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Life Cycle Assessment of Ale and Lager Beers Production

Iolanda De Marco*, Salvatore Miranda, Stefano Riemma, Raffaele Iannone

University of Salerno, Department of Industrial Engineering, Via Giovanni Paolo II, 132, 84084, Fisciano (SA), Italy
idemarco@unisa.it

The food production industry requires great amounts of resources and energy, causing, during the productions, negative effects on environment. For these reasons, in the last years, different products of consumption were analysed from the environmental point of view, following Life Cycle Assessment (LCA) approaches. This work aimed at studying the environmental performance and the energy consumption of different beers produced in Italy by a small brewery. The study followed a life cycle approach and was focused on the industrial phases of the productions. A comparison among *ale* (high fermentation) and *lager* (low fermentation) beers' productions was made with the aim of address the productions toward a higher sustainability. The system boundaries covered by our research are only the industrial steps of the entire products' life cycle path: production in the brewery, bottling, packaging and waste disposal treatments ("gate to gate" and "gate to grave" approach). Raw materials, energy consumption and emissions to air, soil and water were normalized to the functional unit (beer in 33 cL glass bottle). In accordance with the reference standard for LCA (i.e., ISO 14040-14044), data were analysed using SimaPro 8.0.4 software and Life Cycle Inventory (LCI) was obtained using primary data and the Ecoinvent 3.1 database.

1. Introduction

The increasing attention about environment protection and carbon dioxide emissions' reduction encourage the industries to proceed towards sustainable productions. Even if not comparable to the emissions due to chemicals' and mining industries, the ones due to food industries have been under study in the last years, because food productions require large amounts of energy and, therefore, strongly contribute to global warming potential (GWP) and total carbon dioxide emissions (Roy et al., 2009). For this reason, several papers aimed at identifying and lowering environmental emissions due to food productions were published, using Life Cycle Assessment (LCA) analysis. LCA is an internationally recognized and ISO standardized accounting methodology to quantify the environmental impacts of a product, a process or a service throughout its life cycle, by identifying, quantifying and evaluating all the resources consumed and all the emissions and wastes released. Different papers have been published on this matter; among them, LCA has been used to evaluate (Iannone et al., 2014) or to lower (Iannone et al., 2015) the environmental emissions related to the production of wine. Other studies were made on tomato products (Karakaya and Özilgen, 2011), on fruit cultivations (Milà I Canals et al., 2006) or fruit derived products (De Marco et al., 2015). Since beer production uses grains as one of the raw materials, it is considered a food product (Talve, 2001). There are many difficulties in performing LCA studies of food products, due to the lack of databases. The aim of this paper is to perform a LCA analysis of beer production through a comparative study among *ale* (high fermentation) and *lager* (low fermentation) beers. The study has been validated using data set provided, for both the chosen beers, by a small brewery in Southern Italy. The two production chains mainly differ for fermentation conditions (temperatures and times). Different papers on beer production were published. Among them, Lodolo et al., 2008 focused the attention on the yeast used in the fermentation, whereas Ambrosi et al., 2014 made a study on membrane separation processes for the beer industry. Nevertheless, very few papers on LCA made on beer production are available. Cordella et al., 2008 made a "from cradle to grave" analysis on a lager beer packaged in 20 L returnable steel kegs or in 33 cL glass bottle and Talve, 2001 performed an analysis on a lager beer, without considering distribution and waste management. Therefore, no environmental study on comparison between different kinds of beers was made up to now.

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2. LCA methodology

LCA is a multi-stage analysis in which a broad set of data related to the life-cycle of a product or a process are properly collected and organized in order to compare different products, different life-cycle of the same product or to individuate the most critical phase of a life-cycle from the environmental perspective. In the following sub-sections, the main steps that constitute the LCA methodology are presented: 1) goal definition and scope; 2) functional unit, system boundaries and life cycle inventory.

2.1 Goal definition and scope

Goal definition is one of the most important phases of the LCA methodology, because the choices made at this stage influence the entire study. The purpose of this study is to evaluate the environmental impacts of two kind of beers (ale and lager) produced in Southern Italy by a small brewery. Figure 1 represents the scheme of the beer production chain according to the IDEF (Icam DEF for Function Modelling, where “ICAM” is an acronym for Integrated Computer Aided Manufacturing) methodology. In the top part of the figure, the complete production (from cradle to grave) is represented, whereas, in the bottom part, the detailed scheme of the brewing operations is shown.

2.2 Functional unit, system boundary and life cycle inventory

The definition of the functional unit (FU) is based on the quantity or mass of the product under analysis, and it is a reference to which all the inputs and outputs have to be related. The chosen functional unit is one 0.33 L bottle of beer. The system boundaries of the analysis were set from malt transportation to waste disposal; in the top part of Figure 1, a dashed line shows these boundaries. All the activities, the processes and the materials used in the beer production stages were taken into account. The proposal study refers to a “from gate to gate” and "from gate to grave" process, regarding, in particular, the brewery operations, beer bottling and packaging, distribution and waste disposal. In Table 1, the main activities of the observed process are reported. Activities as the potential impacts regarding the consumption were not taken into account. The life cycle inventory (LCI) is one of the most effort-consuming step and consists on the activities related to the search, the collection, and interpretation of the data necessary for the environmental assessment of the observed system.

Table 1: Process details and assumptions

Process	Characteristics and details	
	Ale	Lager
Malt supply to facility	Transport by truck, 40 t from Melfi (PZ)	Transport by truck, 40 t from Melfi (PZ)
Energy supply to facility	Italian energy mix low voltage	Italian energy mix low voltage
Milling	Energy supply	Energy supply
Mashing	T = 63 °C; t = 0.5 h; Energy and water supply	T = 63 °C; t = 0.5 h; Energy and water supply
Filtration	Energy supply	Energy supply
Boiling and hopping	T = 105 °C; t = 1 h; Energy supply, hops addition (3.6 g/L)	T = 105 °C; t = 1 h; Energy supply, hops addition (3 g/L)
Fermentation	T = 17 °C; t = 72 h; energy supply for cooling, *Saccharomyces Cerevisiae* addition	T = 7 °C; t = 336 h; energy supply for cooling, *Saccharomyces Carlsbergensis* addition
Maturation	T = 12 °C; t = 672 h; energy supply for cooling	T = 2 °C; t = 672 h; energy supply for cooling
Filtration	Energy supply	Energy supply
Bottling	White glass (0.33 L); energy supply, supporting materials and components supply	White glass (0.33 L); energy supply, supporting materials and components supply
Packaging	6 bottles; Energy supply, supporting materials and components supply	6 bottles; Energy supply, supporting materials and components supply
Distribution	Transport by lorry, 16-32 ton to Piedmont, Lombardy, Lazio, Campania, Apulia and Calabria and by large tanker to Sardinia	Transport by lorry, 16-32 ton to Piedmont, Lombardy, Lazio, Campania, Apulia and Calabria and by large tanker to Sardinia
Waste disposal	Energy supply, natural resources use for recycling and landfill	Energy supply, natural resources use for recycling and landfill

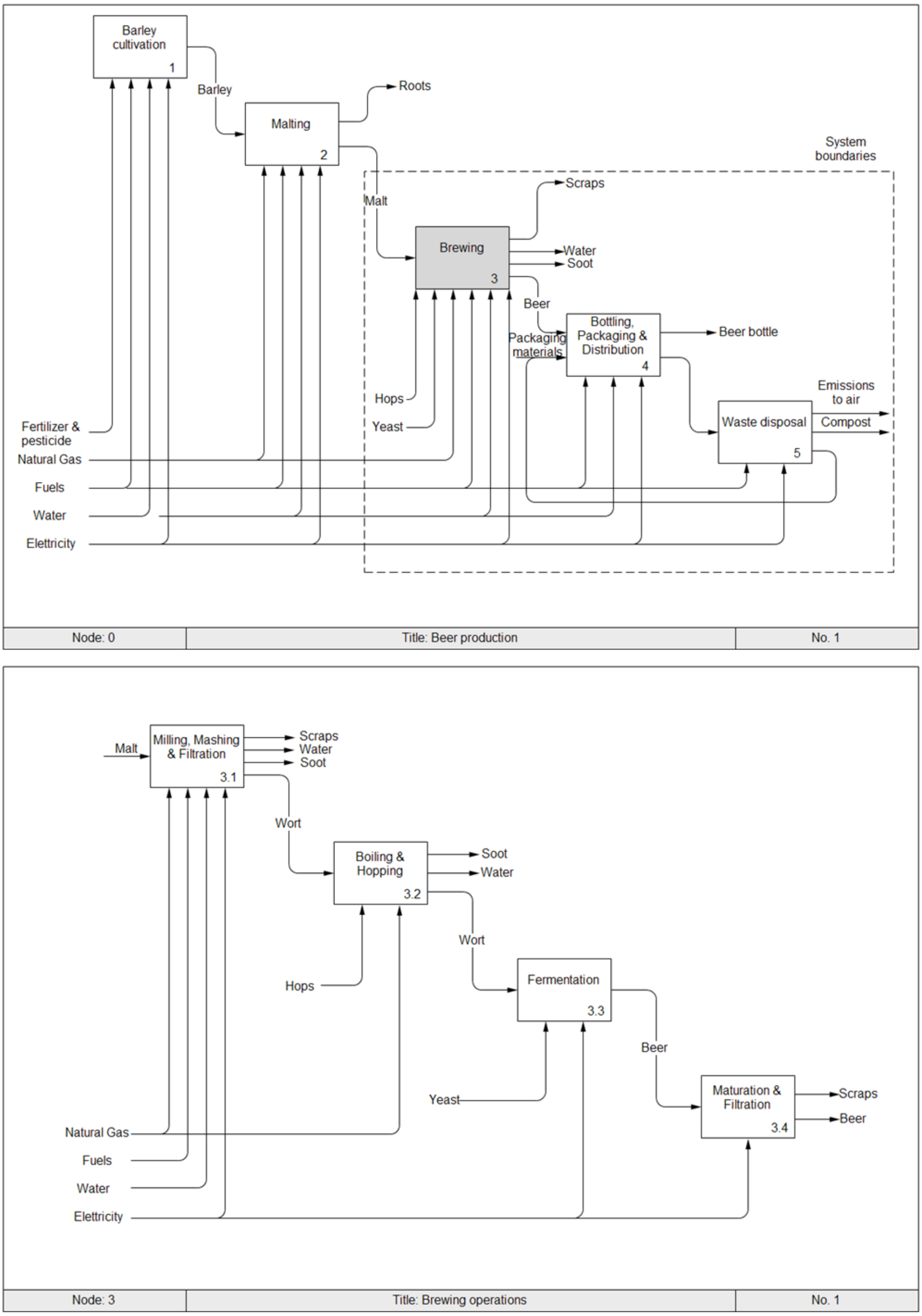

Figure 1: IDEF diagrams; top: beer production; bottom: details of brewing operations.

The Ecoinvent 3.1 database was employed as the principal source of background data and the LCA study is conducted using the LCA software SimaPro 8.0.4 in accordance with the reference standard for LCA (i.e., ISO 14040-14044).However, the majority of the processes and materials information required for the analysis are specific of the observed system and the collection of these data was performed using personal interviews. For the waste disposal, we assumed that all the organic wastes were composted, labels and crown corks were deposited in landfill, whereas for the glass bottles, landfill and recycling were considered. For each unit process within the system boundary, input data, such as energy, water, natural sources and output data in terms of emission to air, water and soil were collected. Table 2 lists the main energy and direct material input to the product systems under the study of a 0.33 L bottle of beer.

Table 2: Life cycle inventory of the main inputs for ale and lager beer (tkm is tonne-kilometre).

Industrial Phase	Input/Output	Unit	Ale	Lager
Transportation	Transport by truck	tkm	1.84×10^{-2}	1.84×10^{-2}
Milling	Electricity	MJ	1.82×10^{-2}	1.82×10^{-2}
	Malt	kg	1.26×10^{-1}	1.26×10^{-1}
	Output			
	Scraps	kg	1.26×10^{-3}	1.26×10^{-3}
Mashing	Grist	kg	1.25×10^{-1}	1.25×10^{-1}
	Mashing water	kg	5.00×10^{-1}	5.00×10^{-1}
	Electricity	MJ	8.47×10^{-4}	8.47×10^{-4}
	Fuel for heating	kg	2.51×10^{-3}	2.51×10^{-3}
Filtration	Mash	kg	6.25×10^{-1}	6.25×10^{-1}
	Electricity	MJ	6.41×10^{-4}	6.41×10^{-4}
	Output			
	Brewers grains	kg	5.00×10^{-2}	5.00×10^{-2}
	Water contained in grains	kg	2.00×10^{-1}	2.00×10^{-1}
Boiling and hopping	Must	kg	3.75×10^{-1}	3.75×10^{-1}
	Hops	kg	1.27×10^{-3}	1.06×10^{-3}
	Fuel for heating	kg	3.46×10^{-3}	3.46×10^{-3}
Fermentation	Must	kg	3.44×10^{-1}	3.44×10^{-1}
	Yeast	kg	1.75×10^{-3}	1.75×10^{-3}
	Electricity for cooling	MJ	2.15×10^{-3}	2.80×10^{-3}
Maturation	Beer	kg	3.46×10^{-1}	3.46×10^{-1}
	Electricity for cooling	MJ	2.37×10^{-3}	4.72×10^{-3}
Filtration	Beer	kg	3.46×10^{-1}	3.46×10^{-1}
	Electricity	MJ	5.79×10^{-4}	5.79×10^{-4}
	Output			
	Yeast and hops	kg	1.04×10^{-2}	1.04×10^{-2}
Bottling	Beer	kg	3.36×10^{-1}	3.36×10^{-1}
	Electricity	MJ	9.00×10^{-3}	9.00×10^{-3}
	Glass bottle	kg	1.90×10^{-1}	1.90×10^{-1}
	Crown cork	kg	2.50×10^{-3}	2.50×10^{-3}
	Label	kg	3.00×10^{-3}	3.00×10^{-3}
	Output			
	Bottle of 0.33 L	m^3	3.30×10^{-4}	3.30×10^{-4}
	Beer loss	kg	1.68×10^{-3}	1.68×10^{-3}
Packaging	Number of bottles	p	6×10^{0}	6×10^{0}
	Cardboard package	kg	4.00×10^{-2}	4.00×10^{-2}
	Electricity	MJ	2.67×10^{-3}	2.67×10^{-3}
Distribution	Transport by lorry	tkm	2.02×10^{-1}	2.02×10^{-1}
	Transport by barge tanker	tkm	2.37×10^{-2}	2.37×10^{-2}
Waste management	Glass bottle	kg	1.90×10^{-1}	1.90×10^{-1}
	Crown cork	kg	2.50×10^{-3}	2.50×10^{-3}
	Label	kg	3.00×10^{-3}	3.00×10^{-3}

3. Results and discussion

The aim of this study is the interpretation of the data collected through the LCI phase and to evaluate and compare the impacts related to ale and lager beers' production on 15 midpoint categories: carcinogens (C), non-carcinogens (NC), respiratory inorganics (RI), ionizing radiations (IR), ozone layer depletion (OLD), respiratory organics (RO), aquatic ecotoxicity (AET), terrestrial ecotoxicity (TET), terrestrial acidification/nitrification (TAN), land occupation (LO), aquatic acidification (AA), aquatic eutrophication (AE), global warming potential (GWP), non-renewable energy consumption (NRE) and mineral extraction (ME). In

Figure 2, the relative contributions of the main phases on each impact category (valid with inappreciable differences both for ale and lager beer's production) are reported in the case of ale beer.

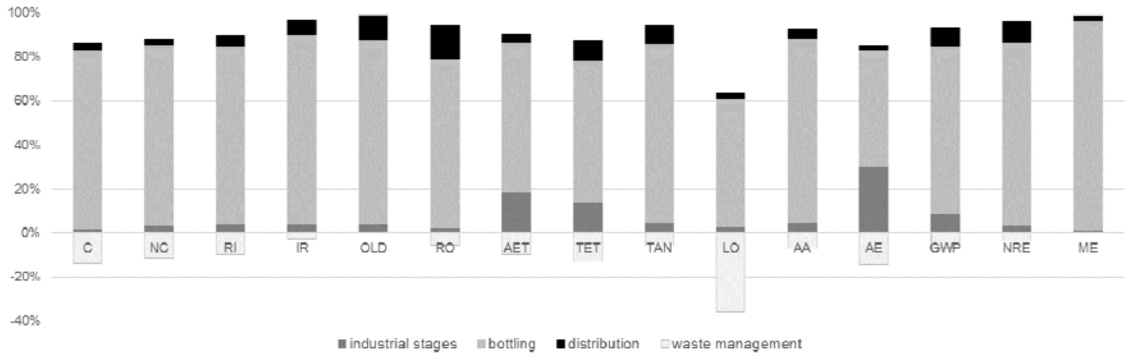

Figure 2: Relative contributions of the main stages in the beer production on the IMPACT 2002+ midpoint categories.

It is clear that the glass bottle production is the higher energy consumer in beer production cycle and, therefore, *bottling* is the stage that mainly contributes to the different emissions. Considering that the scope of the work is a comparative analysis of the emissions related to two different beers' productions, we made an in-depth study considering only the brewing operations, evaluating their contributions to all the midpoint impact categories. In Table 3, the values of the contributes of each brewing stage on all the IMPACT 2002+ categories are reported. Among the brewing phases, in the case of the ale beer, the higher contributes are due to *filtration* and *boiling and hopping* stages for the majority midpoint impact categories. *Mashing* contribute is significant only for IR, AET, GWP and ME, whereas *milling* and *fermentation* contributes are of minor importance. In the case of lager beer production, the relative importance of the phases is quite different. Also in this case, *filtration'*s contribute is the higher one, followed by *boiling and hopping* one. *Mashing* has a significant contribute on the same categories of the ale beer, but, in this case, some categories, i.e., RI, TAN, AA and NRE are quite affected by *fermentation* stage. The different contribution of *fermentation* in the case of the two beers productions is due to the different temperatures at which the two yeasts are active. In particular, in ale beers' production, *Saccharomyces Cerevisiae* is active at temperatures near the room temperature (from 16 to 23 °C) and, therefore, small quantities of energy have to be subtracted from the system to perform the fermentation. On the contrary, in lager (low fermentation) beers, *Saccharomyces Carlsbergensis* yeast is activated from 5 to 8 °C. To make a comparison on the stages that are different among the two productions, in Figure 3 the relative contributes with respect to the lager beer emissions were reported.

Table 3: Contribution to the environmental impact of the brewing stages.

	Unit	Milling	Mashing	Filtration	Boiling&hopping		Fermentation	
					Ale	Lager	Ale	Lager
C	kgC_2H_3Cleq	8.28E-06	6.98E-05	7.80E-05	8.44E-05	8.40E-05	1.22E-05	1.90E-05
NC	kgC_2H_3Cleq	9.35E-06	4.86E-05	1.17E-04	3.37E-04	2.89E-04	8.39E-06	1.63E-05
RI	kgPM2.5eq	4.65E-06	3.49E-06	6.11E-06	4.77E-06	4.63E-06	2.90E-06	7.01E-06
IR	BqC-14eq	5.59E-03	4.89E-02	4.82E-02	6.14E-02	6.12E-02	5.03E-03	9.62E-03
OLD	kgCFC-11eq	1.89E-11	9.11E-11	2.68E-10	1.14E-10	1.14E-10	1.73E-11	3.11E-11
RO	kgC_2H_4eq	2.53E-07	3.91E-07	2.19E-06	4.86E-07	4.79E-07	1.82E-07	3.74E-07
AET	kgTEGwater	1.28E-01	2.51E+00	5.88E+00	1.23E+00	1.06E+00	9.56E-02	2.09E-01
TET	kgTEG soil	3.38E-02	4.63E-02	1.33E+00	8.79E-01	7.39E-01	2.29E-02	5.19E-02
TAN	$kgSO_2eq$	8.76E-05	4.68E-05	1.73E-04	1.34E-04	1.20E-04	5.34E-05	1.30E-04
LO	m^2org.arable	4.51E-05	8.10E-05	1.38E-04	1.22E-03	1.03E-03	2.93E-05	6.76E-05
AA	$kgSO_2eq$	3.14E-05	1.85E-05	3.32E-05	3.17E-05	2.98E-05	1.95E-05	4.73E-05
AE	$kgPO_4P$-lim	8.14E-07	7.21E-07	2.89E-05	8.99E-07	8.93E-07	7.15E-07	1.44E-06
GWP	$kgCO_2eq$	5.33E-03	1.02E-02	4.02E-03	1.36E-02	1.35E-02	3.34E-03	8.09E-03
NRE	MJprimary	5.31E-02	3.21E-02	5.90E-02	3.81E-02	3.77E-02	3.38E-02	8.09E-02
ME	MJsurplus	1.83E-05	2.17E-04	1.69E-04	2.87E-04	2.86E-04	1.32E-05	1.90E-05

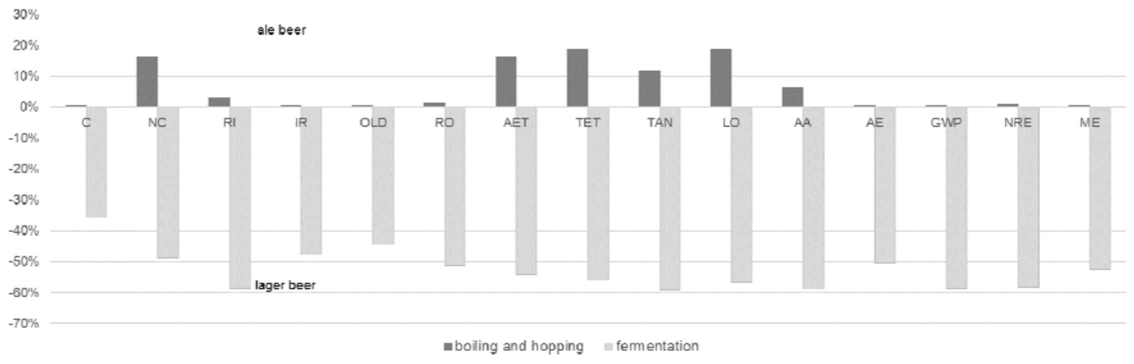

Figure 3: Relative contributions of the brewing stages on the IMPACT 2002+ midpoint categories; top (positive percentages): ale beer; bottom (negative percentages): lager beer.

Obviously only *boiling and hopping* and *fermentation* contributes (that are different among the two productions) are reported, and it is evident that, considering the *boiling and hopping* phase, ale beer's production impacts are higher than lager beer's production impacts on six midpoint categories, whereas on the remaining nine categories the values are comparable. On the contrary, considering the *fermentation* phase, lager beer's production impacts are higher than ale beer's production impacts on all the categories.

4. Conclusions

In this work, a comparative LCA analysis on an *ale* and a *lager* beer was performed, considering the industrial stages according to a "from gate to gate" and "from gate to grave" approach. The study was conducted considering seven main industrial stages, bottling, distribution and waste disposal. Given that the glass bottle production is the higher energy consumer and independently by the beer is the same, only the industrial stages were considered in the subsequent in-depth analysis. The main differences between the two productions were observed for boiling & hopping and fermentation stages; in particular, the ale beer's boiling & hopping stage's impact is slightly higher than the lager beer's one, whereas the lager beer's fermentation stage's impact is sensibly higher than the ale beer's one. In order to reduce the impact of the lager beer's production, the activation yeasts' temperatures would be as higher as possible within the limits that allow the classification of the beer as lager.

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