Wageningen University - Department of Social Sciences

Business Economics

MSc Thesis

Economic viability of non-alcoholic craft beer production

Analysing the viability of producing alcohol-free beer in the Dutch craft beer scene

March 2020 – October 2020

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Thesis code	BEC-80436

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Abstract

Healthy lifestyle trends are emerging. In the beer industry, this is evident from the growing demand for alcohol-free beers. These beers are often perceived to be low in flavour. Alcohol-free craft beer can possibly compensate these shortcomings, as craft beer is regarded as highly flavorous. The aim of this research is to analyse the economic viability of producing alcohol-free craft beer in the Netherlands. The production of alcohol-free beer requires an additional alcohol removing step. The most applicable methods are rectification and thin layer evaporation. Even though the cost price of beer increases, brewers benefit from the reduced taxation on alcohol-free beer compared to alcoholic beer. A minimal production of 400 hL alcohol-free beer is required to offset the increased cost price. This is almost 50% of the total production size of an average Dutch craft brewer. Although it is possible to have a profit of 3 million euros in 30 years, by producing 250 hL of alcohol-free beer per year. The same or more could be earned by selling alcoholic beer, as at this volume the additional cost price is €1.23 per liter. It is not economically viable for an average Dutch craft brewery to invest in the production of alcohol-free beer. The production size of a craft brewery is not sufficient to produce profitable alcohol-free beer and alcoholic beer is generally a better alternative. The advice is to share a dealcoholiser with a select group of brewers to reduce marginal cost and the minimal production size.

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1. Introduction

1.1. Background

Beer is an ancient alcoholic drink that is still consumed worldwide. Brewing beer was discovered over 5000 years ago and has been popular ever since (Hornsey, 2016; Liu et al., 2018). Nowadays, beer is the most consumed alcoholic beverage in the world ahead of ciders and rice wine. The estimated average consumption of beer per capita in the world is 25.7 liters in 2020 (Statista, 2020a). In Europe, consumption is higher on average than in the rest of the world. Czech Republic has the highest consumption in Europe with an average of 141 liters per person in 2018. In the same year, the average consumption in the Netherlands was 70 liters per person (Brewers of Europe, 2019). Even though, heavy drinking (consumption of more than 60 grams of pure alcohol in a single occasion) has decreased since 2000, total alcohol, including beer consumption, has increased. It is expected that this trend remains in the coming years (WHO, 2018).

Alcohol consumption is related with severe health risks. In general, three groups of disorders can occur after excessive usage of alcohol. The first is related to toxic effects on organs and tissues in the body. Alcohol consumption has shown to increase the risk of cardiovascular and liver diseases. Moreover, the risk of development of various cancers is increased by alcohol consumption (WHO, 2018). The second group is about mental disorders, due to the development of alcohol dependency. These can be the foundation for developing depressions (Luminet, Cordovil de Sousa Uva, Fantini, & de Timary, 2016). The last group is about impairments in brain function directly after drinking (Babor, 2010). Irresponsible behaviour is one of the related problems. This is also the reason that driving is not allowed after drinking alcohol. Attentional and behavioural controls of drivers are impaired and this leads to alcohol being a serious risk factor in traffic (Yadav & Velaga, 2020). In total, 5.3% of all deaths worldwide that occurred in 2016 were accountable to alcohol consumption (WHO, 2018).

Creating awareness for these implications of alcohol usage has been on the agendas of governments for a long time. Public campaigns are aimed at informing people about effects of alcohol consumption. Moreover, incentives are to change social norms towards alcohol and to decrease availability of alcoholic beverages (Halim, Hasking, & Allen, 2012; Volksgezondheid, 2019). Awareness to health programs is noticeable as numerous of healthy lifestyle trends are emerging (Santeramo et al., 2018). In the beer industry, this change is evident from the growing demand for low-alcohol and alcohol-free beers. Health-conscious people are expected to consume these beers as alternative for alcoholic types (Ahuja & Rawat, 2019). In the Netherlands, market share of alcohol-free beer has been tripled since 2013. The share of non-alcoholic beer in the beer market was 5.8% in 2018 and is expected to increase further in coming years (Statista, 2019). Large brewing companies have developed non-alcoholic beer varieties and started competing for customers. Increasing product availability through various channels and new product launches are supporting the market growth (Ahuja & Rawat, 2019).

An actual advancement is that the hedonic profile of beers is becoming more important for beer drinkers. Disposable income is increasing and higher quality beer is consumed. This leads to a larger variety of beer styles that are being produced (Brewers of Europe, 2019). This is also apparent in the alcohol-free beer market, as companies start to develop low-alcohol or alcohol-free specialty beers (Ahuja & Rawat, 2019). The taste of regular alcohol-free beers is often conceived by consumers as unsatisfactory and inferior to the taste of their alcoholic variants (Blackmore, Hidrio, Godineau, & Yeomans, 2020). Craft beers can be a counter for the lower sensory properties of alcohol-free beers. Craft beers exist in a wide variety of full-bodied flavours and aromas. Consumers often perceive craft beer as high quality, since specific preferences and likings can be aimed for by craft brewers (Mastanjević et al., 2019). As a consequence, the craft beer sector has been growing in size for over a decade. In Europe, the number of active breweries doubled in the period 2012-2018 (Aquilani, Laureti, Poponi, & Secondi, 2015; Brewers of Europe, 2019). Alcohol-free craft beer is possibly able to become an attractive alternative beverage for beer drinkers, when flavour offset is minimalised and the high-quality perception remains. However, it should be investigated if production of alcohol-free beer is viable for craft brewers.

1.2. Problem statement

Only a few kinds of alcohol-free craft beers can be found on the Dutch market. Low-alcohol craft beers are sold in the same market with more variety, however, they are produced and regulated differently. Alcohol-free beer is often perceived to be low in flavour, whereas craft beer is regarded as highly flavorous (Güzel, Güzel, & Bahçeci, 2020; Mastanjević et al., 2019). Therefore, alcohol-free craft beer can possibly compensate the shortcomings of regular alcohol-free beers.

Production of alcohol-free beer is for the main part similar to regular beer. However, a distinct difference is the additional alcohol removing step. The methods for dealcoholisation require special equipment, which are not inherently available in breweries. Large investment in this machinery and increasing operational costs are expected. Moreover, the extra space needed in the brewery should be considered (Brányik, Silva, Baszczyňski, Lehnert, & Silva, 2012). Eventually, the increase in sales is of large importance for decision making. All in all, it can be a difficult decision whether producing alcohol-free beer is worthwhile for a small-scale brewer. This is even more difficult for craft brewers, as a broad range of beers are produced in limited quantities. Therefore, the aim of this research is to analyse the economic viability of producing alcohol-free beer by craft brewers. This is particularly interesting, as most literature about alcohol-free beer focusses on technical aspects and not on economic aspects of brewing.

1.3. Objectives

The main objective of this research is: "Is it economically viable for Dutch craft brewers to invest in the production of alcohol-free beer?" Before answering the main research question, three subquestions are answered.

Subquestion 1: "How can alcohol-free beer be produced and what is the difference with low-alcohol beer?"
Subquestion 2: "How can alcohol-free beer be produced by craft brewers?"
Subquestion 3: "What are the costs and revenues related to production of alcohol-free craft beer?"

1.4. Demarcation

Craft brewers are defined as "small and independent beer producing companies". The Dutch CRAFT organisation, which has over 170 members, mentions that a brewery can be called a craft brewery, when it satisfies the requirements of four pillars: independency, authenticity, honesty and volume. First of all, less than 25% of the total shares can be owned by a not independent brewer. Secondly, the beer is not diluted and is not allowed to contain maize, rice or other ingredients to reduce costs. The third requirement is that the brewer is honest and open about its ingredients and their origin, as well as the brewing location. The last requirements is that the total yearly production of the brewery is not exceeding one million hectolitres (CRAFT, 2020a).

The geographical focus of this research is the Netherlands. Data about production sizes, costs and revenues are only relevant, when it concerns Dutch craft breweries. The target group of the current study consists of members from the CRAFT organisation. The average production of these brewers was 849 hL in 2016 (Brouwer, 2017). Literature about non-Dutch breweries can be used, however it should be appraised for applicability in the Dutch craft beer industry.

In the Netherlands, the definition of beer is “a beverage obtained after alcoholic fermentation of wort, consisting of mainly sugary raw materials, hops, water and yeast”. Moreover, at least 60% of the sugar concentration, also called extraction content, of the wort should come from barley or wheat malt ("Warenwetbesluit Gereserveerde aanduidingen," 2017). Additionally, fruits, fruit juices, aromas and additives are allowed to be added to the beer. In the Netherlands, alcohol-free beer is defined as beer with a maximum alcohol volume percentage of 0.1%. Low-alcohol beer is defined as beer with an alcohol volume percentage between 0.1% and 1.2%. Both beer types should contain at least an original gravity of 4% ("Warenwetbesluit Gereserveerde aanduidingen," 2017). This is a measure for the number of solid particles in the liquid wort before fermentation and is calculated by the ratio between weight in kilograms and volume in liters. It is an indication of the available fermentable sugars and is therefore an indication of the later alcohol content. These beer definitions are the foundation of the scope of this thesis. Beer like products, which are not produced regarding the Dutch regulations, are not considered.

Furthermore, it is assumed that brewers are able to develop an appetizing alcohol-free beer recipe, which is attractive to consumers. The development of such a recipe is not considered in this thesis, although it is of large importance for the final taste and thus liking of the product.

In addition, the economic feasibility of producing alcohol-free beer is dependent on the market. Products can only be sold in a market, where there is consumer demand for the product. Therefore, to forecast if a product can be a success and that produced products can be sold, the market needs to be analysed for potential demand. However, this is out of the scope of this thesis. It is assumed that the needed demand is available based on the current trends: increasing craft beer consumption and increasing alcohol-free beer consumption.

2. Methodology

This work is in collaboration with the Dutch CRAFT organisation. Their contact channels are used for gathering contacts of interested people and collecting information. CRAFT is an association for independent craft brewers. Their aim is to promote the Dutch craft beer culture and to share knowledge about beer within a community of beer brewers and lovers. They are supporting responsible beer consumption. Therefore, alcohol-free craft beer is an interesting topic for this organisation.

The answer to the main research question: “Is it economically viable for Dutch craft brewers to invest in the production of alcohol-free beer?”, consists of two parts. Firstly, it is investigated how alcohol-free craft beer can be produced. Different production methods are compared to find the most applicable method for small-scale production. The next part of the objective is the evaluation of the costs and revenues associated with the chosen method. In the end, a reflection on the viability is specified and used to decide whether producing alcohol-free craft beer is advantageous.

2.1. Literature review

The first research question: “How can alcohol-free beer be produced and what is the difference with low-alcohol beer?” is answered by performing a literature review about technical aspects of beer production. The literature review is performed by searching at the online databases: Google Scholar, ScienceDirect and the online WUR Library. The effects of the beer ingredients on beer characteristics, including the influence on the formation of alcohol is reviewed. The used search term is: "beer ingredients" AND alcohol. Articles released before 2005 were excluded. Additional articles are found using the snowballing technique. Subsequently, the entire production process of beer is reviewed. All malting and brewing steps are included and the focus for each step is on the effect on alcohol formation. The search string is: "beer production" AND alcohol AND technical AND steps AND malting. In addition, methods to produce low-alcohol and alcohol-free beer are discussed. All methods are categorised within two groups, namely biological and physical methods. The focus is on how alcohol content is minimized or reduced by the different methods. Furthermore, the difference between alcohol-free and low-alcohol beers is discussed. Articles are found with the search term: "alcohol-free beer" AND production AND alcohol. Moreover, the snowballing technique is used to find additional articles.

Nextly, the discussed methods for alcohol reduction in beer are scored for applicability at craft scale production. The ratings are based on the advantages and disadvantages of the various methods. Operational difficulties and the ability to result in beer with less than 0.1% alcohol content is taken into account. Positive ratings are given to methods, which are applicable at craft scale and are able to result in beer with less than 0.1% alcohol. Methods that are difficult to implement at craft scale or that are not able to result in beer with an alcohol content below 0.1%, are given a negative rating. The neutral rating is given to methods that are able to form alcohol-free beer yet are seen as expensive options in literature. The methods with the highest rating are regarded as the most applicable at craft scale production.

2.2. Scenario development

Answering the second research question: “How can alcohol-free beer be produced by craft brewers?” is accomplished by giving a detailed description on how craft brewers can produce alcohol-free beer. The internet is searched for commercially available equipment based on the positive rated methods of the previous chapter. Applicable machines are found and data is gathered through brochures and the advertising websites. The parameters for which data is gathered are listed in Table 1. The combination of these parameters is expected to resemble the cost of producing alcohol-free beer and reveal additional challenges in the production.

Table 1. Parameters of dealcoholisers.

Additional steps required before consumption	Dimension	Investment cost
Life expectancy	Maintenance	Outcoming alcohol concentration
Power	Processing pressure	Processing temperature
Throughput	Water usage	

Missing data is complemented by inquiring the corresponding companies by e-mail. The systems are introduced and the system parameters are combined to create an overview of the various methods. Subsequently, an advertisement is posted on the CRAFT website, see Appendix I, to find CRAFT brewers, interested in alcohol-free beer production. These brewers are questioned via phone about their experiences and about foreseen challenges of producing alcohol-free craft beer. The questions can be found in Appendix I. The challenges are elaborated and supported with literature about the topic.

Based on the data of the dealcoholisers, possible solutions to the challenges are devised and related scenarios are developed. In addition, the differences in the regulations of selling alcoholic and alcohol-free beer are considered. Moreover, data for the use in the investment analysis in the next chapter is decided based on information from brewers, manufacturers and data found on the internet.

The values for discount rate, interest rate, loan term and beer consumer price are based on assumptions. The beer price per bottle (330 mL) is assumed to be between €2.20 and €3.00, which is comparable to prices of craft beers in Dutch supermarkets. The loan term is assumed to be 10, 20 or 30 years, which is based on a maximal loan length of 30 years. The values for the interest rate are based on the current interest rates: 1.5%, 2.0% and 2.5%. The values for the discount rate are assumed to be 2.0%, 3.0% and 4.0%. These are also based on the current interest rate, however a safety margin is included. Moreover, it is assumed that two labour hours are required per machine hour for related operational activities.

2.3. Investment analysis

The final research question: “What are the costs and revenues related to production of alcohol-free craft beer?” is answered by an evaluation of the costs and revenues related to the scenarios from the previous research question. The discounted cash flow analysis is used to calculate the net present value (NPV) of the investment. This method is used, as time is of large importance for the investment. Long life expectancies are considered and the investment costs are spread over multiple years. The NPV takes the time value of money into account using a discount rate for future cash flows. A positive NPV results in added value to the business, while a negative NPV results in a decrease in value for the business.

In the first scenario, the NPV is calculated for all possible parameter combinations from the previous research question. This is done for production sizes between 50 and 500 hL per year. The lowest and highest NPV for each production size is visualised. The NPV that results from the average values of all parameters is also visualised. Moreover, the payback period is calculated for average, least and most favourite combinations of parameters.

The NPV is calculated by a summation of the discounted cash flow for each year, see formula 1. The duration is 30 years and the cashflows within that period are considered. The payback period is calculated by a summation of the not discounted cash flows for each year. The first year, in which the cumulative cashflow is positive, is regarded as the payback period.

$$(1)\ NPV = \sum_{n=1}^{30} \frac{\Delta\ Earnings\ alcoholic/alcohol-free\ beer\ (2)\ \times\ Yearly\ production\ -\ Fixed\ cost_n\ (3)}{(1 + Discount\ rate)\ \hat{}\ n}$$

NPV in €, Δ Earnings alcoholic/alcohol-free beer in €/hL, yearly production in hL, fixed cost in year "n" in €, discount rate no unit

$$(2)\ \Delta\ Earnings\ alcoholic/alcohol-free\ beer = \big(Efficiency \times Selling\ price\ ex.VAT\ and\ excise\ duty\ of\ alcohol-free\ beer - Variable\ cost\ (4)\big) - Selling\ price\ ex.VAT\ and\ excise\ duty\ of\ alcoholic\ beer$$

Δ Earnings alcoholic/alcohol-free beer in €/hL, efficiency in (hL in/hL out), selling price ex. VAT and excise duty of alcohol-free beer in €/hL, variable cost in €/hL, selling price ex. VAT and excise duty of alcoholic beer in €/hL

$$(3)\ Fixed\ cost_n = Principal\ payment_n + Interest\ cost_n + Maintenance\ cost$$

Fixed cost in year "n", principal payment in year "n", interest cost in year "n" and maintenance cost in €

$$(4)\ Variable\ cost = \frac{Water\ cost + Electricity\ cost + Labour\ cost}{Production\ rate}$$

Variable cost in €/hL, water cost, electricity cost and labour cost in €/h, production rate in (hL out/h)

In addition, a multiple linear regression model is devised to investigate the importance of the parameters on the NPV. The Data Analysis tool incorporated in Microsoft Excel for office 365 (Microsoft Corporation, 2020) is used to calculate the coefficient values, standard errors and the significance of all parameters. In addition, the observed difference in NPV between the largest and smallest value of every parameter is given for the case that all other parameters are at the average value. Furthermore, the assumptions for multiple linear regression: homoscedasticity, multivariate normality, linear relationships between NPV and independent variables and no multicollinearity are tested using the same tool. Formula 5 shows the calculation for a multiple linear regression.

$$(5)\ Y_i = \beta_0 + \beta_1 \times x_{i,1} + \beta_2 \times x_{i,2} + \ldots + \beta_p \times x_{i,p} + \varepsilon$$

Y_i = dependent variable, X_i = explanatory variable, β_0 = y-intercept, β_p = slope coefficients for each explanatory variable and ε = residual. "p" is the number of explanatory variables, whereas "i" is the number of observations.

In the second scenario, parameters are held constant for 30 years and the required selling price (excluding VAT and duties) to get an NPV of €0 is calculated. This is done for a yearly production between 50 and 1000 hL. The same procedure is performed for two specific cases. Both cases increase production each year by 10 hL. The first case has a production of 50 hL in the first year, whereas the second case has a production of 20 hL in the first year. A distinction is made between the loan terms of 10, 20 and 30 years and the moment the NPV reaches €0, this is directly after the last instalment is paid. The calculation of the NPV is shown in Formula 6.

$$(6)\ NPV\ (loan\ term) = \sum_{n=1}^{Loan\ term} \frac{(Earnings\ (7) - Variable\ cost\ (8)) \times Production_n - Fixed\ cost_n\ (3)}{(1 + Discount\ rate)\ ^\wedge\ n}$$

NPV in €, earnings in €/hL, variable cost in €/hL, production in year "n" in hL, fixed cost in year "n" in €, loan term in years, discount rate no unit

$$(7)\ Earnings = Efficiency \times Selling\ price\ ex.VAT\ and\ excise\ duty\ of\ alcohol-free\ beer$$

Earnings in €/hL, efficiency in (hL in/hL out), selling price ex. VAT and excise duty of alcohol-free beer in €/hL

$$(8)\ Variable\ cost = \frac{Water\ cost + Electricity\ cost + Labour\ cost}{Production\ rate} + \frac{Alcoholic\ beer\ production\ cost}{Efficiency} + Bottle\ cost$$

Variable cost in €/hL, water cost, electricity cost and labour cost in €/h, production rate in (hL out/h), alcoholic beer production cost in €/hL, efficiency in (hL in/hL out), bottle cost in €/hL

In order to find the selling price required for an NPV of zero, the Solver tool incorporated in Microsoft Excel for Office 365 (Microsoft Corporation, 2020) is used. The objective is to set the NPV to zero, while only changing the selling price. Furthermore, these prices are visualised for the production sizes 50, 100, 250, 500, 750 and 1000 hL per year. The relation with alcoholic production cost, as well as the dependence on loan term is shown. In addition, the same figures are prepared for the scenarios with increasing production sizes. The required selling prices for the different loan terms and production sizes are compared based on the additional cost price, due to using the dealcoholiser. The outcome of the analysis is used to evaluate the viability of alcohol-free beer production by craft brewers.

3. Literature review on alcohol-free beer production

In this chapter, a literature review about technical aspects of beer production is performed. The focus is on the formation and reduction of alcohol during brewing. The influence of all ingredients and production steps on the final alcohol content is considered. Moreover, production methods specific to alcohol-free beer are examined and judged based on applicability in the craft beer scene.

3.1. Influence of ingredients on alcohol formation

Beer is traditionally produced with four primary ingredients: water, barley, hop and yeast. The condition of these ingredients is of large importance for the final product (Anderson, Santos, Hildenbrand, & Schug, 2019). Arguably, the most important ingredient is water, as it accounts for around 90% of the final beer content and most brewing steps require water. Brewers have high quality standards for their brewing water. Water has to be free of pathogens and be safe for consumption. Moreover, the acidity, mineral content and the hardness of the water should be at the right level for a good brewing process (Wunderlich & Back, 2009).

Barley is a versatile grain and is mostly used in beer for its starch content. The starch is stored in the endosperm of the barley granules and accounts for about 63% of the dry weight (De Schepper, Michiels, Langenaeken, & Courtin, 2020). Starch is needed in brewing, as it gets converted into sugars and eventually alcohol by yeast. Furthermore, small amounts of proteins, lipids, vitamins, minerals and polyphenols are present in barley. These affect taste, colour and stability of both beer and foam (Wunderlich & Back, 2009). Moreover, a small amount of cellulose can be found in barley. Cellulose does not dissolve in water and is indigestible for human consumption. During beer brewing, this cellulose is used to filter the beer in the lautering process (Holbrook, 2020). Barley is not always used as the starch source in beer. Different kinds of grains, such as wheat, rice or corn, can be used for the same purpose. Various countries have laws regarding barley substitution in beer. In the Netherlands, at least 60% of the wort should come from barley and/or wheat malt ("Warenwetbesluit Gereserveerde aanduidingen," 2017). Additional rules of the CRAFT organisation do not allow for craft beers to contain any corn or rice (CRAFT, 2020a).

The third ingredient is hop, which is traditionally added for its preserving effects. Hops are also responsible for the bitter taste of beer (Anderson et al., 2019). Three groups of substances in hops are appealing for brewing. The first is the hop resins, which are accountable for the bitter taste. Moreover, these increase foam stability and induce bacterial safety. The second group is flavouring agents, which are volatile oils and give beer a hoppy flavour. Polyphenols are in the last group and are responsible for antioxidative effects and influence foam stability. The variety of hops, cultivation is also of importance for the properties of a certain hop (Wunderlich & Back, 2009). The main difference between hops is the distribution between bitter and aromatic flavours (Anderson et al., 2019).

The final ingredient of beer is yeast. Most breweries have their own yeast strains responsible for characteristic flavour formations. Usage of different yeast strains will result in different fermentation behaviour, fermentation performance and side product formation (Wunderlich & Back, 2009). The right nutrient concentrations are needed for the best fermentation performance and yeast propagation. During fermentation, mainly sugar is converted into ethanol and CO_2. However, also other flavour contents are formed (Boulton, 2020).

3.2. Influence of brewing steps on alcohol formation

Brewing consists of a range of consecutive steps to produce a beer from the raw ingredients. Malting is often regarded as part of the brewing process, since it has a large influence on the final beer taste. An overview of the processes of the beer production is given in Figure 1.

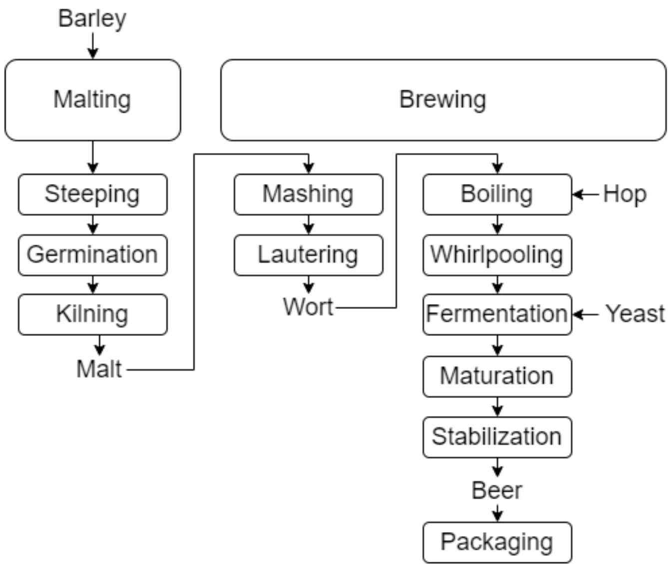


Figure 1. Overview of traditional beer production process (Adopted from Nederlandse Brouwers (2020)).

The first process of beer production is malting. The aim of malting is to artificially start and have control over the germination of barley. Enzymes are activated to break down large starch molecules into smaller sugar molecules (De Schepper et al., 2020). First, barley is inspected carefully, as initial quality is determined for the final beer quality. During this purification, unwanted grains and other substances are removed, so that the malting process starts with homogenic barley (Wunderlich & Back, 2009).

The first step of malting is steeping, barley grains alternate between being immersed in water and being pulled out of the water. Oxygen is needed for respiration during steeping and therefore barley is not constantly immersed in water (Howe, 2020). Moreover, excess CO_2 produced by the respiring barley is removed. During this step, the water content of the barley has to get to around 45%. After steeping, germination starts and the barley granules start swelling, which allows the formation of peptidases, amylases and other relevant enzymes for brewing. The entire process of steeping and germination takes six days, in which the temperature is held constant at about 15°C (De Schepper et al., 2020; Wunderlich & Back, 2009).

Next is the kilning step, water is removed, while colours and aromas are created from available sugars and amino acids by the Maillard reaction. Water content is reduced at low temperatures to 10%, by air flows and heating at temperatures below 55°C. Effective kilning is achieved by aligning fast termination of germination, while causing minimal damage to the present enzymes. Additional reduction takes place at high temperatures (80-105°C) and brings down water content to 1.5-4% depending on the demanded beer type. The swelling of the barley stops without causing the enzymes to denaturate (Howe, 2020). The germinated and dried barley grains are called malt.

The brewing process starts after malting and consists of multiple consecutive steps. The brew starts with a clean mixture of malt. The malt is milled after cleaning to increase the reactive surfaces of enzymes and nutrient dissolvability. The husk of the malt remains integer, as it is needed later as filtration layer (Wunderlich & Back, 2009). The next step is mashing, the ground kernels are mixed with water. Enzymatic activity is reactivated and optimised by regulating temperature and residence time. Proteases produce peptides and amino acids from the present proteins. Glucanases and amylases convert available fibres and sugars. The various enzymes have their own optimal temperature. Mashing temperature is changed periodically, to stimulate the different enzymes. The productivity of the amylases is important, as alcohol concentration is dependent on the quantity of fermentable sugars formed during mashing (Tschoeke et al., 2019). Lautering is the process to separate the liquid from the solid particles. The malt husks are used as filtering layer. Residual grist is flushed a few times to extract the remaining sugars. The temperature is increased slightly during lautering to decrease viscosity of the sugary liquid, which is now called wort (Holbrook, 2020).

The subsequent step is the boiling of the wort together with the hops. One of the aims of boiling is evaporation of water. The wort has been diluted in previous steps, the sugar concentration needs to be restored accordingly (Holbrook, 2020). This extraction content or original gravity value is an important estimator for the final alcohol percentage in the beer. During boiling, enzymes are inactivated and the wort is sterilised to remove bacteria. Moreover, proteins coagulate and flavours from the hops are released into the wort. Additional ingredients for taste or stability can be added during boiling (Holbrook, 2020). The final beer taste is dependent on the moment the hops are added to the wort. Hop particles and precipitated proteins are removed, when the boiling is finished. This is done by a whirlpool. Rotating the wort pushes the liquid to the outside, while the solid particles go to the inside. The wort is then cooled to quickly as possible to 5-10°C for bottom fermentation or to 15-25°C for top fermentation (Wunderlich & Back, 2009).

The wort is aerated with oxygen and the yeast is added. Yeast should be distributed evenly throughout the wort. Fermentation tanks are mostly closed, so that pressure and CO_2 can be regulated by the brewer. Higher temperatures increase the speed of fermentation, however also side products are formed. Additional pressure decreases the formation of side products (Boulton, 2020). It is expected that pH drops during fermentation to enhance microbial stability. The wort is transferred to a second fermenter to remove exposure of death yeast cells, when most fermentable sugars are broken down. During the second fermentation, called maturation, the residual sugars are fermented and volatile substances are removed by formed CO_2. The beer clarifies, as yeast settles (Wunderlich & Back, 2009).

Subsequently, beer is stabilised, which is mostly done with filtration. However, adsorption of dissolved substances or centrifugation can be used to remove dispersed particles. The shelf-life of the beer is dependent on the intensity of stabilisation, which relates to the type of beer being produced (Boulton, 2020; Wunderlich & Back, 2009). The final process of producing alcoholic beer is filling the kegs and bottles with beer. The aim is to conserve beer quality, while creating an attractive appearance for consumers. Dissolving gasses during filling can be important for the quality of the beer and the creation of foam after opening (Wunderlich & Back, 2009).

3.3. Evaluation of alcohol-free beer production methods

Traditionally produced beers can get free of alcohol, when applying physical methods to reduce alcohol content after brewing. Unfortunately, the beer loses a large part of its flavour, body and freshness (Brányik et al., 2012; Güzel et al., 2020). There are two types of physical dealcoholisation methods, thermal and membrane processes. Contrary, there is a different group of methods that do not require further processing, since the original brewing process is altered. Fermentation is carefully controlled and adjusted to minimize alcohol formation. The methods discussed in this section are summarised based on their categorisation in Figure 2.

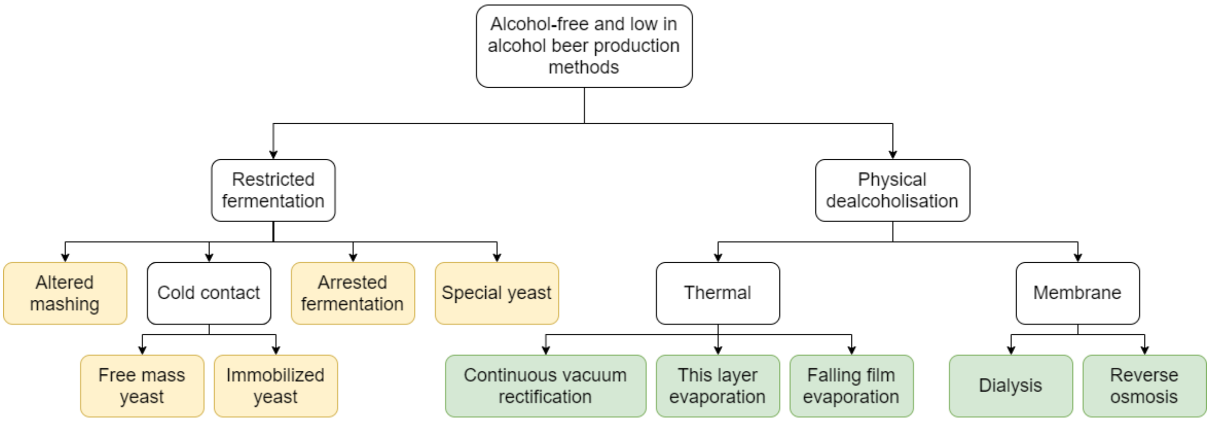


Figure 2. Categorisation of alcohol-free (green) and low-alcohol beer production methods (yellow) (own figure).

3.3.1. Restricted fermentation

Most of the restricted fermentation or biological processes can be performed in a traditional brewery. Careful attention to the production process is required. In general, there are two options for limited alcohol formation, the first option is to use wort with a small amount of fermentable sugars. The second option is to restrict yeast in converting sugars into alcohol. Common methods for both techniques are listed in this section.

Altered mashing

Mashing is the brewing step to degrade starch into fermentable sugars. Two enzymes, α-amylase and β-amylase are responsible for this conversion. The first mainly forms dextrins and small amount of fermentable sugars. The latter is responsible for converting the dextrins into fermentable sugars. The ratio of fermentable and non-fermentable sugars can be regulated during mashing, as both enzymes have a different optimal temperature (Güzel et al., 2020). Thermal inactivation of part of the enzymes is also used to interfere with the enzyme ratios. Generally, a higher mashing temperature leads to less fermentable sugars in the wort, as α-amylase is more stable than β-amylase at high temperatures (Montanari, Marconi, Mayer, & Fantozzi, 2009). Liguori (2018) mentions that barley varieties with a β-amylase deficient can be used to decrease the fermentability of the wort. The downside of this method is that the beer gets a sweet flavour, due to the remaining sugars (Liguori et al., 2016).

Special yeast

The use of special yeast is one of the restricted fermentation methods. Specific kinds of yeast cannot ferment maltose, due to the lack of maltase and invertase (Muller, Neves, Gomes, Guimaraes, & Ghesti, 2019). This leads to a lower concentration of fermentable sugars and thus to a lower final alcohol percentage. Many species of yeast are investigated for the usage in commercial beer production. Positive results are found, however the alcohol percentage always ended up in the low-alcohol beer range. Promising results were found with genetically modified yeast, however extensive testing has not yet been performed, due to negative consumer perception (Güzel et al., 2020; Muller et al., 2019).

Arrested fermentation

Stopping the fermentation process before all fermentable sugars are converted is another method to reduce the amount of alcohol in beer. This technique is performed at low temperatures with low concentrations of fermentable sugars. The fermentation is carefully regulated to have the yeast produce as little alcohol as possible (Brányik et al., 2012). Rapid cooling of the wort or centrifugation can be used to stop the fermentation. Wort dilution is another possibility to reduce fermentable sugars. Worty flavours can persist, when using this arrested fermentation methods, as taste of the beer is influenced by by-products of the fermentation. Malt composition is important for beer produced with arrested fermentation, as more inherent flavour substances get in the final beer (Montanari et al., 2009).

Cold contact

The combination of long fermentation at low temperatures can be used to limit fermentation. The metabolism of yeast is less than usual. On the one hand, this means very little ethanol produced. On the other hand, flavours are not produced. Moreover, the beer does not reach the right acidity and the beer need additional acidification (Montanari et al., 2009).

Cold contact - Free mass yeast

The fermentation starts with a wort with low concentrations of fermentable sugars. Sulfuric compounds are eliminated by pressurising with CO_2 or N_2. Normally, these are removed by the metabolism of yeast. Air flow through the wort enhances the contact of yeast with wort. Minimal alcohol can be produced, however analytical control is needed (Montanari et al., 2009).

Cold contact - Immobilized yeast

Various methods to immobilize yeast exist. One of the methods is attaching yeast to a surface. It is also possible to trap yeast within a porous network. Moreover, yeast cells can aggregate and form a natural immobilisation, which is initiated by calcium ions. The application in brewing often needs a carrier material, which is inert, cheap, stable and non-toxic, such as gels (Montanari et al., 2009). Alcohol-free beer production is possible at commercial scale, controlled fermentation is required. The aim of the fermentation is to reduce the worty flavours, while not producing alcohol. It is important that the temperature remains low and that the process is carried out without oxygen to suppress yeast growth and lipid oxidation, which results in off-flavours (Brányik et al., 2012).

3.3.2. Physical dealcoholisation

Opposed to limiting alcohol formation, physical processes are aimed to remove alcohol from the beer. Additional steps are added to the production process, which require specific equipment not inherent to a common brewery. Sensory properties are impacted, as not only alcohol, but also aromatic compounds are removed. Physical dealcoholisation processes belong to two groups. The first one makes use of heat to separate the alcohol from the beer. The methods in the second group rely on membranes for separation (Muller et al., 2019).

Thermal

The simplest method to make alcohol-free beer is distillation. Beer is heated to evaporate the alcohol. The main disadvantage is that volatile substances are also removed from the beer. As a result, the beer quality deteriorates. Moreover, due to temperature damage, sugar caramelises and the beer colour intensifies (Brányik et al., 2012). This method is not used for alcohol reduction in commercial beer production, as the resulting quality is low. Reducing pressure, during distillation, contributes to a better outcome, as temperature damage decreases (Güzel et al., 2020). Compensation for the sensory damage can include brewing a more aromatic beer or adding a small amount of the original beer. However, this means that also a small amount of alcohol returns. Moreover, the volume loss of the beer has to be compensated by adding the same amount of water and CO_2 (Montanari et al., 2009).

Thermal - Continuous vacuum rectification

Vacuum rectification utilizes pressure to decrease the boiling point of alcohol to reduce thermal damage to the beer. In addition, part of the volatile compounds can be redirected to the beer in the rectification section (Brányik et al., 2012). Degassed beer is heated in a plate exchanger. The beer is then fed in the rectifying column to drop down the column. While dropping down, the beer gets in contact with rising vapours to start selective separation of alcohol. At the same time, the volatile compounds and CO_2 are extracted by the vacuum degasser. During rectification, pressure is applied to be able to evaporate the alcohol at lower temperatures. After removing the alcohol, the beer is cooled and the aromas in the alcohol are concentrated in the rectification section and redirected to the beer (Güzel et al., 2020; Montanari et al., 2009).

Thermal - Thin layer evaporation

The idea of thin layer evaporation is that beer is spread over a large area heat exchanger under vacuum, to reduce residence time and thermal impact. The thin layer is created by rotational movements, so that the beer is mechanically spread out. In contrast to conventional evaporation, which takes about 30 seconds, heat is only applied for about 1 second in thin layer evaporation (Güzel et al., 2020). The alcohol vapour condensates in an exhaust pipe, leading to a condenser chamber. A downside of the method is that the rotation can result in oxygen coming in the beer, which result in oxidation reactions and off flavours (Güzel et al., 2020).

Thermal - Falling film evaporation

Falling film evaporation is similar to thin layer evaporation in that a thin layer is created to have minimal thermal impact on the beer. The main difference is that the layer is not spread out, but that there are tiny tubes in which beer falls down. The steam flows around the tubes to vaporise the alcohol, the alcohol is collected in a condenser. Falling film evaporators have no moving parts and are cheaper than the rotating thin layer evaporators (Güzel et al., 2020; Montanari et al., 2009).

Membrane

Dealcoholisation using membranes has less thermal impact on the beer, as opposed to thermal processes. Semi-permeable membranes are used, which can only be passed by small molecules, such as water and alcohol. The major part of the beer remains at one side of the membrane, while alcohol and water travels to the other stream (Montanari et al., 2009). Dealcoholisation membrane processes are in section distinguished by two main methods: dialysis and reverse osmosis.

Membrane - Dialysis

In dialysis separation of substances dissolved in liquids primarily occurs by diffusion. Therefore, the difference in concentration between the liquids is of large importance. Another determining factor for the rate of removal is the contact time of the beer with the dialysate. Optimal diffusion is obtained by counter current flow at the other membrane side. This guaranties a high concentration gradient between dialysate and the beer. However, not only alcohol diffuses, also small molecules, such as esters and higher alcohols diffuse. Damage to the beer flavour is prevented by having a dialysate similar to the beer. This results in less flavour molecules being diffused. The molecule concentrations in the dialysate should be considered, as diffusion into the beer is also possible (Brányik et al., 2012; Liguori et al., 2018).

Membrane - Reverse osmosis

Reverse osmosis is a pressure driven membrane process with selective separation, because it makes use of very small pore sizes. The method has higher pressure requirements than other membrane processes, as flux between the pores is small (Muller et al., 2019). Beer dealcoholized by reverse osmosis needs a posttreatment to recreate the original volume of the beer. Large volumes of water are removed during the process, so the beer has to be diluted with demineralized beer to the original volume (Güzel et al., 2020).

3.4. Evaluation of methods

In this section, the previously discussed methods are evaluated on applicability at craft scale production. Positive ratings indicate that the related method is applicable at craft scale, while, negative ratings indicate that the corresponding method is not suitable for alcohol-free beer production at craft scale. The evaluation can be found in Table 2.

Table 2. Advantages, disadvantages and ratings of applicability at craft scale of different production methods for alcohol-free beer. (- is negative, +/- is neutral and + is positive)

Method	Advantages	Disadvantages	Applicability craft scale
Restricted fermentation			
Altered mashing	Method works well in combination with other dealcoholisation techniques (Liguori, Russo, Albanese, & Di Matteo, 2018).	Results in beer with sweet flavours. The method does not provide enough dealcoholisation to get alcohol-free beer (Brányik, Silva, Baszczyňski, Lehnert, & Silva, 2012).	-
Special yeast	Easy to implement, as only different yeast is required (Brányik et al., 2012).	Alcohol formed is not in alcohol-free beer range (Brányik et al., 2012).	-
Arrested fermentation	Final alcohol concentration can be regulated (Brányik et al., 2012)	Accurate control over fermentation is needed and results in beer with pale flavour (Güzel, Güzel, & Bahçeci, 2020).	-
Cold contact - free mass yeast	Alcohol content of less than 0.1% is achievable (Montanari, Marconi, Mayer, & Fantozzi, 2009).	Fermentation takes 50-100 hours and careful control is needed (Montanari et al., 2009).	-
Cold contact - immobilized yeast	Very limited alcohol is produced (Liguori et al., 2018).	The method is expensive and difficult to regulate (Muller et al., 2019).	-
Thermal			
Continuous vacuum rectification	Allows for beer with alcohol content below 0.05%. Continuous vacuum rectification is one of the most economic processes for dealcoholisation (Güzel, Güzel, & Bahçeci, 2020).	The method has high operational costs. Temperature sensitive compounds are damaged and beer losses volatiles, bitterness and CO_2 (Muller, Neves, Gomes, Guimaraes, & Ghesti, 2019).	+
Thin layer evaporation	Method gives little thermal damage to the beer and allows for alcohol content below 0.05%. Process only takes a few seconds (Brányik,	There is a risk of oxygen introduction to the beer. Equipment requires high maintenance and energy expenditures (Güzel et al., 2020).	+/-

	Silva, Baszczyňski, Lehnert, & Silva, 2012).		
Falling film evaporation	No moving objects are present. Maintenance is easier compared to thin layer evaporation. Method has lowest operation and investment cost of the thermal methods (Brányik et al., 2012).	Large amounts of esters are removed (Güzel, Güzel, & Bahçeci, 2020). Method requires high temperature in first stage, which has thermal impact on the beer (Liguori, Russo, Albanese, & Di Matteo, 2018).	+
Membrane			
Dialysis	Does not result in thermal damage to beer (Muller, Neves, Gomes, Guimaraes, & Ghesti, 2019).	Method results in large removal of esters and higher alcohols. There is a need for counter-current liquid (Montanari, Marconi, Mayer, & Fantozzi, 2009).	-
Reverse osmosis	Temperature sensitive molecules are retained (Güzel et al., 2020).	High pressure is needed for the operation. Method is not economically feasible for alcohol content below 0.45% (Montanari et al., 2009; Muller et al., 2019).	+/-

All restricted fermentation methods are scored as negative. These methods are aimed at limited alcohol formation, while the aim of this research is to produce alcohol-free beers. On the other hand, thermal dealcoholisation methods are generally rated as positive. These methods are aimed at removing alcohol from beer and succeed in this. The main downside is thermal damage to the beer, which is of lower importance than the ability to create alcohol-free beer. Thin layer evaporation is scored neutral, as extensive maintenance is needed compared to falling film evaporation. Similarly, membrane dealcoholisation is able to produce alcohol-free beer. Therefore, one of these methods, reverse osmosis, is rated neutral for application at craft scale. Dialysis is scored negatively, as the need for counter current liquid is difficult for craft brewers. The reason for this is that craft brewers produce a variety of low quantity beers, which would all require a specific counter-current liquid.

3.5. Conclusion

Rectification and thin layer evaporation have the ability to preserve aroma compounds. However, both methods suffer from thermal damage in flavour. Membrane-based processes are emerging and are possibly less affecting the taste. Unfortunately, these methods are still very costly to perform. Biological methods are most economically, as no additional equipment is needed. The downside is that these methods ask for high intensity inspections and that a limited amount of alcohol is still formed. Low-alcohol beers are produced in this way and are therefore not an intermediate product for alcohol-free beer production. Based on advantages and disadvantages of the various methods, continuous vacuum rectification and falling film evaporation are the most suitable methods for alcohol-free beer production at craft scale. Reverse osmosis is seen as the best alternative to the thermal dealcoholisation methods.

Regarding the ingredients and production process of beer, barley has the most impact on the alcohol concentration, during malting and mashing. These processes influence the sugar composition of the wort. Moreover, the yeast is influential for the fermentation of the wort, which leads to the alcohol formation. All in all, the combination of ingredients and process settings result in beer with various alcohol concentrations. Subsequently, the beer can be dealcoholized by thermal or membrane processes to create alcohol-free beer.

4. Practical implementation of alcohol-free craft beer

Commercially available dealcoholizing methods are discussed in this chapter. Challenges based on the specifications of these methods are examined. In addition, scenarios for commercial craft brewery implementation are devised.

4.1. Equipment specifications

Various suppliers of physical dealcoholisation equipment are available. Continuous vacuum rectification, falling film evaporation and reverse osmosis are processes with existing commercial technologies. For this research, six relevant machines were found and their producers were enquired. Data is provided for five of the dealcoholisers.

4.1.1. Continuous vacuum rectification

The SIGMATEC dealcoholisation system is designed by API Heat Transfer, a company specialised in the design and manufacture of heat transfer technologies for a variety of industry markets, including beverages, such as beer. Standard units and custom designs are marketed by the company. One of the standard units is the SIGMATEC dealcoholisation system, which is designed for the removal of alcohol in beer and wine. The SIGMATEC uses continuous vacuum rectification as dealcoholisation procedure. Beer is introduced to the dealcoliser and is heated to 43-48°C by indirect contact with hot water or steam. The smallest flow capacity is 4 hL per hour and can increase to over 150 hL per hour. After dealcoholisation, aromas are redirected from the vapour into the beer. The alcohol concentration of the outflowing beer is less than 0.1%. The process is completely continuous and is controlled automatically, based on the settings and formulations of the desired product (API Schmidt-Bretten, 2020).

4.1.2. Falling film evaporator

Multiple companies are offering dealcoholisers based on the falling film evaporator method. One of those companies is Alfa Laval and they produce equipment for a variety of industries. Numerous of beer processing solutions for all production stages are sold. Alfa Laval offers two dealcoholisation solutions, one based on the falling film evaporator technique and one based on reverse osmosis (Alfa Laval, 2020a). The Alfa Laval De-alcoholisation module is a plug-in for regular beers that removes alcohol efficiently and gently to produce full-flavoured alcohol-free beers in a single passing. There are three standard modules, differing in capacities of 10, 50 and 100 hL per hour. Moreover, the modules have little maintenance costs, as there are no rotating parts. Low pressure (10-11 kPa) and temperature (40°C) are applied to the beer to minimize damage to the flavour of the beer. In addition, the system can be configured to recover aromas back into the beer (Alva Laval, 2019).

Centec is another company producing equipment for a variety of industries, including food. DeAlcoTec is one of their products. This system is able to conserve beer aromas, while removing alcohol from beer. In addition, part of the removed aromas is added back to the beer. The evaporated alcohol is concentrated up to 90% and is able to be sold. Control and critical product characteristics can be regulated precisely with integrated sensors. The system has a modular design and removes alcohol at low temperature and low pressure. The capacity is ranging from 3 to 200 hL per hour (Centec, 2020).

4.1.3. Reverse Osmosis

Next to the thermal dealcoholisers, Alva Laval provides a membrane alternative. The Lowal De-alcoholizer is a fully automated membrane based dealcoholiser. The use of low processing temperatures (10-20°C) preserves beer taste and results in an energy efficient production. The flow capacity of the module is around 120 hL per day. In addition, pressure applied on the beer during separation is 3500 kPa. (Alva Laval, 2020b).

Similarly, GEA is developer and supplier of production technologies for food processing. For the alcohol-free beer industry, a dealcoliser based on reverse osmosis is marketed. One of their products is the GEA AromaPlus Membrane Dealcoholization Unit, aiming for alcohol reduction through filtration. Temperatures below 15°C are used. The system can be delivered as a compact module with feed rates between 50 to 1000 hl per day (GEA, 2020).

4.1.4. Overview

An overview of the operational specifications of the dealcoholisers mentioned in previous section is given in Table 3. For commercial reasons, the data is combined for the thermal and membrane types of dealcoholisers.

Table 3. Operational specification of five commercially available dealcoholisers aimed at small scale production.

Dealcoholiser	Thermal (3 samples)	Reverse Osmosis (2 samples)
Temperature (°C)	± 40	10-20
Throughput	± 8 hL/h	± 100 hL per batch (20 hours)
Pressure (mbar)	± 80	5,000 - 35,000
Water usage (hl/h)	0.5-15	± 250 hl per batch
Power (kW)	± 18	± 30
Dimensions (m)	L = 2-7m, W = ± 2m, H = ± 6m	L = ± 4.5m, W = ± 2m, H = ± 2.5m
Alcohol outflow	30-90% v/v	<10% v/v
Beer ready for consumption	Yes, microbial stability can be enhanced	Water, CO_2 required and microbial stabilisation needed
Maintenance (€/year)	± 3500	± 10,000
Investment cost (€)	± 350,000	± 225,000
Life expectancy (years)	± 30	± 30

In general, there are three incoming streams to the thermal dealcoholisers. First of all, alcoholic beer to be de-alcoholised enters the machine. Secondly, water is used for heating, cooling the vacuum pump and for blending lost aromas. The last input is electricity for powering the machine. Depending on the specific supplier a dealcoliser needs about 5-15 m^2 free space and is about 6 meters in height. The outcoming streams include the dealcoholized beer, which decreases in volume, due to loss in alcohol. Wastewater and alcohol are the remaining outcoming streams. The alcohol concentration is dependent on optional accessories of the dealcoholiser. Concentrated alcohol has a small selling value, whereas unconcentrated alcohol can be regarded as waste.

4.2. Challenges for craft brewery

Installation of the dealcoholisation equipment requires space in the brewery. The height of 6 meters is more than the usual equipment in a craft brewery. Moreover, the space of around 20 m^2, should be available. Piping to the water supply and drainage, as well as a pipeline to the exhaust pipe is necessary for excess gasses. In addition, access to a power grid able to handle a power of 20 kW, is needed.

A clean production process is important for beer brewing to avoid infections. This is even more important for alcohol-free beer production, as alcohol is a natural inhibitor of microbial contamination. Alcohol-free beers are more prone to spoilage than their alcoholic counter parts (Gooischebierbrouwerij, 2020). Therefore, it is likely that the shelf-life of alcohol-free beer is shorter, compared to alcoholic beer. Pasteurisation of the beer is an option to enhance microbial stability, however it is not a process inherent to brewing and interferers with the beer taste. Acquisition of pasteurisation equipment is not always an option, as these can be large and expensive (Wray, 2020). Moreover, alcohol reduces the freezing point of water-based liquids. This means that the risk of freezing increases for alcohol-free beer (Sohrabvandi, Mousavi, Razavi, Mortazavian, & Rezaei, 2010). Spoilage is more likely in lower shelf-life products. In order to reduce waste, inventory levels should remain minimal. Reducing production size, while increasing production frequencies, results in a longer average shelf-life (van Elzakker, Zondervan, Raikar, Hoogland, & Grossmann, 2013).

Furthermore, most craft breweries are not able to constantly produce alcohol-free beer using the machines described in previous section. The lowest production rate is 3 hL per hour, which results in a yearly production of 4800 hL, when taking into account 40 production weeks of 40 hours. In 2016, the average production of a craft brewery with an own kettle, aimed at selling their own brand of beer, was 849 hL (Brouwer, 2017). This means that producing 4800 hL alcohol-free beer per year is more than five times the total production quantity of an average craft brewery.

Brewing alcohol-free beer includes an additional step compared to regular brewing. Actually, alcoholic beer is used as feed and should thus be produced in advance. Therefore, the brewing capacity of alcoholic beer should be sufficient in order to produce alcohol-free beer. It is an option to decrease part of the alcoholic beer sales volume to allow for the production of non-alcoholic beer, when capacity is limited. This is only a viable substitution, when the profit margin of alcohol-free beer is higher than that of alcoholic beer. The market potential of alcoholic beer can be regarded, when then there is capacity of producing more beer. Essentially, sales of alcohol-free beer are still substituting alcoholic beer sales, when there is a market potential for an increased alcoholic beer sales volume.

4.3. Implementation scenario's

The utility of the dealcoholisation equipment is of importance for the evaluation. The fixed cost per unit decreases, when production size increases. Therefore, in all scenarios, different production sizes between 50 and 500 hL per year are considered, these correspond to 6-60% of the average yearly production of a craft brewery. Moreover, the minimal life expectancy of 30 years is considered as lifespan.

The first scenario accounts for substitution, the total production size of the brewery does not change. Part of the produced alcoholic beer is transformed into alcohol-free beer. In this scenario, no attention is given to the production costs of alcoholic beer, since the same amount of beer is brewed. The revenue of alcoholic beer should be compared with the revenue of alcohol-free beer, while taking the additional costs into consideration. The increased revenue for the brewer is partly a result of reduced excise duties. Depending on the original gravity of the beer it is categorised in one of the four duty groups. In general, regular beer belongs to category I or II. The Dutch duties for those categories are respectively €37.96 and €28.49 per hl. Alcohol-free is categorised as lemonade, which has a duty of €8.83 per hl. Moreover, the value-added tax (VAT) of beer is 21%, whereas the VAT of alcohol-free beer is 9% in the Netherlands (Belastingdienst, 2020a, 2020b, 2020c). This means that in most cases selling alcohol-free beer for the same price as alcoholic beer results in more earnings for the brewery. Exceptions exist, as volume is lost during dealcoholisation.

The second scenario assumes additional beer production to satisfy the feed of the dealcoliser. In this case, the production cost of alcoholic beer is required. The total production costs are compared with the required selling price for an NPV of €0, while keeping the other parameters at the average value. In addition, the production sizes are increased up to 1000 hL per year to account for collaboration between craft brewers. Producing this amount of alcohol-free beer is assumed to be impossible for craft brewers, as it exceeds current production. Still it is possible, when sharing the dealcoholiser with other brewers. Collaboration costs, such as transporting costs from the location of the dealcoholiser to the brewer using the dealcoholiser are not included in the analysis.

4.3.1. Settings of scenario calculation

Investment analyses are performed for both scenarios. The values regarding the dealcoholisation are based on the data of the thermal dealcoholiser of section *4.1. Equipment specifications*. Various combinations of parameters are tested and used to calculate minimal selling price, NPV and regression coefficients. The parameters used are listed in Table 4.

Table 4. Calculation parameters

Parameter	Values	Reference
Bottle cost (€)	0.30	de Vleeghel (2020)
Discount rate (%)	2.0 – 3.0 – 4.0	
Excise duty alcoholic beer (€/hL)	33.23*	Belastingdienst (2020c)
Electricity (€/kWh)	0.20	Statista (2020c)
Electricity usage (kWh)	18	See 4.1
Interest rate (%)	1.5 – 2.0 – 2.5	
Investment cost (€)	300.000 – 350.000 – 400.000	See 4.1
Labour cost (€/hour)	70	CBS (2020)
Loan term (years)	10 – 20 – 30	
Production cost alcoholic beer (€/liter)	0.50 – 0.75 – 1.00 – 1.25 – 1.5 – 1.75 – 2.00 – 2.25 – 2.50	de Vleeghel (2020)
Production rate (hL/h)	10 (9.5 out)	See 4.1
Beer selling price including VAT/duties (€/liter)	7.00 – 7.50 – 8.00 – 8.50 – 9.00	
VAT alcohol-free beer	9%	Belastingdienst (2020b)
VAT alcoholic beer	21%	Belastingdienst (2020b)
Water cost (€/m^3)	1.50	Statista (2020b)
Water usage (hL/h)	15	See 4.1
Yearly maintenance (€)	2000 – 3500 – 5000	See 4.1

** Average of the beer category I and II ((28.49+37.96)/2)*

4.4. Conclusion

A variety of dealcoholisers are available for the Dutch market. Water and electricity supply, as well as sufficient space in a brewery is required for installation. One of the main challenges for brewers is to create a microbial safe product with a decent shelf-life. Moreover, the large throughput and low utilisation for craft breweries can result in difficulties. To counter the utilisation problem, one of the scenarios included is collaboration between brewers. This allows for larger production sizes. The other scenario makes use of the fact that alcohol-free beer is taxed less than alcoholic beer.

5. Investment analysis

In this chapter, the costs and revenues of the scenarios are elaborated. In the first scenario, the total production size of the brewery remains constant. A fraction of the produced alcoholic beer is processed into alcohol-free beer. The second scenario introduces production cost for the alcoholic beer and discusses collaboration between brewers.

5.1. Substitution

In the substitution scenario, parameters were held constant for 30 years and the payback period and NPV of the investment was calculated. This was done for a yearly production between 50 and 500 hL, resulting in an alcohol-free beer production of 47.5 to 475 hL per year, when considering volume loss. In Figure 3, the feasible area of possible NPV values is given, it includes a line indicating the NPV at the different production sizes, when considering the average value for all parameters. The production size related payback period for the least, average and most favourable values is given in Figure 4.

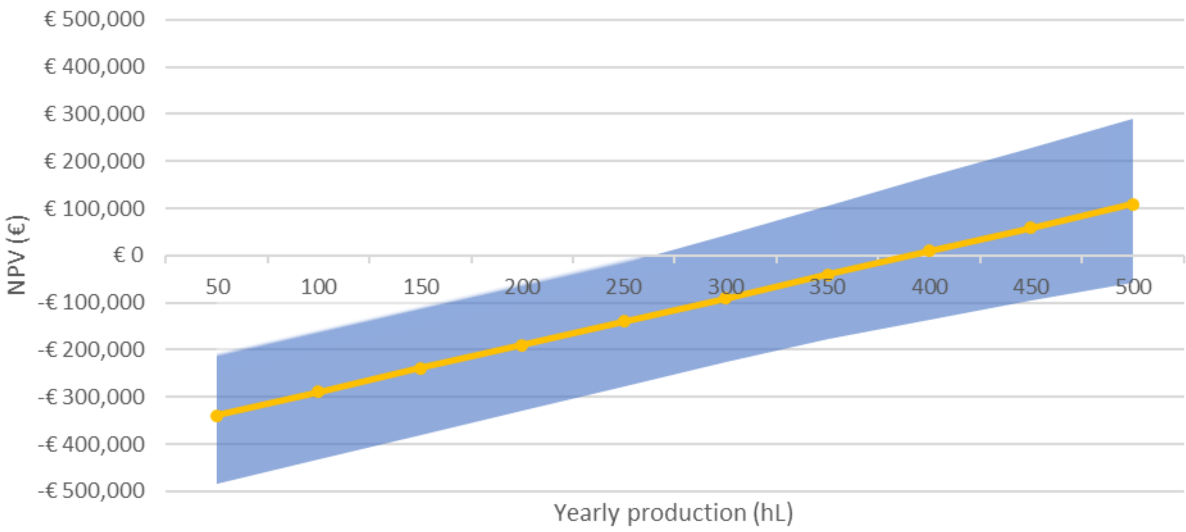


Figure 3. Possible values of NPV for substitution, the line indicates the values under average input variables.

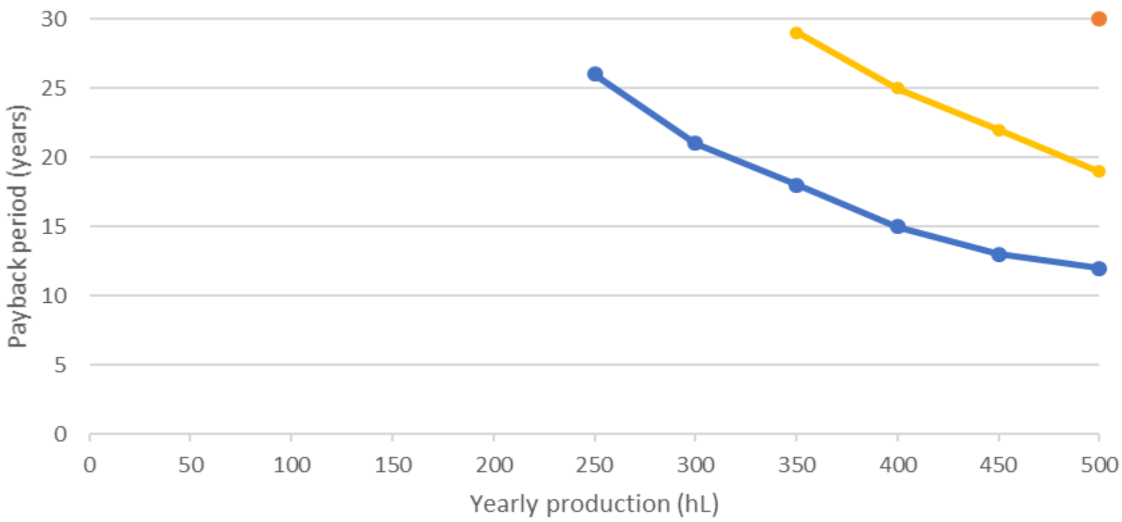


Figure 4. Payback period for all production sizes with a payback period less than 30 years for the substitution scenario for the least favourite ●, most favourite ● and average ● input variables.

In Figure 3, it can be seen that the a positive NPV value can only be found at a yearly production of at least 270 hL. When considering the least favourable values, the NPV is still negative for a production size of 500 hL per year. On average, a positive NPV is found at 400 hL production per year. The highest NPV found at a yearly production of 500 hL is €290.000, while it is €-59,000 at the minimum. The payback period at all production sizes is the lowest at 12 years for the case with the most favourable values. Furthermore, it can be seen from Figure 4, that increasing the yearly production decreases the payback period. Moreover, in the least favourite case there is only a payback period within 30 years at 500 hL production per year, while the most favourite case has a payback period for all production sizes between 250 and 500 hL per year.

Depending on the brewery and dealcoholiser specific circumstances, the increase in company value can be calculated. In the best case, a value increase is found at a yearly production of at least 250 hL. It would take 26 years to payback the investment. Using the same input variables at a production size of 500 hL per year, the value of the company would increase by €290.000. It will take 12 years to payback the investment. Contrary, on average a production size of at least 400 hL per year is required to create more value from alcohol-free beer than from alcoholic beer. Moreover, an increased value of €108.000 over alcoholic beer is found at a production of 500 hL and in this case the investment is paid back within 19 years. Regarding the least favourite circumstances, a yearly production size of 500 hL for 30 years is not sufficient to benefit more with respect to alcoholic beer.

5.1.1. Regression analysis

A multiple linear regression analysis is performed on the NPV values of all cases of the substitution scenario. The coefficients, including standard error and significance are found in Table 5. The observed difference in NPV between the largest and smallest value at average parameter values is also shown in Table 5. The regression statistics are found in Appendix II.

Table 5. Coefficients of the multiple linear regression analysis of the substitution scenario.

	Coefficients	**Standard error**	**P-value**	**Interval***
Intercept	-150,921	2,877	<0.01	
Investment cost (€)	-0.92	0.00	<0.01	-91,462
Loan term (year)	1073	22.0	<0.01	23,295
Maintenance (€/year)	-19.8	0.15	<0.01	-58,801
Discount rate (%)	538	219	<0.03	9,211
Selling price (€/L)	23,292	253	<0.01	42,001
Interest rate (%)	-29,244	439	<0.01	-29,881
Production size (hL/year)	1002	1.25	<0.01	447,467

** Difference in observed NPV between the largest and smallest value with other parameters at the average value*

The linear regression model as shown in Figure 5, has an intercept value of -150,921. The coefficients with a positive effect on the NPV are loan term, discount rate, selling price and production size. The largest difference in NPV between the largest and smallest value at fixed values for the other parameters can be found for production size. The observed difference in NPV between a production of 50 hL and 500 hL is €447,467. The smallest difference is found for discount rate with a difference in NPV of €9,211 between 2.0% and 4.0%.

The assumptions regarding multiple linear regression models are successfully tested. No multicollinearity was found, while homoscedasticity and multivariate normality were observed. Moreover, linear relationships between the NPV value and the independent variables were found. All parameters are discussed in more detail in the next sections.

Selling price

It can be noted from Table 5 that the selling price has large effect on the profitability of the investment. The reason for this is that, if the selling price of alcoholic beer is increased, 21% of the additional turnover is VAT, while this is only 9% for alcohol-free beer. This 12 percent point difference is extra revenue for the brewer. The increase in NPV, due to the selling price increase can also be seen in Figure 5.

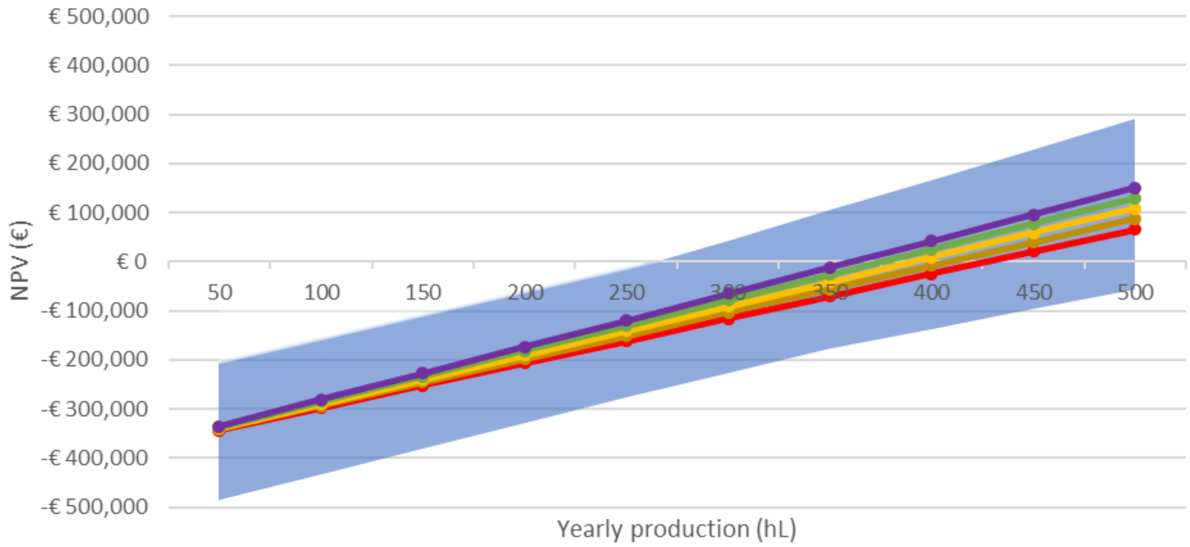


Figure 5. NPV at different selling price inc. VAT/duties, €7.00 (●), €7.50 (●), and €8.00 (●), €8.50 (●) and €9.00 (●).

Figure 5 shows that an increased selling price results in larger NPV, when keeping all other parameters constant. At every production size, the highest selling price results in the highest NPV. Moreover, a larger production size results in a larger difference in NPV between the various selling prices. The NPV becomes positive at a yearly production of 350 hL for a selling price of €9.00, whereas it becomes positive at 425 hL for a selling price of €7.00.

The selling price is influencing the value increase, due to investment in alcohol-free beer equipment. It is evident that a larger selling price is resulting in more profit, but it should be considered that the demand is also related to the selling price. Moreover, the calculations consider the same selling price, which includes taxes and duties, for both alcoholic and alcohol-free beer. Price premiums for alcohol-free beer would result in an even larger value increase.

Investment and maintenance cost

The coefficients for investment cost and for maintenance cost are negative. Every euro, which is invested in the installation decreases the NPV with €0.92. Similarly, every euro maintenance per year is decreasing the NPV with €19.8. Figure 6 shows the relation between the NPV and the investment cost for various yearly production sizes.

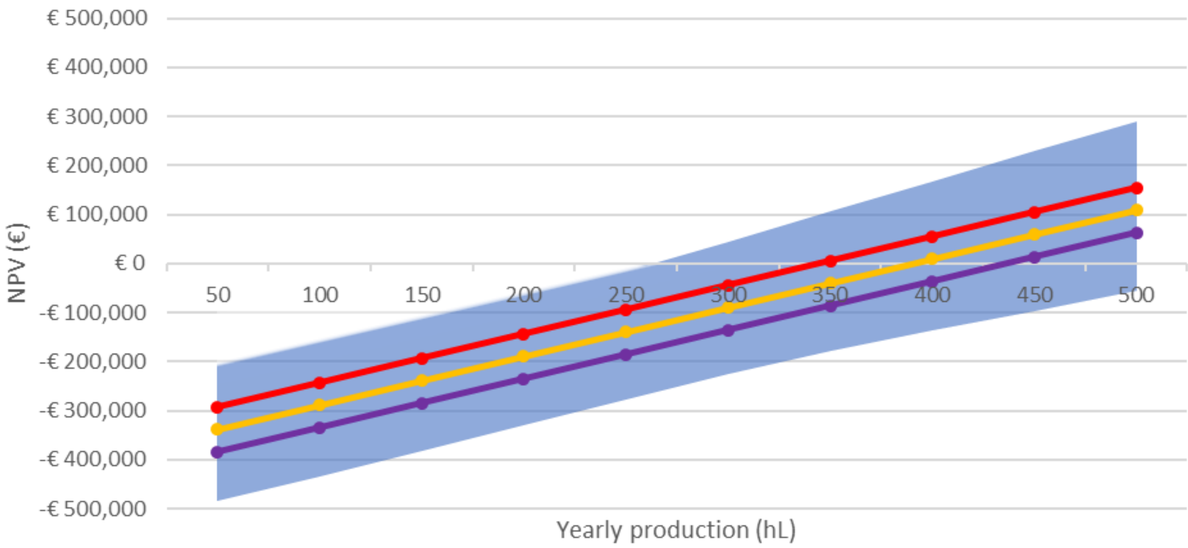


Figure 6. NPV at different production sizes for an investment cost of €300,000 (●), €350,000 (●), and €400,000 (●).

It can be seen from Figure 6 that a lower investment cost result in a higher NPV. This is true at all production sizes. Moreover, it is seen that the difference in NPV is the same at all production sizes. The NPV becomes positive at a production of 350 hL per year for an investment cost of €300,000, while it only becomes positive at a yearly production of 430 hL for an investment cost of €400,000.

Investment cost has a negative influence on the value of the investment. A larger cost results in a less valuable investment. The effect of investment cost is double sided. On the one hand, a larger investment means larger principal payments. On the other hand, the outstanding dept is larger, meaning that interest costs are higher. Maintenance costs have a similar effect on the value of the investment. Instead of yearly instalments, a fixed maintenance cost has to be paid. Therefore, maintenance costs are also negatively influencing the value of the investment. However, there is an important difference between the two costs. The size of the principal payment and interest costs is known well in advance, whereas the size of the maintenance costs is only predictable on short notice and is not the same every year.

Discount rate, loan term and interest rate

The coefficients for discount rate, loan term and interest rate are respectively, 538, 1073 and -29,244. Loan term and discount rate are positively influencing the NPV of the investment, whereas interest has a negative influence on the NPV. In Figure 7, the NPV is shown for the various discount rates at all production sizes.

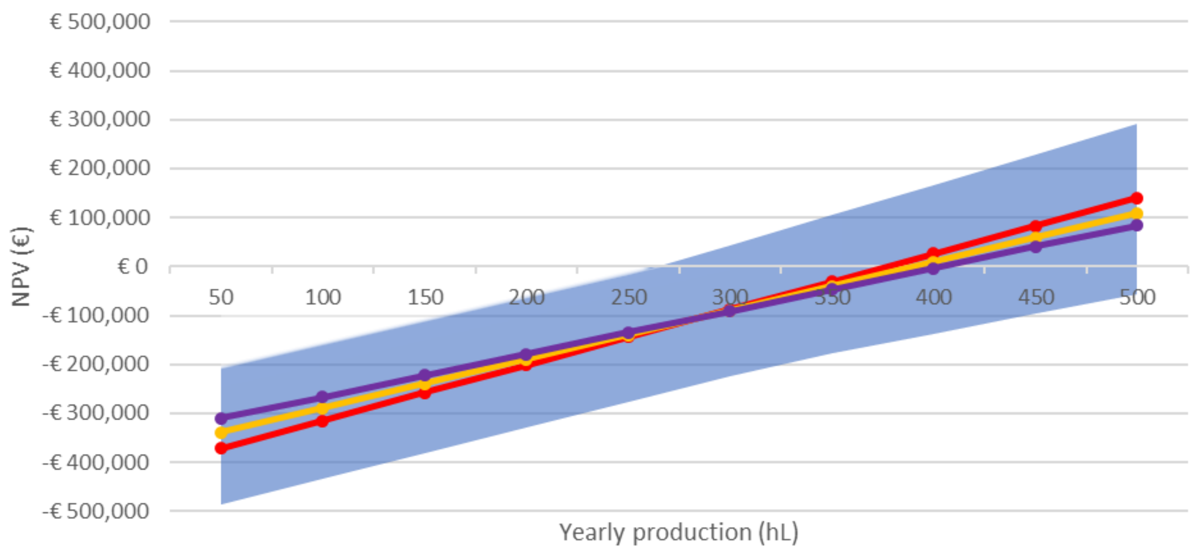


Figure 7. NPV at different discount rate, 2.0% (●), 3.0% (●) and 4.0% (●).

It can be seen from Figure 7 that the NPV of the smallest discount rate is the lowest at a low production rate, whereas it is the largest at a high production rate. Producing 280 hL of alcohol-free beer results in no deviation in NPV, due to discount rate, when the other parameters are at the average value.

The coefficient of the discount rate is doubtful, since its influence on the NPV seems to be correlated with other factors. It is valid that discounting decreases the NPV, when profits are made. These profits are valued less, when discounted more. However, when losses are made, these are also discounted by a higher discount rate. This means that losses are valued as a smaller loss, therefore the coefficient of discount rate is expected to be negative in an interval with larger production sizes. This also explains the small effect of the discount rate, a total of about €1500 (~538*3), is the difference in NPV, due to discount rate between the highest and lowest rate.

It is expected that the production size, in which there is no difference in NPV, due to discount rate is dependent on other parameters. For example, the loan term is important, since principal payments in late years are discounted more than in the early years. A short loan term has all payments within the first ten years and therefore has a larger burden on the value of the investment. The equilibrium of the discount rates is reached at a lower production rate, since the benefit of discounting expenses is reduced, while the discounted earnings remain the same.

Loan term and interest rate are also related. Increasing the loan term or the interest rate increases the total interest expenses. Both parameters are negatively influencing the value of the investment. However, as previously described, a longer loan term is also beneficial, since later principal payments are discounted more.

5.2. Additional capacity

In the additional capacity scenario, parameters were held constant for 30 years and the required selling price excluding VAT and duties for an NPV of €0 was calculated. A distinction is made between the loan terms of 10, 20 and 30 years and the moment the NPV reaches €0, this is directly after the last instalment is paid. The NPV at other moments, considering the minimal selling price can be found in Appendix III.

In Figure 8, the required selling price for an NPV of €0, after 10, 20 and 30 years is shown for a range of alcoholic beer production prices.

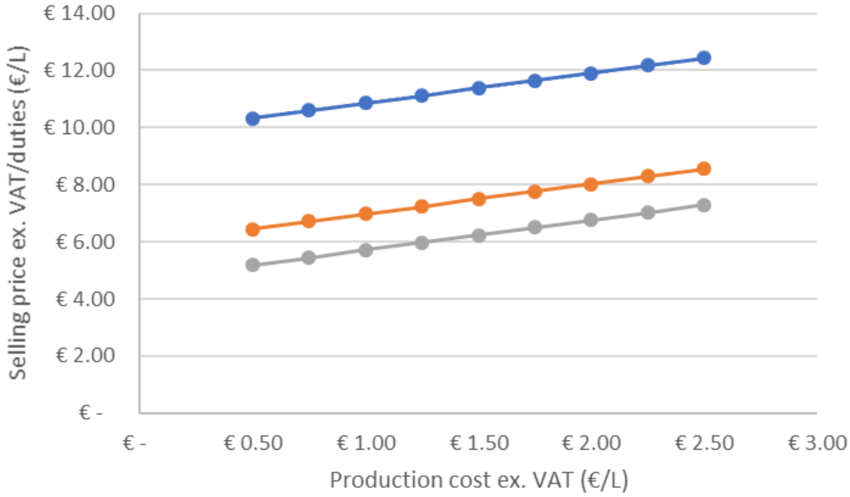
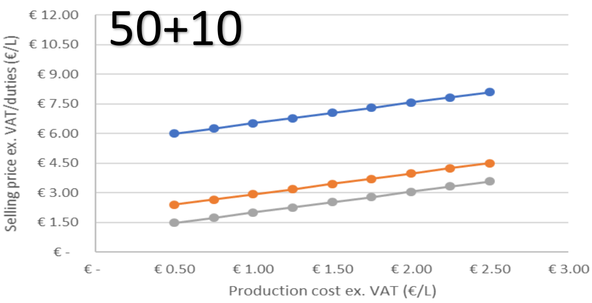


Figure 8. Required constant selling price at a production size of 50 hL per year to get an NPV of €0, after 10 (●), 20 (●) or 30 (●) years for various alcoholic beer production prices.

It can be seen that the lines in Figure 8 are parallel. The shortest loan term requires higher minimal selling prices for each production cost than the longer loan terms. In order to have an NPV of €0 after 10 years, the selling price of alcohol-free beer needs to be larger than €10 per liter. The highest required selling price for a loan term of 20 and 30 years is respectively €8.55 and €7.27 per liter for an alcoholic beer production cost of €2.50.

Producing 50 hL per year is possibly an achievable production size for craft brewers. However, using the average production cost of €1.50 per liter alcoholic beer, a minimal selling price of €6.23 excluding taxes and duties is required to have the company start benefit from the investment. Current taxes and duties would increase the consumer price to €6.89 per liter, which equates to €2.27 per bottle of 330 mL. In addition, higher prices are required, when the loan should be paid off, within 10 or 20 years. However, profits are expected after the loan term has ended, since the installation has a life expectancy of at least 30 years.

In fact, it is sensible that breweries expand during the lifespan of the dealcoholiser. In Figure 9 and 10, the minimal selling prices are shown for expanding breweries. Figure 50 shows the required selling prices for a brewery expanding with 10 hL per year, while starting with a production of 50 hL in the first year. In Figure 20, the same expansion is shown, however with a production of 20 hL alcohol-free beer in the first year.



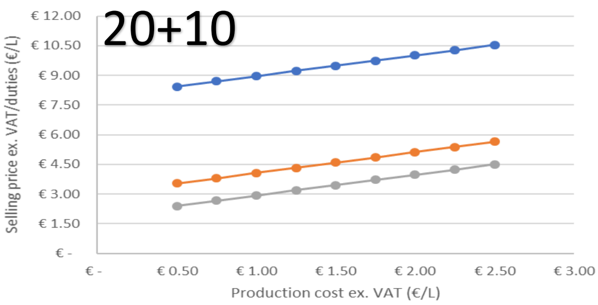


Figure 9 (left). Required constant selling price at an increasing yearly production size of 50 + 10#years hL to get an NPV of €0, after 10 (●), 20 (●) or 30 (●) years for various alcoholic beer production prices. Figure 10 (right). Required constant selling price at an increasing yearly production size of 20 + 10*#years hL to get an NPV of €0, after 10 (●), 20 (●) or 30 (●) years for various alcoholic beer production prices.*

Regarding Figures 9 and 10, the minimal selling prices for the case with a production of 20 hL in the first year are higher than these of the case with a production of 50 hL in year one. The difference between the two cases is the largest for the loan term of 10 years, while it is the smallest for the 30-year loan. When the production of the alcoholic beer costs €2.50 per liter, a selling price excluding VAT and duties of €4.50 is required for the case starting at 20 hL per year and an NPV of €0 after 30 years.

Taking these production size developments into account, it is possible for craft brewers to invest in a dealcoholiser and enhance value. Nevertheless, a positive NPV after 10 years is still difficult to achieve. The main difference between the required selling prices for both cases is at a loan term of 10 years. At all production prices, the difference is €2.44 between the two cases. Increasing the loan term to 30 years decreases this difference to €0.92. The reason for this is that the percentual difference in production size is larger in the first years than in the later years. Essentially, the difference between the two cases is that the one starting with a production of 20 hL is 3 years behind in production size. The rate at which the production sizes increase is fixed and this results in a heavy load for the first years. Having a production of 20 hL in year one and 30 hL in year two is an increase of 50%. The same increase in year 30 is only 3.3%. In the perception of a brewery it would be more feasible to have a fixed percentage increase in production size. The downside is that the profitable period is shifted backwards and thus, the required selling prices are expected to increase.

5.2.1. Collaboration

Increasing the production size of dealcoholized beer is an option to improve the profitability of the investment. It is possible to share the installation with other brewers, either by sharing the investment and ownership or by producing beer for other brewers. In Figure 11 A-E, the required selling prices excluding taxes and duties for an NPV of €0 after 10, 20 and 30 years are shown for various production sizes and costs.

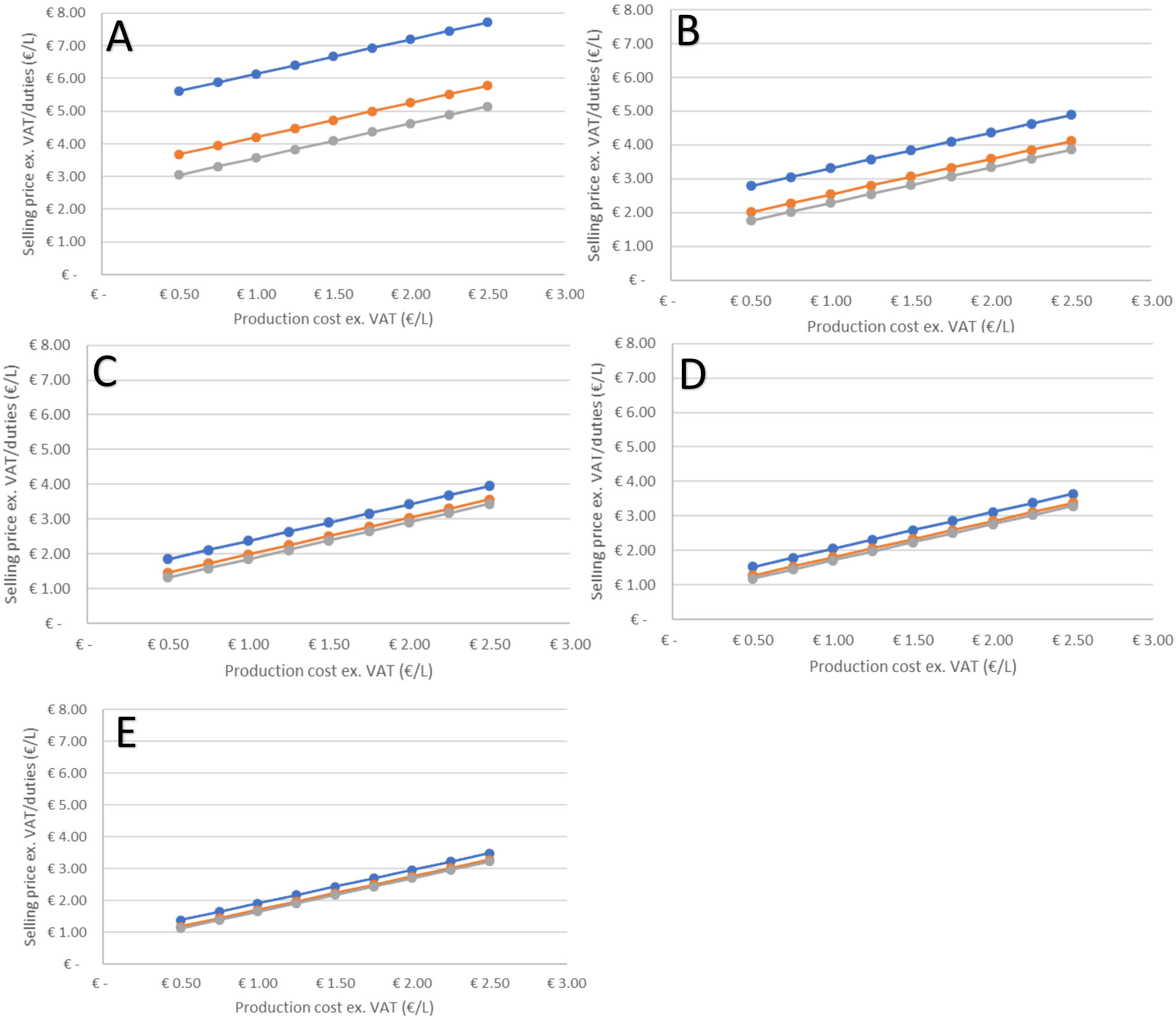


Figure 11. Required constant selling price at a production size of 100 hL (A), 250 hL (B), 500 hL (C), 750 hL (D) and 1000 hL (E) per year to get an NPV of €0, after 10 (●), 20 (●) or 30 (●) years for various alcoholic beer production prices.

Figure 11 shows that increasing the yearly production size reduces the required selling prices for an NPV of €0. Moreover, the difference between the various loan terms reduces, when the production size is larger. The percentual increase in the required selling price between a loan term of 10 and 30 years at an alcoholic beer production cost of €1.50 is 63% at 100 hL, while only 12% at 1000 hL. In addition, an NPV of €0 is reached after 10 years with a yearly production of 1000 hL at the highest cost price, when the selling price is just €3.48 per liter. In all cases, the result of increasing the production cost by 25 cents, is an increase in selling price of 26.3 cents.

The reason that increasing the production cost does not result in a similar increase in required selling price is that 5% of the feed is removed from the beer (26.3/1.05=25.0). This means that the production cost can be subtracted from the selling price. The additional cost price that is derived is valid for all production costs, this is shown in Figure 12.

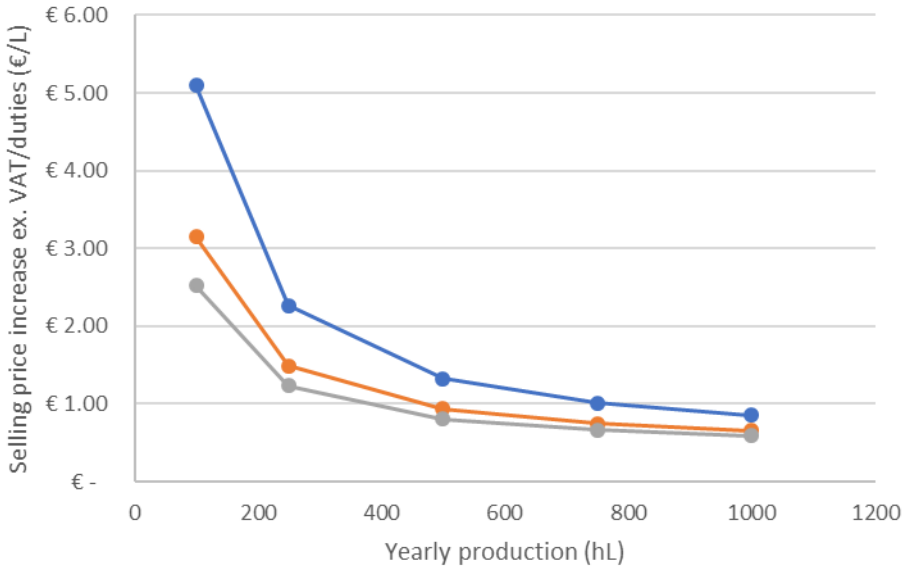


Figure 12. Selling price increase for various production sizes required for an NPV of €0, after 10 (●), 20 (●) or 30 (●) years.

Increasing the production size results in a smaller deviation between the loan terms. Still, the 30-year loan needs a lower price increase to result in a positive NPV. The price increase is below €1 per liter, when the production size is at least 500 hL per year for a loan term of 20 and 30 years. Producing 750 hL per year, requires a price increase of €1.01 for the loan of 10 years.

Fundamentally, the selling price increase is an increase in production price. It should be considered to calculate the break-even price. The effect of the shorter loan term is that the break-even point is reached after a shorter time period, however, a higher selling price is needed. In the end, the effect of a higher selling price is more profit over the lifetime of the dealcoholiser. Moreover, the selling price increase flattens, when production rate is increased. There is only 7 cent difference between the 30-year loan of 750 and 1000 hL production per year. The same difference is 42 cents, when comparing 250 with 500 hL. This means that increasing production size is beneficial for the profitability of the investment.

On average, at a production size of 250 hL per year, €1.66 per liter is added to the production cost. Having a production cost of €2.50 per liter, results in a minimal consumer price of €4.63 per liter -or €1.53 per bottle-. In comparison with other specialty beers, this price is below average price. Therefore, profits are likely to occur, when a suitable consumer price is chosen.

5.3. Conclusion

Selling price and yearly production sizes are important indicators for evaluating the value of investing in alcohol-free beer production. In the case that producing alcohol-free beer results in a decrease in alcoholic beer production sales, at least 270 hL of alcohol-free beer needs to be processed per year. Yet, in an average brewery a larger production size is required to create value for the company. Collaboration between brewers can be an alternative to reduce costs, as the fixed costs are shared among multiple brewers. Individual brewers can produce their preferred quantities, as long as the total production of the dealcoholiser is at least 250-500 hL per year.

6. General discussion

The multiple linear regression model can be used to calculate the expected value of producing alcohol-free beer, as alternative for alcoholic beer. Brewers can use their own parameter values, within the tested range. The coefficients fit well with an adjusted R square of 0.983. The reason for this is that all observations are calculated individually with the exact same procedure, the values of the constants are similar for all observations. In addition, a vast number of 12150 observations increases the model fit. Doubtful is the linear relationship of the discount rate on the NPV, since a large discount rate does not only reduce the value of profits, but also reduces the value of losses. The largest difference in NPV is found for production size, however this parameter also had the largest difference in parameter values.

In general, using the prescribed parameter values of an average craft brewery, the required production size is limiting brewers affiliated with CRAFT to invest in dealcoholisers. Even when substituting a third of the production of alcoholic beer for alcohol-free beer, the company will not benefit from the investment within 30 years. The investment gets a positive NPV, if the brewer is willing to produce more than 400 hL of alcohol-free beer instead of alcoholic beer for 30 years. This is about 50% of the total production of a craft brewer (Brouwer, 2017). The payback period is 29 years in this case and the total profits are very minimal. Producing more than 400 hL is sole positive, as the majority of the costs is the fixed cost of installing the dealcoholiser. Variable costs are low and profits will increase substantially, when expanding utilization. Still a very small amount of the capacity of the dealcoholiser is used, just 40 operating hours are required to produce 400 hL. Considering an even production throughout the year, this results in less than one operating hour per week.

Furthermore, it is uncertain, if the value increase is satisfying the length of the investment. The parameter values used, are not likely to be constant for 30 years, as legislations and consumer preferences change throughout the years. Even though, risks are covered by the discount rate, the market is unpredictable for this length of the investment. Producing alcohol-free beer should be part of the long-term strategy of the brewer, due the extensive length of the investment. Without an increase in total production, it is only viable for craft brewers to invest in alcohol-free beer, when they are willing to specialize in this beer type. This means that the largest fraction of the beer sold, should be non-alcoholic.

Next to the substitution of alcoholic beer for alcohol-free beer, additional beer can be produced to increase the utilization of the dealcoholiser. The difference is that for the substitution scenario the profit margin of alcohol-free beer is the same as that of alcoholic beer, whereas the additional capacity scenario does not take profit into account. Only cost price is considered and a minimum selling price is calculated. This means that just cost price is covered at an NPV of €0 and no profits are involved. The eventual selling price, and thus profit margin is the decision of the brewer.

Consider a brewery starting with a production 50 hL of alcohol-free beer in the first year after obtaining a dealcoholiser. While having a production cost of €2.50 per liter alcoholic beer, the calculated minimal selling price for an NPV of €0, after 20 years is €8.55 per liter excluding taxes. This equates to a bottle price of €3.14 per bottle, including taxes. In the case the brewer expands production by 10 hL per year, this bottle price including taxes becomes €1.67. This is a realistic price, even a small margin can be added. Producing 50 hL of alcohol-free beer should be achievable, as one of the brewers affiliated with CRAFT produces 40 hL of low-alcohol beer each year (Gooischebierbrouwerij, 2020).

Furthermore, collaboration between brewers is an option to reduce unit fixed costs and thus the required production sizes. The CRAFT organization mentioned that collaboration already happens between brewers, as brewing installations are sometimes shared. Collaborative usage of dealcoholisers is expected to be an opportunity (CRAFT, 2020b). Depending on the structure of the collaboration between brewers, investing in a dealcoholiser can be profitable for all parties. Even when producing 250 hL per year and sharing the investment, profits can be expected. A single brewer has the same profitability per unit, when he produces 250 hL per year, compared to when he produces 50 hL and shares the investment with four others. Another possibility is that brewers do not share the investment with other brewers. In this case, alcohol-free beer can be sold to other brewers, like contract brewing. The same additional cost prices, as in section *5.2.1. Collaboration* apply to make a profit for the producing company. In this case, the buying company can resell the alcohol-free beer to consumers under their own branding. Since the risk of the reselling company is smaller, as no large investments are made, it is likely that both companies increase the price with a small profit margin.

Economies of scale are of importance, the theoretical lowest increase in cost price is the same as the variable cost of using the dealcoholiser, including the production cost of the lost beer volume. The variable cost consists of water usage, electricity usage, labour cost and bottling cost. The largest part of this cost is the labour cost. It is difficult to assume the right amount of labour cost, as no related data was acquired. In all experiments, it was assumed to be two hours of €35.00 per machine hour (CBS, 2020). The variable cost is about 38 cents per liter, excluding the production cost of the lost beer volume, which is 5.3% of the production price per liter. This means that the theoretical lowest price increase is around 40-50 cents per liter alcohol-free beer. Producing 1000 hL per year comes close with a price increase of €0.59. This means that producing more than 1000 hL per year will not reduce cost price by much, since it will only be able to decrease by 10 cents per liter. Even the price increase of producing 500 hL per year is barely double the theoretical lowest price at €0.81. This indicates that collaboration is beneficial to a fare extent. However, it is not advisable to use the dealcoholiser with a large group of brewers, since increasing production size is not decreasing production cost by much after 1000 hL per year. Centralised dealcoholisers are not providing much benefits, when producing more than 500-1000 hL per year, since transportation costs as well as organisational difficulties get more prevalent. The location of the dealcoholiser is important, as transportation cost is related with the average transportation distance. In the case that transporting expenses are larger than the benefit of sharing a dealcoholiser, it is not worth it to increase utilization. The exact boundaries are unknown, as travelling expenses and transfer prices were not included in this research.

Moreover, producing 250 hL of alcohol-free beer per year could result in a total profit up to around 3 million euros in 30 years, depending on selling price. It should be noted that the same or more could be earned with selling alcoholic beer. Even though, producing less than 250 hL per year can be profitable, it is not advisable. The production of alcoholic beer is more beneficial for the company for these production rates. Especially, if you consider the development of a good alcohol-free beer recipe will take extra time and money (den Drul en Stollenberg, 2020). There are other options to produce alcohol-free beer like drinks. Beer mixes, liquids with added beer aromas or malt fermented by lactic acid bacteria, however these cannot be classified as beer by the Dutch regulation.

7. Conclusions

The aim of this research was to analyse the economic viability of producing alcohol-free beer by craft brewers. The focus was on Dutch craft brewers, and therefore data was collected in the Netherlands. The production process of alcohol-free beer was evaluated and implementation scenarios were proposed. The first scenario considers reduced tax as profit, whereas the second scenario introduced production cost and included collaboration between brewers. Subsequently, an investment analysis was performed based on commercially available equipment. The viability of the investment was derived from the discounted cash flow analysis. The influence of the parameters was evaluated with a multiple linear regression model. Finally, the minimal selling prices, required to make profits were calculated.

The main objective of this thesis is: “Is it economically viable for Dutch craft brewers to invest in the production of alcohol-free beer?”. The answer is that it is not economically viable for an average Dutch craft brewery to invest in the production of alcohol-free beer. However, it can be economically viable for specific Dutch craft breweries. In general, the production size of a craft brewery is not sufficient to produce profitable alcohol-free beer. Investing in alcohol-free beer production can still be profitable, when producing more than 250 hL per year. It is a possibility to share a dealcoholiser with a select group of brewers. In this case, the total production is also required to be at least 250 hL per year. It is not advisable to share the dealcoholiser with a large group of brewers, as cost price will not decrease much after at a greater production than 1000 hL per year.

In addition, the first research question: “How can alcohol-free beer be produced and what is the difference with low-alcohol beer?” is answered in chapter 3. Continuous vacuum rectification, falling film evaporation and reverse osmosis are the most applicable methods to dealcoholize beer. Contrary, low-alcohol beers are mostly produced with biological methods. These methods produce small amounts of alcohol, nevertheless more than allowed for alcohol-free beer. Nextly, the second research question: “How can alcohol-free beer be produced by craft brewers?” is discussed in chapter 4. Small scale dealcoholisers are available on the market. Access to the power grid, water supply and a free space of about 10 m^2 is required for installation. Finally, the third research question: “What are the costs and revenues related to production of alcohol-free craft beer?” is elaborated in chapter 5 and 6. The cost of producing alcohol-free beer is an extension to the production cost of alcoholic beer. The revenues relate to the selling price of the beer and the reduction in taxes.

In conclusion, it is not clear whether it is economically viable for Dutch craft brewers to invest in the production of alcohol-free beer. In general, it is not economically viable for an average Dutch craft brewer and it is more profitable to produce alcoholic beer. The decision to invest remains to the brewer and should be based on the circumstances of their own brewery, their own preferences and risk attitude. Collaboration between brewers is possible to reduce marginal costs.

7.1. Limitations of the study

One of the limitations of the study is the lack of demand data. It is assumed that any amount of beer that is produced is sellable. Even though predictions of the market can be made, it is very unclear what the perception of alcohol-free or even beer in general will be in 20-30 years. The consumption of alcohol-free beer has risen in recent years and it is expected to continue, however the exact future is unknown (Statista, 2019). An issue with insufficient demand is more likely to occur, when large numbers of brewers start with producing alcohol-free beer. The lack of relevant literature is a large limitation for the study, most of the references are websites. In addition, the majority of the articles focused on the technical aspect of alcohol-free beer, economical evaluations are lacking. Data in general is based on little references. Response from brewers and manufacturers was limited and could take over a month after inquiring. This is also the reason that the calculations are done with a production size of 10 hL per hour, while the average of the three samples was around 8 hL per hour. The first response was above the average and most calculations were finished before more response arrived. Likely the conclusions would not change as throughput is related with variable cost and that was only a small portion of the total cost.

In addition, calculations are done with a rather small discount rate, this means that most risks are not accounted for. Changes in duties or taxes are probable to occur within the timespan of the investment. Profits will decrease and the investment can become unprofitable. Another limitation is that it is unclear how much labour is associated with the dealcoholiser. For example, cleaning, operating, maintaining and controlling are activities related with having a dealcoholiser. The labour associated with dealcoholisation is assumed to be two hours per operating hour of the machine. The labour cost is not dependent on the total operating hours per year. The labour cost is the largest fraction of the variable cost and is therefore of large importance at a large production size. Decreasing labour cost can result in larger profits, when producing large quantities of alcohol-free beer. Lastly, the calculations do not consider the development of a recipe. A successful alcohol-free beer takes time and costs money to develop. This will reduce the profitability of the investment at the start.

7.2. Recommendations for further research

It is recommended for further research to take a more in dept look at the use of dealcoholisers at craft scale breweries. Additional details regarding the brewery could be included. In this research no attention was given to overhead cost or running a craft brewery. The business as a whole and especially the change should be considered. The partial budgeting approach can be used to compare the situation before installing a dealcoholiser with the situation in which a dealcoholiser is purchased. One of the details to investigate is the behaviour of labour cost. Multiple labour activities are related with operating a dealcoholiser. It is of large importance to have a clear overview of those tasks and the related costs, as labour cost is the largest fraction of the variable cost of operating a dealcoholiser. Minimizing this cost can have a large influence on the profitability of producing alcohol-free beer. The amount of labour required can be related to factors, such as operating hours, as more beer can be processed before cleaning.

It is advisable to investigate the possibilities of investing in larger sized dealcoholisers, when using the machine with a group of brewers. Possibly, it is more viable to invest in larger equipment as unit cost price can be cheaper, when sharing a dealcoholiser, the organisational and transporting cost should be considered. Increasing the number of brewers that use a single machine means that the average transporting distance will increase. There is a point at which the reduction in production cost will not satisfy the additional transporting cost.

Furthermore, it is recommended that consumer demand is studied with for example a survey. The total demand for alcohol-free craft beers is unknown. Besides, it is unknown how much (Dutch) people are interested in alcohol-free craft beers. Having demand data can result in a better evaluation whether investing in alcohol-free beer is economically viable, since calculations can consider a maximum production size.

Another recommendation for further research is to investigate the development of a successful recipe. Alcohol-free craft beer can only be sold, when the product is enjoyed by a large group of consumers. This enjoyment does not only consist of the flavour and taste of the beer, but also on the uniqueness and safety of the beer (Jaeger, Worch, Phelps, Jin, & Cardello, 2020). The development of such recipe can cost a lot of time and money. This should be considered, as it is part of the cost related to the investment.

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Appendices

Appendix I – Contact CRAFT brewers

Advertisement CRAFT website

Original in Dutch

Voor een onderzoek naar alcoholvrije craftbierproductie in Nederland, is Luc de Bont (master student aan de Universiteit van Wageningen) op zoek naar leden van CRAFT die alcoholvrij en/of alcoholarm bier brouwen of dit overwegen. Hij wil namelijk graag samen met een Nederlandse brouwer onderzoeken wat de beste oplossing is om alcoholvrij craftbier te brouwen op zowel technisch als economisch vlak. Ook wil hij weten hoe dit bier gebrouwen wordt en enkele korte vragen stellen over de ontwikkeling.

Als CRAFT steunen wij dit onderzoek van harte. Indien jouw brouwerij op dit gebied actief is willen we je dan ook vragen met Luc contact op nemen via het e-mailadres luc.debont@wur.nl of telefonisch via het telefoonnummer XXX.

In English

For a study on alcohol-free craft beer production in the Netherlands, Luc de Bont (master student of Wageningen University) is looking for members of CRAFT, who are producing or willing to produce alcohol-free and/or low-alcohol beers. Together with a Dutch brewer, he wants to research the best solution to produce alcohol-free craft beer at both technological and economical level. Besides, he wants to know how this beer is brewed and will ask some short questions about the development.

As CRAFT we sincerely support this research. If your brewery is active in this field, we want to ask you to contact Luc via the e-mail address luc.debont@wur.nl or by phone via the phone number XXX.

Questions for brewers

Brewer 1, producing low-alcohol beer

- How much of the low-alcohol beer do you produce per year?
- Do you use special ingredients for the production of the low-alcohol beer?
- Which method(s) do you use to reach a low alcohol percentage?
- Why did you choose for this method (these methods)?
- Do you pay attention to the alcohol formation during other production steps?
- In which steps, do you restrict alcohol formation?
- Are there difficulties or problems (expected) in the production process?
- Is it considered to start producing alcohol-free beer?
- Why did this not progress?

Brewer 2, willing to produce a low-alcohol beer

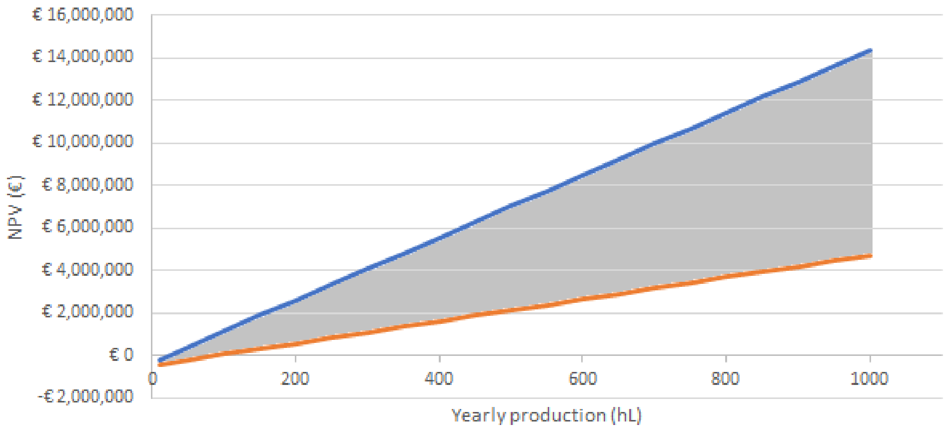
- What type of beer (low-alcohol/alcohol-free) are you willing to brew and why?
- How much do you expect to produce of this beer per year?
- Do you want to produce the beer in your own brewery or do you want to outsource it?
- Which method(s) are applied to reach 0% (or <1.2%) alcohol in the beer?
- Why did you choose these methods?
- Do you want to use special ingredients for the production of the low-alcohol beer?
- Do you expect difficulties or problems in the production process?
- Do you expect difficulties or problems to the beer, outside the production process?

Appendix II – Regression statistics

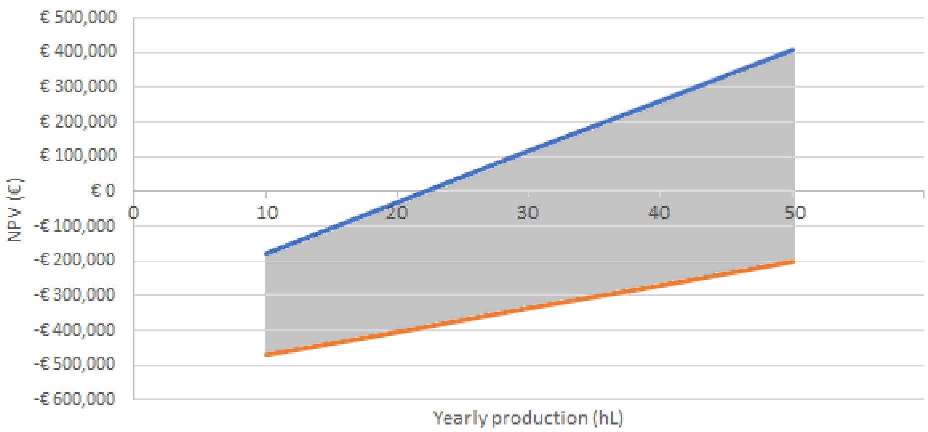
Appendix table 1. Statistics of multiple linear regression analysis on substitution scenario.

Multiple R	**0.992**
R square	0.992
Adjusted R square	0.983
Standard error	19752
Observations	12150

Appendix III – NPV additional capacity



Appendix figure 1. Possible values of NPV for additional capacity, based on settings in Table 3 for a yearly production size between 50-1000 hL.



Appendix figure 2. Possible values of NPV for additional capacity, based on settings in Table 3 for a yearly production size between 10-50 hL.

Appendix table 2. NPV at different moments, when considering the minimal selling price for the constant and increasing production sizes.

Production size	Loan term	NPV (10)	NPV (20)	NPV (30)
50+10	10	0	539,000	1,157,000
	20	-62,000	0	202,000
	30	-52,000	-42,000	0
20+10	10	0	679,000	1,505,000
	20	-99,000	0	278,000
	30	-109,000	-89,000	0
50-1000	10	0	248,000	432,000
	20	-13,000	0	102,000
	30	-16,000	-13,000	0