013). Accordingly, the price per Watt can be calculated leading to 1.72 EUR/W.

Solar energy started to be supported by the government only last year and the market is not fully developed. That is also the reason why there are still no incentives or very small ones for stimulating PV sector, so none of the incentives in the calculations will be included.

Even though there are very few incentives and the initial investment of solar system is high, there is a large solar energy potential, considering that Brazil on average receives more than 2.500 sun hours a year and Sao Paulo approximately 2000 hours (PV Energy in Brazil, 2015).

As literature search states, the solar energy PPA rate was 0.087 USD/kWh (0.078 EUR/kWh) in 2014 (PV Energy in Brazil, 2015).

After inputting the numbers into a LCOE model, the outcome is: the LCOE is only 0.101 EUR/kWh buying directly and with PPA the result is 0.1 EUR/kWh as well. In San Paulo the commercial electricity tariff now is 0.09 EUR/Kwh excluding charge for distribution, which is around additional 0.01 EUR/kWh (Tarifa de energia elétrica, 2016). That means that installing Solar PV when buying directly, the company breaks even. However, the environmental factor and labor creation factor creates a competitive advantage and can still pay a role. When considering Power Purchase Agreement, the capacity of the system has to be carefully evaluated, and the ratio of PPA with a developer has to discussed. If using this system as an example, the ratio of PPA cannot be higher than 0.077 EUR/kWh. Only then the grid parity could be reached.

HEINEKEN SINGAPORE

In average a system of 1kW in Singapore can produce 1250 kW annually (Luther et al, 2014) with a module cost of 1.25 USD/kWh (1.11 EUR/W) (Doshi et al, 2013). This is a conservative value, which is based on 76% quality factor for the PV plant (Performance ratio). Very high performance PV systems can reach up to 80 %, which would make the annual production in Singapore even higher.

Singapore practices not subsidizing energy, so it is not included in calculations. Even though without financial support, Singapore government tries to provide the basics of a supportive environment for rooftop solar business models. They try to define a clear framework for market participation, payment settlements and the grid interconnection process (Energy studies institute, 2015).

When talking about PPAs in Singapore the leasing term is generally 25 years and the solar tariff is fixed at a discount from the retail tariff rate. Literature case studies estimate a 17 SGD cents/kWh (0.13 EUR/kWh) (Energy studies institute, 2015).

Given all the input, the LCOE with direct purchase is only 0.09 EUR/kWh. It is a low price that is why solar PV continues to be the most promising renewable technology for Singapore (Sabba et al, 2016). PPA output is 0.16 EUR/kWh. Considering that the electricity tariff is Singapore now is 19.27 cents SGD/kWh (0.13kWh), we can easily conclude that in this country solar PV would reach grid parity (Energy market Authority, 2016). Using this PPA rate is not an option. If the client cannot afford to directly invest in solar PV, the PPA rate should be negotiated. It should be lower than 13 Euro cents per kWh, without taking solar system ownership. Normally, the PPA rate is established according to the electricity tariff, and is usually lower.

In general, without any access to comparative costs of renewable technologies it is very difficult to make an accurate assessment of which technologies are the most appropriate for their particular circumstances (IRENA, 2012). This comparison can help to close the significant gap in information accessibility, because there is very little up to date data and big fluctuation of units.

LCOE COMPARISON

LCOE model was used to compare solar PV projects in different markets. Three Operating Companies in HEINEKEN were chosen located in USA, Brazil and Singapore. The results, how the costs of Solar PV differ per region are depicted in the figure 15.

Country/ State where Operating Company is placed	New York, USA	San Paulo, Brazil	Singapore
LCOE with direct purchase (EUR/kWh)	0.142	0.101	0.09
LCOE with PPA (EUR/kWh)	0.172	0.099	0.16
Regulated electricity tariff in the area (EUR/kWh)	0.135	0.10	0.13

Figure 15. LCOE comparison

The results of LCOE model in the countries show that only in Singapore it is profitable for company to implement solar PV. However, the differences in Brazil are very small. In New York, installation via Power Purchase Agreement compared to regional electricity tariff from the grid is also marginal. The company still might install the technology for other sustainable reasons, this way creating themselves a competitive advantage.

10. DISCUSSION

HEINEKEN companys target in production of 40 % CO_2 emission reduction by 2020 has been split up into 10% increase in supply by renewable energy sources and 30% reduction in energy usage. The main consumers during the brewing process are mashing and wort boiling. There are quite some possibilities of decreasing energy consumption during wort boiling. The discussed vapour condensation method can be used to capture the steam, produced during wort boiling, which otherwise, would be lost in the air. The condensation of 1 kg of steam can be turned into 1 kg of water which produces 2.260 kJ of energy (Kichula et al, 2008). However, since then most of the steam stays in the kettle, it causes unpleasant smells inside.
During the wort boiling if the atmospheric pressure gets compressed with a few bars, the temperature already increases with few degrees, that's why compression seems to be a possible option. The mechanical compression is more efficient then the thermal vapour compression. It can reduce emissions by around 95%. It does have disadvantages, such as high electricity demand, high maintenance costs, noise production, etc. However, peak electricity demands can be reduced by using internal boiler in the

kettle and energy storage system. Besides, when the compressed vapour gives up its heat to boil the wort, it is being sent to the waste water treatment plant as a fluid. Whenever there is a water treatment plant, the anaerobic digester can be introduced, this way reducing energy and disposal costs. The thermal compression is not efficient enough to align with large breweries operations. Nevertheless, the capital investment is lower and it does not have peaks in electricity consumption (Tomescu, 2012). The drawback of the compression system is that in the vapour of boiled wort has a 1% of organic constituents, but some of them cannot be compressed. Then the bio filter is needed to treat them, or they are released outdoors, which is harmful to the atmosphere (Willaert et al, 2005). Studies show that low pressure boiling consumes 47% less energy compared to atmospheric boiling, which results in 1.13 kg of CO_2 decrease per hl (Githuka, 2012). Very important nuance is that internal boiler in the system operates at very slow steam pressure, so the pipes get contaminated slower which provides higher intervals between cleanings and leads to higher efficiency of brewing (Hornsey, 2003). The internal boiler can work even with 3–5% evaporation rate when the kettle is full of wort. Even though, only one kettle at a time can be used with vapour condenser, pre-heater or energy storage tank, it still outranges other systems of boiling (Githuka, 2012). Merlin system has also very high energy efficiency and consumes approximately 62% less energy compared to conventional boiling. When taking a 100hl production volume, it produces 64% less CO_2 with a total evaporation lower than 4% (Weinzierl et al. 2000). Unlike in compression systems, the organic compounds here are almost completely expelled (Willaert et al, 2005).

Equitherm system is primarily used in energy reduction purposes during mashing processes. It can greatly downsize the thermal energy consumption. A brewery with 0.2 mln hl production per year can save around 250,000 kilowatt-hours of thermal energy (Krones, 2014). Here, the energy is being reused, while Meura filtration system uses less water in mashing process in general. To reduce more energy during processes, boilers can have economizer function installed. Economizers are special mechanical devices which help to improve boilers efficiency. An Economizer guarantees 9 % of energy input savings (Mutua et al, 2012).

The studies demonstrate that the best applied energy recovery system during wort boiling for HEINEKEN is dynamic low pressure boiling or Merlin system. They both can not only significantly reduce CO_2 emissions and unwanted volatiles, but also improve efficiency of brewing process itself. For the mashing process improvement, Equitherm system, which promises up to 30% percent energy savings by heating the mash with the energy recovered from wort cooler, seems like a good solution. In the paper, economical figures of the machines were not present, as well as their applicability to the brewery, that is why further research is recommended regarding economical and technical aspects to ensure adequate requirements for installation in an individual brewery.

The mentioned energy efficiency suggestions can significantly reduce CO_2 emissions, waste and water consumption (Galitsky, 2003). However, part of on-site emission reduction can be achieved through energy conservation practices. It seems like a good primary solution mainly due to an inexpensive investment compared to the clean production equipment. Problems such as bad maintenance, leak identification, bad insulation, inefficient lightning and other similar energy consumption incidents that were discussed in energy conservation section are quick fixes. Breweries can benefit greatly by implementing various strategies that are simple, easy and low cost. The measures for energy conservation are just the upgrades, repairs or simple monitoring that have shot payback periods. It is important to put emphasis on the system monitoring. It is recommended to carry out inspection regularly, which is the primary tool to avoid unnecessary losses and leakages. Other energy conservation measures, such as replacement investments, that have short payback periods, can be carried out in phases.

To meet indirect carbon emission and renewable energy targets in production by 2020, it is important to understand the technology itself, its advantages and drawbacks. Generally speaking, renewable energy has a huge potential, but there are certain limitations for the potential buyers. The renewables are relatively new technologies, which leads to insufficient information to make the most suitable choice. Most providers don't disclose information about carbon emissions or water consumption right away. Clients are also concerned about reliability of energy supply and are likely to comprehend them as a risky investment. That's why the author describes six most suitable renewable energy technologies for the company - Solar thermal, Biomass, Tidal power, Wind onshore, Geothermal and Solar PV – in a rather detailed way, considering their working principle, pros and cons. The technologies were evaluated according to the 6 key criteria, in order to quantify the sustainability impact. The 6 ranking criteria were: Area requirements, LCOE, Capital investment costs, CO2 emissions, Efficiency of electricity and Water consumption. All the criteria were considered equally important and according to the findings, Solar PV and Wind mills came out as the two best options.

In the paper, an extensive literature data collection was provided in order to determine the best estimated values. However, the study holds some uncertainties, because in some cases there were quite big variations between the weights. Furthermore, each of the technologies are highly geographically dependent. In the paper, however, only the global average conditions were considered. Unit inconsistency, rounding ups and different technology usage are also big factors contributing to the uncertainties of the study.

Solar PV, according to sustainability criteria, seemed to be the most suitable option for the company. For that reason, there was an LCOE model developed to compare solar PV project financial outcomes in different locations. Three Operating Companies in HEINEKEN were chosen located in USA, Brazil and Singapore. This choice of selection was mainly due to their high manufacturing turnovers. The results revealed that only in Singapore the grid parity can be reached.

While there are other factors that vary depending on the climate, in the paper it was assumed that only the energy yield will differ. Naturally, it is not taken into account that locations with high temperature and humidity can increase systems degradation rate (Pingel et al, 2010). Besides, different solar PV technologies respond to climate differently. Specific types of solar panels also have different efficiencies that influence the level of energy produced. It is important to highlight, that the residual value was not taken into account in the calculations. If the system is well maintained the residual value can be quite significant and would make a LCOE lower. However, it is very hard to measure the residual value, because it is highly dependent on the systems monitoring, performance, inflation, etc. Incentives might change over time as well: governments might start supporting solar PV in countries like Brazil, and reduce the ratio in USA. The costs are also highly depended on the system size and efficiency. The more assumptions there are, the higher uncertainty of LCOE output there is. However, even with these assumptions, it is easy to identify which market has a chance to reach the grid parity and which one exceeds regional electricity tariff too much.

The established solutions in this paper might be useful for the brewing process productivity, locking-in energy costs for the future and carbon footprint reduction. They can help closing or even exceeding the gap between the current situation and the set target. Green power also provides self-sufficiency to the company. Prospective employees could use these solutions as indicators of a company's values and culture and finally these methods may be found as a competitive advantage from a consumer’s perspective (Ilinitch et al, 1999).

11. CONCLUSIONS

Carbon dioxide is essential for the beer. During the brewing process it is used for adjusting carbonation level and removing and preventing foreign gas uptake. The biggest source of carbon dioxide emissions in the brewing industry is the combustion of fossil fuels – either at the brewery itself or in the generation of the electricity supplied. HEINEKEN 40% less CO2 emissions target for 2020 is meant to be achieved by energy efficiency and applying renewable sources. While wort boiling and mashing being the biggest energy consumers during the brewing process, there are quite some opportunities to recover the energy. The proposed energy efficiency equipment do not interfere with the brewing process and some of them improve beer quality and show significant energy savings, leading to lower CO2 emissions. Process monitoring, maintenance and control systems also play an important part in energy management. Renewable energy technologies, depicted in the paper, are solutions for electricity generation and combined with energy efficiency methods, have a high potential towards making HEINEKEN a “sustaining corporation” having zero emissions in production. Renewable technologies were ranked according to several important criteria including: Area requirements, Levelised cost of electricity (LCOE), Capital investment costs, CO2 emissions, Efficiency of electricity generation and Water consumption. The results showed that currently wind onshore and solar PV energies are the most sustainable. Due to this ranking and rapid PV price reduction, LCOE methodology was examined in different geographical locations. The model revealed that grid parity can be reached in Singapore. In New York and Pan Paulo solar PV integration is not profitable due to high prices or low annual yield. However, the difference between regional electricity tariff and LCOE price is not high.

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