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Reducing Carbon Footprint and Water Consumption in Alcohol-Free Beer Production: Comparing Maltose- and Crabtree-Negative Yeast to Thermal Dealcoholization

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ABSTRACT

The majority of the world's non-alcoholic and alcohol-free beer is currently produced using thermal dealcoholization. In a future where energy and water resources will become more scarce, a more environmentally friendly approach could be to utilize maltose- and Crabtree-negative yeasts. In order to compare the two methodologies, Chr. Hansen has developed a calculation tool with which we aim to illustrate the significant differences between the two methods in terms of specific malt consumption, energy consumption, water usage, and carbon footprint. For the production of 100,000 hL of <0.05% ABV alcohol-free beer (AFB), the calculation shows potential savings of 59,499 hL of water and 1,055,892 kg of malt (66% less malt overall) and a reduction in carbon footprint of 1,260 tons of CO_2e (equivalent to 100 trips around the globe by car) by choosing a direct brewing solution via maltose- and Crabtree-negative yeasts instead of dealcoholization. It is our hope that our calculation tool can inform brewers and provide relevant environmental insights for the AFB production methods available to them.

Keywords: alcohol-free beer, estimating environmental impact, maltose- and Crabtree-negative yeast, thermal dealcoholization

Introduction

The non-alcoholic (NAB) and alcohol-free beer (AFB) segment is predicted to experience strong growth in the U.S. market in the coming years due to consumer adaptation to healthier and more mindful ways of living—on average >10% growth in the next two years in the U.S. market (5). Until recently, physical removal of ethanol from beer was the primary method of choice for larger brewing groups to produce <0.05% ABV beer (used in this article as the definition of AFB), despite the fact that these methods remove the majority of natural yeast and hop-derived aroma and flavor compounds. At the time, the most common alternative to thermal dealcoholization was the cold contact method, which is associated with drawbacks such as worty character, excessive sweetness, and lack of natural beer flavor. A review of methods for production of NAB and AFB can be found in Salanță et al. (9).

As viable alternatives to dealcoholization did not exist until recently, questions of climate impact were limited to which physical method a brewery should choose and optimization of the individual physical methods. However, a team of scientists at Chr. Hansen has pioneered an approach utilizing a maltose- and Crabtree-negative yeast (M&CNY) of the *Pichia kluyveri* species in combination with an aerobic brewing process to produce AFB that only requires mixing of the fermentation tank content and a system to control the oxygen concentration at a low specific range.

This new method offers a viable alternative for AFB production compared with physical dealcoholization as no aromas are lost and the total time to produce a batch of AFB can be reduced from 8–10 days to only 2–3 days. As this method consists of fermentation at "normal" fermentation temperatures (typically between 10 and 20°C), it eliminates the drawbacks of the cold contact method by effectively reducing wort aldehydes and forming typical beer flavors. Furthermore, it offers a choice for breweries conscious about their environmental impact and interested in reducing their carbon footprint. To demonstrate the advantages in terms of environmental impacts, we have developed a calculation tool that is third-party verified and helps to illustrate the real-life impact of different choices and their associated footprints. This report will outline the basics and general assumptions of the tool together with our key findings in terms of savings on malt and energy, reduction in water consumption, and

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Simon Carlsen is currently working as principal application specialist in the Fermented Beverages Department at Chr. Hansen A/S. He joined the company in 2018 and has primarily been working with the application of existing products for the brewing industry and with the development of new bacterial and fungal cultures for brewing applications. The main scope of this work has been on non-alcoholic and alcohol-free beer production, with a focus on optimizing the application of non-*Saccharomyces* yeast. Simon holds a B.S. degree in chemical engineering, an M.S. degree in biotechnology, and a Ph.D. degree in metabolic engineering.

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overall reduction in carbon emissions associated with the production of AFB.

Overview of Comparison Tool and Key Inputs and Figures

As a basis for the calculation tool, we have chosen to compare the application of M&CNY to thermal dealcoholization, as we believe this is one of the most prevalent dealcoholization methods used by breweries today. Because these methods are very different, some consideration is required to determine the best approach to performing a "fair" comparison. Therefore, we will explain our method of creating this comparison and our reasoning, and the basics of the calculation tool will be described in broad terms. An outline of the two methods will be provided as well.

Thermal Dealcoholization

The alcohol content present at the start of the dealcoholization process is important. As many international breweries have main brands in the range of 5% ABV with a real degree of fermentation (RDF) of approximately 67%, we have chosen this as the basis for our comparison. These brewing groups could typically apply a level of high-gravity brewing (HGB) with a wort strength 25–30% higher than required for brewing without dilution. With these assumptions, we will look at a case where a wort of 14.5% P is fermented to 6.5% ABV, centrifuged, debrewed/diluted to 5.0% ABV, and then dealcoholized to <0.05% ABV before being filtered, carbonated, packaged, and pasteurized. Wort and beer characteristics at relevant steps in the dealcoholization process are provided in Table 1.

M&CNY

Perhaps the fairest comparison to the AFB created using dealcoholization (as described above) would be to aim at having the same level of real extract and the same low level of alcohol in the final beer. This, we could argue, would offer the potential for achieving a similar body and mouthfeel for both beers. If it is also assumed that we will apply the same level of HGB (25–30%) during this process, the wort and beer characteristics for this case will align with those shown in Table 2.

Table 1. Wort and beer characteristics at relevant steps in the dealcoholization (DeAlc) process used in the comparison

Characteristic	Wort	HGB[a] Beer	Before DeAlc	After DeAlc = Final beer
Original extract (% P)	14.50	14.50	11.40	3.85
Real extract (% P)	14.50	4.76	3.77	3.77
Alcohol (% ABV)	0.00	6.50	5.00	<0.05

[a] High-gravity brewing.

Table 2. Wort and beer characteristics at relevant steps of the maltose- and Crabtree-negative yeast process used in the comparison[a]

Characteristic	Wort	HGB Beer	Debrewed Beer = Final Beer
Original extract (% P)	5.09	4.90	3.85
Real extract (% P)	5.09	4.80	3.77
Alcohol (% ABV)	0.00	<0.07	<0.05

[a] The drop in original extract between the wort and high-gravity brewing (HGB) beer stages is due to the fact that the aerobic fermentation process consumes a bit more extract for biomass production than what is accounted for in Balling's formula in "traditional" brewing calculations.

Calculation Tool Used for Comparison

The calculation tool our team developed is Excel-based and calculates raw material (malt) requirement, as well as energy and water consumption, for the production of a certain volume of AFB at <0.05% ABV, comparing the two production methods. Input for the calculation tool, besides the beer analyses mentioned in Tables 1 and 2, includes brewhouse yield (BHY) and beer losses throughout the production process, which we define at 100% BHY and 7% overall losses until finished goods for both methods. However, it could be argued that overall losses would be smaller using the M&CNY method, as dealcoholization encompasses an extra unit operation.

Having chosen the final beer composition based on what seems relevant for a larger brewing group using dealcoholization technology, we also chose to use 100,000 hL of final beer for our comparison, a fairly large volume, to provide the most relevant example for current technologies that we could. The conclusions also hold true for smaller volumes, because it is a yeast, after all, not a piece of processing equipment.

Results and Discussion

With the case assumptions described above, the calculation tool returns a comparison on raw material requirement, energy and water consumption, and a sustainability report in the form of carbon emissions for the two methods.

Raw Material (Malt) Requirement

For each method, the tool calculates the amount of malt required to produce 100,000 hL of final beer under assumptions previously mentioned with respect to composition, BHY, and overall process losses and under the assumption of malt used with 80% extract as is. The results are listed in Table 3.

While it is intuitively obvious that making beer by direct fermentation without alcohol production requires less raw material (malt) than first producing a full-strength beer and removing the alcohol afterward, it might nonetheless come as a surprise that it is possible to save significant amounts of malt (in this case 66%) by choosing this method (M&CNY).

Table 3. Calculation tool output on raw material (malt) consumption for producing 100,000 hL of <0.05 ABV beer using dealcoholization (DeAlc) and maltose- and Crabtree-negative yeast (M&CNY) methods[a]

Parameter	DeAlc	M&CNY
Beer before DeAlc/wort before M&CNY		
Plato (% P)	11.40	5.09
Real extract (% P)	3.77	5.09
Alcohol by volume (% ABV)	5.00	0.00
Final beer after DeAlc or M&CNY protocol		
Plato (% P)	3.85	3.85
Real extract (% P)	3.77	3.77
Alcohol by volume (% ABV)	0.05	0.05
HGB, BHY, and losses[b]		
HGB (%)	27.2	27.2
Wort strength/Plato at fermentation (% P)	14.50	5.09
BHY (%)	100	100
Total losses after brewhouse (%)	7.0	7.0
Wort cast (hL)	83,548	84,178
Raw materials used		
Extract in wort (kg)	1,281,703	436,989
Raw materials (malt) used (kg)	1,602,129	546,237
Index (%)	100	34

[a] Volume of alcohol-free beer: 100,000 hL; final beer alcohol level: 0.05% ABV.

[b] HGB: high-gravity brewing; BHY: brewhouse yield.

Energy Consumption (Process Heating/Cooling)

Brewing beer is relatively energy intensive due to the thermal processes used in the brewhouse, the wort cooling stage, the energy released during fermentation by the yeast, and the final cooling required for the beer. For this particular comparison of methods, it is also relevant to look at energy consumption in the dealcoholization module used. As energy for all other purposes (filling, room heating/cooling, lighting, auxiliaries, etc.) are equal for the two methods, these are not considered here—we are only assessing direct production process steps in which energy requirements (heating or cooling) can be calculated and are directly comparable between production methods.

Table 4. Calculation tool output on energy consumption (heating and cooling) for producing of 100,000 hL of <0.05% ABV beer using dealcoholization (DeAlc) and maltose- and Crabtree-negative yeast (M&CNY) methods[a]

Parameter	DeAlc	M&CNY
Mashing		
Water/grist ratio (L/kg)	2.7	4.0
Mashing-in temperature[b] (°C)	60	70
Mashing-out temperature (°C)	78	78
Heating of mash[c] (MJ)	564,833	254,924
Wort boiling		
Wort volume after boil = cast volume (hL)	83,548	84,178
Evaporated volume[d] (hL)	4,177	4,209
Wort volume before boil (hL)	87,725	88,387
Heating from mashing-out to boil[e] (MJ)	837,173	813,474
Energy for evaporation (MJ)	939,910	947,001
Wort cooling		
Wort temp after water cooling (°C)	20	20
Final wort temp after glycol cooling (°C)	13	17
Cooling energy (glycol)[f] (MJ)	253,689	105,646
Fermentation		
RDF$_{\text{Classic}}$[g] (%)	67.0	5.8
Amount of extract fermented (kg)	857,842	25,127
Tank cooling energy[h] (MJ)	503,553	14,749
Maturation		
Maturation temp[i] (°C)	0	1
Energy used for cooling from fermentation temp (MJ)	459,645	549,702
Dealcoholization[j]		
DeAlc heating energy (MJ)	4,393,421	n/a
DeAlc cooling energy (MJ)	4,255,579	n/a
Total energy		
Total heating energy (MJ)	6,735,337	2,015,399
Total cooling energy (MJ)	5,472,466	670,097

[a] Volume of alcohol-free beer: 100,000 hL; final beer alcohol level: 0.05% ABV.

[b] Calculations assume 60°C as a normal mashing-in temperature and 70°C as a typical temperature when working with maltose-negative yeasts, where it is common to raise mashing-in temperature to shift the sugar profile from maltose to dextrins to reduce the residual sweetness of the final product.

[c] Using a water/grist ratio of 2.7 and 4.0 L/kg and specific heat for mash of 3.55 and 3.71 kJ/kg/K, respectively (based on 4.18 kJ/kg/K for water and 1.84 kJ/kg/K for malt [7]).

[d] Assuming 5% evaporation during boil for both processes.

[e] Using specific heat for wort of 4.1 kJ/kg/K (9).

[f] For wort cooling, it is assumed that a two-stage (water/glycol) heat exchanger is used and that the first step (water) is able to cool to 20°C and from there to the second stage (glycol) cools to the fermentation temperature (which is different for the two methods, as normal bottom-fermenting brewer's yeast generally works at a much lower temperature than brewer's yeast in M&CNY).

[g] RDF: real degree of fermentation.

[h] Assuming a fermentation energy of 587 kJ/kg of extract fermented (9).

[i] Regular beer is typically stabilized at 0°C or lower, while M&CNY beer has a significantly higher freezing point and, therefore, cannot be cooled to the same degree.

[j] Based on data from "Product_leaflet_De-alcoholization_module_EN.pdf" available on the Alfa Laval homepage (1).

As can be seen in Table 4, we have used consumption data for dealcoholization obtained from the product data sheet from a well-regarded equipment supplier for their dealcoholization module. In light of the lack of data on dealcoholization technology from other suppliers, we make the assumption that these data are representative for thermal dealcoholization in general.

The results listed in Table 4 indicate that the dealcoholization method consume 3.35 times more heating energy than the M&CNY method and more than 8 times the cooling energy when comparing the same volume of final AFB.

It is interesting to note that consumption in the dealcoholizing module aside, other process steps have significantly different energy consumption for the two methods. Examples include

- During mashing, the "normal" mashing-in temperature would be 55–60°C (60°C was used in the calculation), and energy is used to heat mash from this temperature to the mashing-off temperature, typically 78°C. When using M&CNY, it is often advantageous to optimize for maltotrioses and higher saccharides and minimize maltose production by mashing in at temperature above β-amylase activity optimum (70°C was used in the calculation), and this method, therefore, uses less heating energy for this step.
- Wort cooling can be a two-stage process, where cold water cools wort from the kettle to a certain level (20°C was used in the calculation), and a secondary cooling step (often glycol) takes it to the desired fermentation temperature or often slightly lower, which for a typical lager fermentation could be 10–13°C (13°C was used in the calculation). M&CNY often works at a higher temperature (17°C was used in the calculation), and therefore, less glycol cooling is required here.
- Fermentation tank cooling (removal of the heat of fermentation) is proportional to the amount of fermentation going on, and when comparing methods having a tenfold difference for this parameter (RDFs of 67 and 6% were used in the calculations), there will be a tenfold difference in the cooling requirement during fermentation.

Water Consumption

The two methods naturally use similar amounts of water for the direct brewing process. However, the dealcoholization module adds significantly to overall water consumption. Based on the data sheet from the global equipment supplier, it can be calculated that producing 100,000 hL of AFB will utilize around 17,263 hL of soft water, or the water that is evaporated and used in the vacuum stripper to remove alcohol from the original 5% ABV beer. When operating the dealcoholizer, it is important to add sufficient steam so that ethanol vapors can be diluted to a concentration that is below the flash point (depending on the water–ethanol mixture [i.e., primarily the ethanol concentration and storage temperature]) or subsequently dilute with additional deaerated water. Practically, it seems that most often alcohol concentration in the by-product stream is kept around 20% ABV, and therefore, we will use this as the basis for our calculations. Intuitively, total water consumption for dealcoholizing 100,000 hL of 5% ABV beer could be argued to be 5,000 hL for direct replacement of alcohol in AFB and 20,000 hL for keeping 20% ABV in alcohol by-product (i.e., in total, 25,000 hL of water).

The calculation model does not look into water consumption outside of the direct process, but the extra process steps utilized by the dealcoholizer and the fact that two tanks are required simultaneously while the dealcoholizer is in operation requires more clean-in-place cycles for the equipment and, thus, more water and cleaning chemicals.

In the United States, federal regulation considers alcohol removal a process in distillation if the alcohol "waste" stream has a higher ethanol concentration than the ethanol concentration in the process feed stream, according to ATF ruling 85-6 (3). As it would be unusual to use a feed stream with an ethanol level equal to or higher than the ATEX level of 20% ABV defined above, any dealcoholizing process that does not increase the ethanol level would either require more water than what was calculated for the ATEX case or a distillation license (the latter increases complexity and adds a requirement for the production facilities). Alternatively, the ethanol waste stream could be converted into a revenue stream by utilizing it as a base for hard seltzers or other alcoholic products. This, however, would increase operational complexity, does not address environmental issues, and is only a partial solution to the increased utilization of water. Finally, this would imply that the sales of the two products need to be balanced, which is difficult to achieve.

While there are direct water savings at the brewery, the fact that less malt is used means that the needed water to produce the unused malt is also saved at the maltster. This is seen in the following calculation. Steeping the grains in the initial stages of malting requires between 0.6 and 7 m^3/ton depending on the method (8). Calculating with an approximate average of 4 m^3/ton and a malt saving of 1,055,892 kg (malt required for dealcoholization minus malt required for M&CNY on a 100,000 hL basis), the difference in water consumption between the two methods is 42,236 hL.

Total difference in water consumption between dealcoholization and M&CNY methods appears to be easily 17,263 hL + 42,236 hL = 59,499 hL, or 0.6 hL/hL of AFB.

Electricity

In the brewery, electricity is used to operate various process equipment, such as pumps and compressors. As we compare the two methods, there are a number of steps that are interesting to analyze, particularly cooling compressors in (typically) glycol cooling plants and vacuum pumps in the dealcoholization module.

Electricity Use by Cooling Compressors. Our results in Table 4 demonstrate a total cooling energy requirement in various process steps, which by applying coefficient of performance and cooling plant energy efficiency, can be used to calculate electrical power consumption (MJ), which may be converted to electricity consumption (kWh). These calculations are outlined in Table 5.

Table 5. Cooling energy requirement for producing 100,000 hL of alcohol-free beer using dealcoholization (DeAlc) and maltose- and Crabtree-negative yeast (M&CNY) methods

Parameter	DeAlc	M&CNY
Cooling energy (MJ)	5,466,278	670,097
Coefficient of performance ($kW_{Cooling}/kW_{Electricity}$)	4	4
Cooling plant energy efficiency (%)	80	80
Electrical power (MJ)	1,708,212	209,405
Electricity consumption (kWh)	474,503	58,158

Electricity Use by the Dealcoholization Module (Vacuum Pump Only). The data sheet from the equipment supplier provides an idea of the electricity requirement for creating a vacuum of 10–11 kPa corresponding to a required stripping temperature of slightly above 40°C. If we assume that the model's dealcoholization module is a 50 hL/h version (a midsize module for plants between 5 and 100 hL/h), then the module will have to run for at least 2,000 h to produce 100,000 hL of AFB. While doing so, it will consume slightly more than 18 kW of power, resulting in total electricity consumption of 36,842 kWh.

Looking only at cooling compressors and vacuum pump electricity use, the dealcoholization method is already at 511,345 kWh, or more than 5 kWh/hL, while the M&CNY method uses approximately one-tenth of that amount.

For the M&CNY method, a circulation loop needs to be in place to distribute yeast and disperse oxygen evenly throughout the tank volume. The recommendation for larger tanks (>500 hL) is to use a dedicated tank mixing system, such as Iso-Mix™ from Alfa Laval or similar system. The pump installed is typically 0.25 kW (2) and needs to run during fermentation and tank cooling (i.e., for 84 days) to produce 100,000 hL of AFB (Table 6). This amounts to a total of 504 kWh.

Electricity is also consumed by the roller or hammer mill. The milling operation requires more than double the amount of electricity when using the dealcoholization method as it does when using M&CNY, as it uses more than twice the malt throw. However, because energy consumption varies across milling systems, and because this contribution to overall electricity consumption is relatively small compared to the factors outlined previously, the calculation model does not account for this form of energy use.

Process Time

Analyzing differences in process time may not seem to be directly related to energy use. That said, if one process is significantly faster than the other, it is possible, over time, to utilize the process equipment more effectively using this method, thereby getting more product out of a fixed equipment volume (e.g., fermentation tank volume) or allow the brewery to install a smaller fermentation tank volume to produce the same volume of AFB.

Table 6. Comparison of tank occupancy for producing 100,000 hL of alcohol-free beer (AFB) using dealcoholization (DeAlc) and maltose- and Crabtree-negative yeast (M&CNY) methods and 2,000- and 5,000-hL tanks[a]

	2,000-hL Tank (42 Batches)		5,000-hL Tank (17 Batches)	
Parameter	DeAlc	M&CNY	DeAlc	M&CNY
Fermentation tank days (DeAlc: 8 days/batch; M&CNY: 1.5 days/batch)	336	63	136	26
Fermentation tank cooling (1 day regardless of tank size)	42	42	17	17
Centrifugation (2 tanks × batches × volume/350 hL/h/24 h/day)	20	20	20	20
Dealcoholization (2 tanks × batches × volume/50 hL/h/24 h/day)	141	n/a	141	n/a
Filtration (2 tanks × batches × volume/350 hL/h/24 h/day)	20	20	20	20
Total tank occupancy time (days)	559	145	334	83

[a] When the number of batches required is not simply AFB volume (100,000 hL) divided by tank size, it is due to the fact that high-gravity brewing and process losses are taken into account.

M&CNY beer production requires less tank occupancy and fewer processing steps. The dealcoholization method utilizes a “normal” amount of time to produce the 5% ABV “mother beer” (e.g., one tank for 8 days of fermentation and 1 day for cooling per batch). In addition to this, time and one extra tank is occupied in each of the subsequent process steps:

- Centrifugation
- Dealcoholization
- Filtration

In comparison, the M&CNY method has a typical fermentation time of 1–1.5 days, and we assume one tank for 1.5 days of fermentation and 1 day of cooling, plus two tanks during centrifugation and filtration, and no need for dealcoholization tank occupancy.

Looking at two scenarios with 2,000- and 5,000-hL fermentation tank volumes, the total tank occupancy for the two methods are calculated in Table 6. Our analysis suggests that the M&CNY method will allow for up to 4 times higher production volume in a fixed tank volume and, thereby, delay the need for investment in additional tank volume.

Sustainability Report

After developing our calculation tool, colleagues from our sustainability department conducted a sustainability analysis based on our work. This has been done following global standards for carbon footprint and life-cycle assessments, and all calculations have been critically reviewed in this process and validated by a third party (The Footprint Firm, Copenhagen, Denmark). The “output report” on sustainability from the calculation tool, which calculates carbon footprint (tons of CO_2e emissions from the two methods), is depicted in Figure 1.

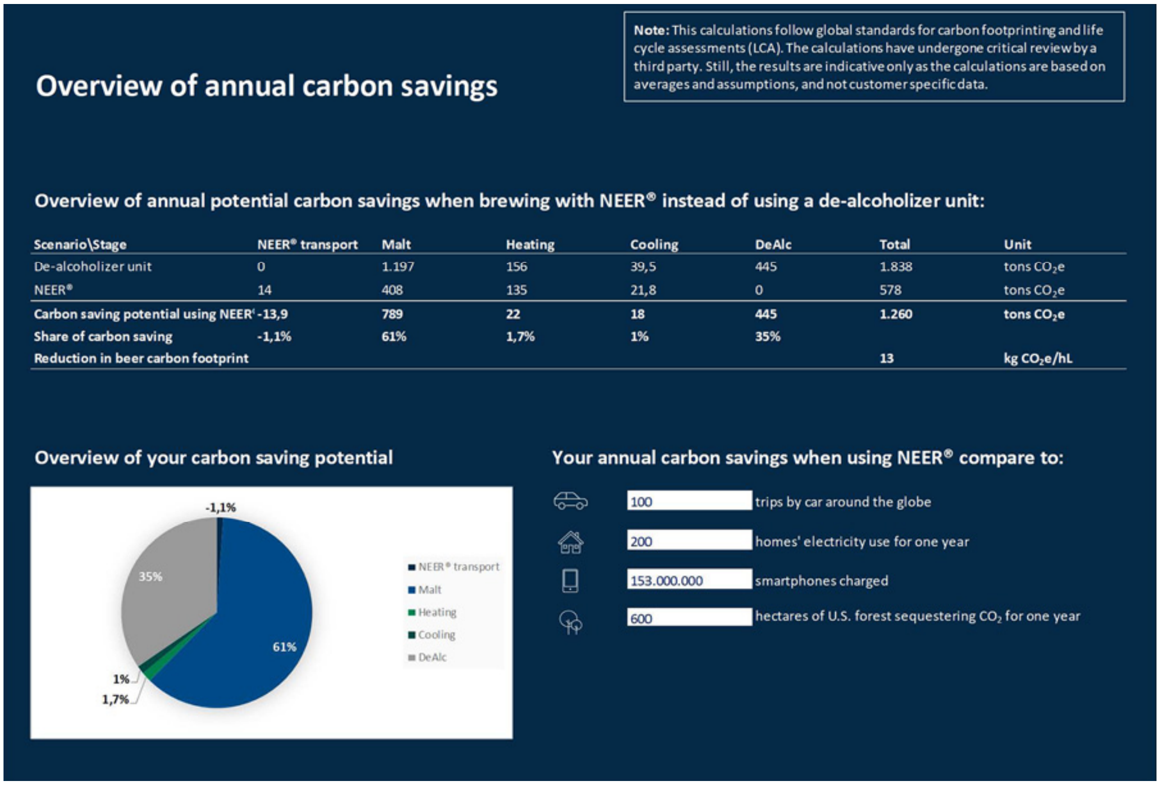
Results were consistent with our prediction: significant savings in carbon emissions can be obtained by choosing a method based on an M&CNY instead of a method based on thermal dealcoholization of a “normal” beer (Fig. 1).

The majority of the emission savings originates from the fact that a beer with the same level of real extract can be produced using significantly less malt when using the M&CNY method (responsible for 61% of the difference in emissions). Most of the remaining difference is derived from running the dealcoholization unit (35%), which is quite energy intensive, while only 2.7% of the difference can be attributed to differences in heating and cooling schemes related to the brewing/fermentation processes of the two methods.

Summary

We have explained how the choice between two different production routes for a given volume of seemingly similar AFB (same level of real extract) can have enormously different effects on energy consumption and subsequent environmental impact. The numbers reported in previous sections of this article are summarized in Table 7, and we can see that the M&CNY method consistently yields unit operation energy savings between 65 and 95% from start to finish.

Needless to say, product quality is paramount to a brewery’s success, and a choice of method can only be justified if the quality of the beer that it produces is equal to that of the other options available. The dealcoholization method has been a long-standing option, and combinations of high-vacuum (low stripping temperature) and complex external aroma packages have resulted in the products that are now leading in global consumption.



Overview of annual carbon savings

Note: This calculations follow global standards for carbon footprinting and life cycle assessments (LCA). The calculations have undergone critical review by a third party. Still, the results are indicative only as the calculations are based on averages and assumptions, and not customer specific data.

Overview of annual potential carbon savings when brewing with NEER® instead of using a de-alcoholizer unit:

Scenario\Stage	NEER® transport	Malt	Heating	Cooling	DeAlc	Total	Unit
De-alcoholizer unit	0	1.197	156	39,5	445	1.838	tons CO_2e
NEER®	14	408	135	21,8	0	578	tons CO_2e
Carbon saving potential using NEER	**-13,9**	**789**	**22**	**18**	**445**	**1.260**	**tons CO_2e**
Share of carbon saving	**-1,1%**	**61%**	**1,7%**	**1%**	**35%**		
Reduction in beer carbon footprint						**13**	**kg CO_2e/hL**

Overview of your carbon saving potential

Your annual carbon savings when using NEER® compare to:

100 trips by car around the globe
200 homes' electricity use for one year
153.000.000 smartphones charged
600 hectares of U.S. forest sequestering CO_2 for one year

Figure 1. Sustainability output report from the calculation tool when used to compare dealcoholization and maltose- and Crabtree-negative yeast methods for producing 100,000 hL of alcohol-free beer made using the United States as a basis.

Table 7. Overview of savings from the application of the maltose- and Crabtree-negative yeast (M&CNY) method compared to the thermal dealcoholization (DeAlc) method[a]

Parameter	DeAlc	M&CNY	Savings with M&CNY (%)
Malt (ton) (Table 3)	1,602	546	66
Heating energy (GJ) (Table 4)	6,735	2,015	70
Cooling energy (GJ) (Table 4)	5,472	670	88
Vacuum pump (kWh)	36,842	504[b]	99
Tank occupancy time (days) (Table 6)	559/334	145/83	74/75
Water consumption (hL) (DeAlc + malting of saved malt)	59,499	0	100
CO_2e emission (tons CO_2e) (Fig. 1)	1,838	578	69

[a] Volume of alcohol-free beer: 100,000 hL; final beer alcohol level: 0.05% ABV.

[b] Vacuum pump of DeAlc method compared to Iso-Mix™ pump in M&CNY method.

The M&CNY method, on the other hand, is a newcomer to the beer brewing space. It introduces concepts that are new to the brewing industry and even some that may be a “red flag” for brewers, such as adding oxygen throughout fermentation. However, the M&CNY method does reduce wort aldehydes (data not shown), and it starts to produce typical beer aroma compounds after undergoing a short “neutral phase” in which wort character is eliminated and aroma compounds are still mainly below the flavor threshold. It is very much up to skilled brewers to design their M&CNY methods so they can craft beers with the body, texture, flavor, and aroma that they would like to offer consumers—with or without the assistance of flavor houses. Here we have presented a case comparable to the dealcoholization approach, but even if the brewery would prefer to have a higher final specific gravity for their AFB, the savings and reduction in environmental impact would still be significant.

Outlook

In a future where resources and raw materials may become more scarce, choosing the most environmentally friendly beer production method will help determine a brewery’s profitability, as well as shape its brand image. Large brewing groups have already put in great efforts to reduce their water consumption, with Carlsberg reducing use to 1.4 hL of water/hL of beer (4) at their Fredericia Brewery in Denmark and Heineken noting that they have reduced water consumption from 5 hL of water/hL of beer, by almost one-third, as part of their strategy to reduce water use before 2030 (6). As sales of AFB are expected to keep increasing, it will become more relevant for breweries to assess available production methods in an endeavor to drive down overall water and energy consumption. It is easier to choose between methods with considerable differences before entering the market for which they are used, and at this stage, capital and operating expenditures are important parameters to consider. Even though large capital expenditures in dealcoholization equipment have already been made, it is our hope that presenting our findings on carbon emissions together with savings on water, and energy will demonstrate a scenario where the dealcoholization capital expenditure made will be redeemed through potential operating expenditure savings, thereby encouraging breweries to reevaluate their approaches and consider being part of shaping a better future for the climate and providing their customers with great AFB offerings.

The calculation tool we have developed is not available online, but we will be happy to work with interested breweries to assess their breweries and analyze the potential savings obtainable by choosing the M&CNY method. Carbon emission factors vary from country to country (depending on local methods for electricity production, among other variables), and we will happily assist in applying our analysis to the individual scenarios and variables relevant to the specific production site.

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CONFLICT OF INTEREST

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