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State of the Art Survey of the Energy and Media Demand of German Beverage-bottling Plants

Sustainability is a megatrend in the packaging industry. Increasing costs, legal requirements and societal trends have put energy optimisation into the focus of the beverage-bottling industry. An essential requirement for profound energy optimisation is a reliable database. The study presented in this paper gathered energy and media demand data from bottling plants at the machine level, as there is a lack of scientific and publicly available data. A detailed questionnaire was provided to German bottling companies. The companies surveyed provided information characterising their bottling plants in terms of nominal speed, age and product range. They also provided data regarding production planning, information on the use of energy management systems and detailed data on machine-related power demand. With an increasing level of detail (e.g. state-based energy demand of machines) the amount of available information decreases. Data were gathered on the installed load of the machines, which could showed a linear correlation to the nominal speed of most machines. Further data for the demand of electrical energy during operation and standby and for the heat and water demand were raised. The electrical energy demand during standby has the highest value for the example of the bottling cleaning machine (median 7.5 kW for n = 10 machines). The heat demand of bottle cleaning machines was found to be 25–80 kJ/bottle. For the fresh water consumption values below 300ml/ bottle (arithmetic mean: 220 ml) where found for most machines. The survey shows that more than 80 % of the surveyed companies in the bottling industry are already investing in measures to reduce energy and media demand or plan to do so in the future. The assembled database allows a first benchmark of machines in industrial applications and serves as a reference point for the purchase of new machinery and for further research on optimisation strategies. However, the study shows that there is still insufficient knowledge of the energy demand of bottling plants. Only few companies were able to give detailed information of the energy and media demand at machine level. Further effort are still necessary to increase the database to provide representative values for the bottling industry. General demand models, unified standards for data acquisition and further research on bottling-plant energy demand are necessary to fully exploit the potential energy savings.

Descriptors: energy demand, bottling plants, machine level

1 Introduction

Climate change, resource scarcity, increasing energy costs and a rising level of environmental awareness and a sense of responsibility of consumers are increasingly influencing the beverage-bottling industry. As a result, sustainability has moved increasingly into the focus of the packaging industry [1]. For new investments, energy demand is increasingly important in the cost calculation (capital expenditure vs operational cost) and for total cost of ownership considerations. A study for the German machine supplier sector shows that energy efficiency has a growing impact on sales for machines [2]. Fundamental for optimisation considerations is a reliable database.

Filling and packaging in the beverage industry is one of the main contributors to energy demand in the entire production process with up to 30 % of the total energy and media demand [3, 4]. A number of machines interlinked by buffering transport elements are involved in this process. Beverage-bottling plants are found not only in breweries but also in other industries, such as fruit-juice production, mineral springs and spirits and wine production. The plant technology is similar, but differs in the nominal output [5]. In addition to large breweries, small- and medium-sized companies in the brewing and beverage industry are also aware of the importance of saving energy and maintaining a small ecological footprint [6, 7]. Nevertheless, industry-specific studies found that consumers feel that the brewing industry is putting too little effort into a more rational use of energy [8]. Thus, energy-saving efforts not only provide monetary benefits through reduced energy demand, but also benefit the corporate image by promoting energy efficiency

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strategies that go beyond simply fulfilling regulatory requirements, thus demonstrating environmental responsibility.

For breweries, a number of guidelines with recommendations are available, mainly regarding the production process [6, 9–12]. Case studies were made for several applications and were examined in terms of their relevance and effectiveness for the companies involved [13–16]. A comparison of the energy-demand structure and the production process can help to identify specific deficits within the plant and to initiate suitable countermeasures [17, 18].

Numerous guidelines recommend that individual companies determine their actual energy demand structure – in part using the attached data tables (e.g. ABMI media template [19]) – as a first step toward sustainable enterprise management [20, 21]. The results of comparative investigations, the so-called benchmarks, provide general values, such as water demand in [l/hl] or electricity demand in [kWh/hl] of beer to be sold. However, specific data on the energy or resource demand of company departments or individual machines are not mentioned in these templates. Until now, only a few systematic optimisation approaches have been suggested or introduced for the specific area of beverage filling to reduce the high demand. Collecting and evaluating accurate energy data will help operators, production managers and the management board of breweries to understand the relationship between energy demand and resulting costs. Guidelines recommend the use of energy Key Performance Indicators (KPIs) with monthly and yearly benchmarks. Monitoring and analysis can be the basis of corrective actions, leading to reduced energy costs and a smaller carbon footprint [9]. Concrete machine-related demand values for bottling plants, which are fundamental for the development of generic optimisation strategies, are rarely available or are not accessible to the public. Detailed knowledge of the energy and media demand behaviour of the machines is the basis for identifying optimisation routes and the development of sustainable energy-saving measures. In addition, publicly available demand values enable a classification of company-owned machines for benchmarking, thus deriving the potential need for modification of individual machines. Detailed knowledge of demand patterns can also form the basis for further simulation studies, which can reduce the risk of investing in inefficient energy-saving approaches. The field of bottling and packaging, with its high demand for electrical energy, should also be the centre of energy-optimisation efforts.

Because of the lack of concrete publicly available data for benchmarks, the aim of the present work is to summarise scientific publications and publicly available knowledge on actual demand data in the field of beverage bottling and to generate further knowledge from an industry-wide survey on energy use in beverage-filling companies.

2 Literature overview

2.1 Bottling technology: Description of study area

Beverages and liquid food are packed in industrial bottling plants. The plant structure and the machines applied depend on the packaging type (bottle, can and keg), the packaging material (glass, polyethylene terephthalate, aluminium, or steel) and packaging concept (single use, returnable). The plant design is modular, and the different requirements of beverage filling can be fulfilled by a variety of machines. According to *Manger* [22], the components of a beverage-filling line are essentially the same:

Table 1 General functionalities and machines for bottling. From Ref. [22]

	Function	Machine
Essential	depalletising	depalettiser
	depacking	depacker
	cleaning and control of overpacking (e.g. crates)	crate washer
	cleaning and control of packaging material (e.g. bottles/cans)	bottle-cleaning machine
	filling and sealing of the packaging material	filler and capper
	décor (e.g. labels) and labelling (e.g. best before date) and control of the package	labeller
	packaging into the overpackaging	packer traypacker
	palletising	palletiser
	transport	bottle conveyer palette conveyer
Additional, if required	increase of shelf life	flash pasteuriser tunnel pasteuriser
	cleaning and disinfection	CIP/SIP systems
	sorting systems for returnable containers	selective depacking machine
	machines for the production of soft drinks	beverage mixing and carbonising plants
	machines for bottle manufacturing	stretch blow moulder for PET bottles

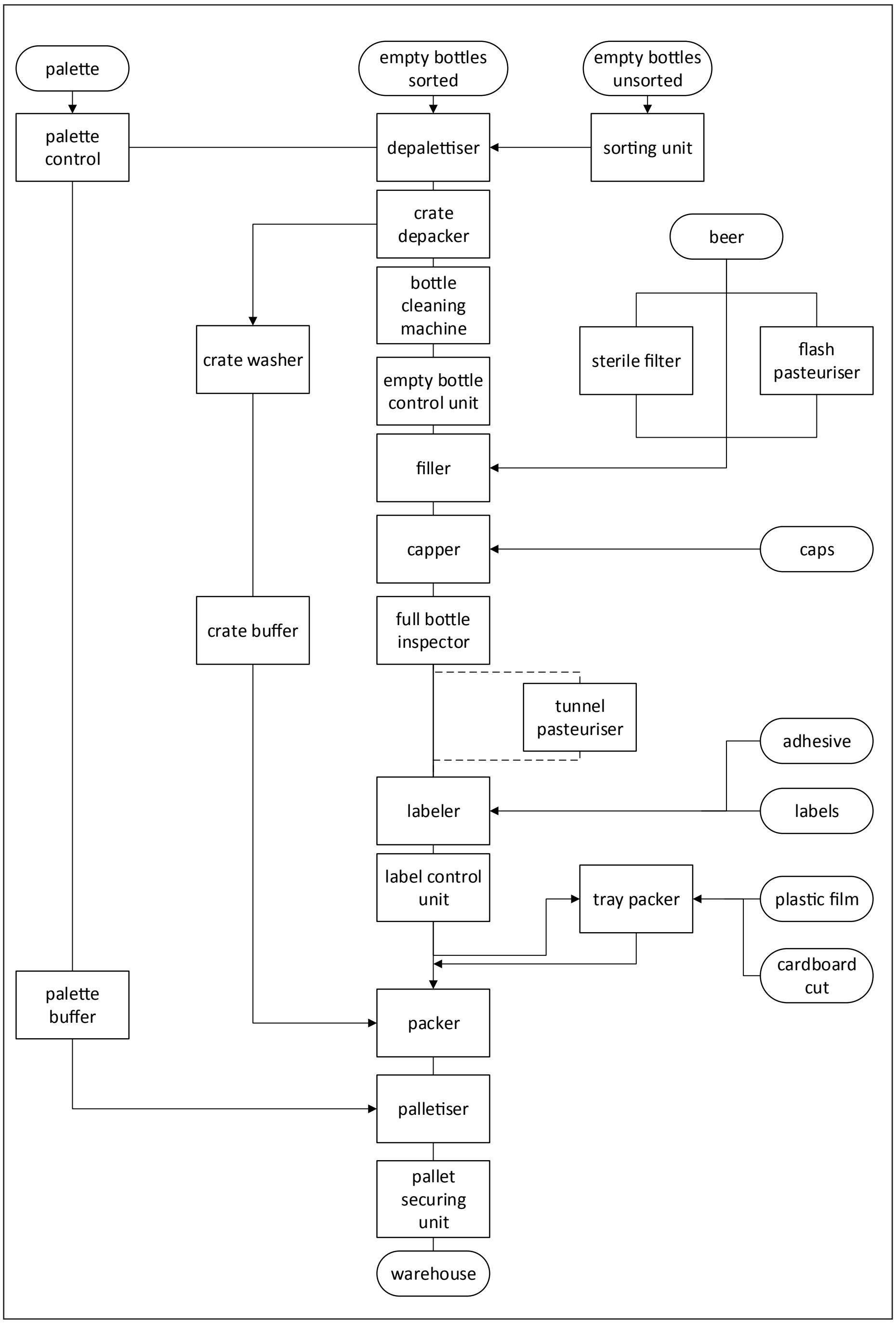

Fig. 1 Flow chart for typical beverage-bottling plant for returnable glass bottles. From Ref. [22]

The plant configuration is influenced by the product requirements, the annual output, the resulting nominal speed of the filler, the product portfolio, the number of bottling plants available in the plant, any spatial conditions and production planning. The machines are laid out according to the nominal machine speed of the lead machine (usually the filler). With buffering conveyers between the upstream and downstream, machines are oversized in terms of machine speed to compensate for downtimes in the up- and downstreaming process and thus keep the lead machine running efficiently (compare to the V-diagram according to *Berg* [23]). The machinery used in breweries is similar to that used for bottling mineral water and soft drinks. Figure 1 shows a flow chart for the process of filling returnable glass bottles.

2.2 Data for characterising energy and media demand of bottling plants

Running a bottling plant requires different types of energy that are clustered into two main forms: electrical power and heat. Most approaches in breweries also deal with water, which is the main media demand. All machines used for bottling require electrical energy. The electrical energy is basically used to drive the machines that perform the basic mechanical functions, for moving the containers through the machine, for driving pumps (e.g. for the filled product or media) and for producing compressed air. Thermal energy is usually needed for heating various media (e.g. cleaning lye) and is mainly used in the cleaning machines (bottle-cleaning machines and crate washers) and pasteurisers (flash and tunnel type). Compressed air is used for beverage filling either as an energy carrier (e.g. stretch blow moulding of PET bottles, transport of empty PET bottles) or for signal transmission (pusher) or cleaning (blow-off, drying). Compressed air is a comparatively energy-intensive energy carrier and can be linked back to demand of electrical power of the compressor (kWh/m^3). Fresh water is used for cleaning the machines and in the bottle-cleaning machine (fresh water spray is used in the final step of cleaning the returnable bottles). Other media, such as lye, belt lubricants and additives, are mainly used in the bottle-cleaning machine and during container transport. The main energy consumers for bottling plants for non-returnable bottles are thus the stretch blow moulder (PET) and the bottle-cleaning machines (glass).

Established energy KPIs for the bottling process are often related to a defined quantity of the product:

$$\text{Specific energy demand} = \frac{\text{Total amount of energy used}}{\text{Total amount of product produced}} \quad \text{(Eq.1)}$$

Other common energy KPIs are related to hectolitres of the corresponding product (see Table 2).

The following standards give information and recommendations on the energy demand of bottling machines:

- **DIN 8784** stipulates minimum and order related specifications for beverage-filling lines, including the installed load of the machines and machine-specific information (e.g. ml/bottle water) [24]:
  - installed load of all machines [kW];
  - machine-specific: process parameter (e.g. times, tempera-

Table 2 Main energy and media types in bottling plants and common metrics

Electrical power	Heat	Media
electrical power	steam	hot water
compressed air	fuel (gas/oil)	cold water
cooling	heating media (e.g. water)	treated water
kW installed load	kJ/bottle	ml/bottle
kWh/week	kJ/h	m^3/h
kWh/hl	MJ/week	m^3/week
kWh	MJ/hl	l/l; l/hl
Nm^3/h	kg/week (e.g. steam)	
Nm^3/week and kWh/Nm^3	l/l	

tures), specific electrical demand [kJ/bottle], compressed air/sterile air [m^3/h], gas demand (CO_2 or N_2) [kg/h], heat demand [kJ/bottle] or [MJ/h], steam [kg/h], specific data for heating processes.

- **Association of the Beverage Machinery Industry** (ABMI): **Sustainability Templates** [19, 25]: Recommendations for the communication of environmental performance of packaging lines between machinery suppliers and operating or beverage companies including an online availably template:
  - scope of supply;
  - general conditions and boundary conditions;
  - sheet for data input and calculations;
  - ecological summary: values for heat, water and electricity summarised for reference parameter: per week/per container/per litre of beverage.

No numerical values are given by the ABMI recommendations or the DIN 8784.

2.3 Publicly available energy data and energy data in scientific literature

Over the last years, some industry associations have published demand values and benchmarks, mainly recorded by consulting companies. The data are related to total production processes or single process areas (e.g. packaging). Most data are published for thermal and electrical energy. The data are mainly in relation to a product volume (e.g. one hectolitre of beer to be sold). In contrast to breweries, for manufacturers of nonalcoholic beverages, few demand data are publicly available. Energy costs for a brewery vary worldwide between 3 % to 10 % of the total budget [3, 10, 12]. In the last ten years the volume of water required to produce one hectolitre of beer decreased from 5–5.2 hl/hl to 4.2–4.3 hl/hl [10, 18, 18, 26, 27]. According to the published data the energy required to produce a hectolitre beer is 21.6–90 MJ/hl (electrical power) and 100.8–141.12 MJ (thermal power) or 116.8–271 MJ/hl (total demand) [10, 28]. Thermal energy accounts for an average of 70 % of the total energy demand in a brewery, yet results in only 30 % of the energy costs. Therefore, priority should be given to efforts to reduce the electrical energy demand because it represents the greatest potential savings. Data from the U.S. Environmental Protection Agency show that refrigeration, packaging and compressed air consume 70 % of a breweries' electrical energy [9]. Bottling accounts for 16.5 %–30 % of the heat and 12 %–35 % of the electrical power [4, 12, 23, 29].

Schreiner published detailed machine-related energy parameters for bottling plants connected with a cogeneration approach in the early 1980s [5]. He published detailed machine-related data for the installed load in [kW] and the thermal energy ([kW] and [MJ/h]) required by machines with variable nominal output (from 20,000 up to 100,000 bottles/h).

To summarise the available literature, it can be said that no reliable detailed demand data on machine level are available for industrial bottling. Table 3 (see page 90) shows selected energy and media demand values for breweries to put the energy and media demand in bottling into perspective. The data available are mostly related to processes (e.g., packaging) as opposed to machines. The data available from Schreiner are no longer state of the art and consider a limited number of machines. With regard to the optimisation approaches mentioned, a publicly accessible database and detailed measurements in the plants are essential to assess the actual situation and to plan optimisation approaches.

3 Data acquisition

Data acquisition was done by a questionnaire that was designed according to the scientific principles of quantitative-empirical data collection. It contained 25 questions that were customised for every machine type. There are grouped as follows:

- General questions about the company:
  - brewery, mineral springs, or fruit-juice production;
  - number of bottling plants;
  - packaging material, type and size;
  - equipment.
- Detailed information about the most frequently used bottling plant:
  - type of manufacturer;
  - year of construction;
  - nominal speed [bottles/h] or [crates/h];
  - installed load [kW];
  - electrical power demand during operating [kW];
  - electrical power demand during standby [kW];
  - specific energy demand [kJ/bottle];

Table 3 Selected energy data publicly available and published in scientific literature

	Country	Sample size	Value	Unit	Year	Source
share of energy cost on total costs	Canada	n.a.	3–8	%	2011	[10]
	USA	n.a.	3–8	%	2003	[12]
	Germany	n.a.	10	%	2003	[3]
	n.a.	n.a.	30	%	2015	[30]
share of thermal power for bottling	USA	n.a.	20–30	%	2003	[12]
	UK	n.a.	20–30	%	2000	[31]
	Germany	4 breweries	20	%	2001	[29]
	Austria	14 breweries	25	%	2000	[4]
	n.a.	n.a.	16.5–25.7	%	1993	[23]
share of electrical power for bottling	USA	n.a.	15–35	%	2003	[12]
	UK	n.a.	15–35	%	2000	[31]
	Germany	4 breweries	15	%	2001	[29]
	Austria	14 breweries	18	%	2000	[4]
	n.a.	n.a.	12	%	1993	[23]
	USA	n.a.	25	%	2013	[9]
heat demand for bottling	Germany	n.a.	16–26	kWh/hl	2002	[32]
water demand for bottling	n.a.	n.a.	0.06–0.16	m³/hl	2002/ 2012	[33]
water demand for a specific amount of beer	Europe	n.a.	4.2	hl/hl	2012	[26]
	worldwide	225 breweries	4.3	hl/hl	2012	[18]
	Canada	n.a.	5	hl/hl	2011	[10]
	worldwide	143 breweries	5.2	hl/hl	2008	[18]
	Europe	n.a.	4–10	hl/hl	2006	[32]
	Finnland	1 brewery	3	hl/hl	2003	[32]
	Germany	n.a.	3.7–4.7	hl/hl	2002	[32]
	UK	n.a.	5	hl/hl	2006	[27]
	Portugal	n.a	4.9	hl/hl	2005	[33]
	n.a.	n.a.	2.5–4.5	hl/hl	1993	[23]
electrical power demand for a specific amount of beer	Canada	n.a.	42	kWh/hl	2011	[10]
	Latvia	1 (SME)	22,5–25	kWh/hl	2016	[34]
	Austria	13	6.2–35.1	kWh/hl	2010	[28]
	Germany	n.a.	7.5–11.5	kWh/hl	2002	[32]
	Europe	n.a.	8.9–13.7	kWh/hl	2008	[6]
	Portugal	n.a.	12.7	kWh/hl	2005	[33]
	n.a.	n.a.	8–12	kWh/hl	2012	[33]
	Germany	n.a.	39	kWh/hl	2010	[28]
	n.a.	n.a.	42	kWh/hl	2012	[33]
	USA	n.a.	19–35	kWh/hl	2013	[9]
	Austria	n.a.	39	kWh/hl	2010	[28]
thermal power demand for a specific amount of beer	Portugal	n.a.	110	M//hl	2005	[33]
	Canada	n.a.	28.8–43.2	MJ/hl	2011	[10]
	Latvia	1 (SME)	219–231	MJ/hl	2016	[34]
	Germany	n.a.	28.6–54	MJ/hl	2010	[28]
	Europe	n.a.	85–118	MJ/hl	2008	[6]
	Austria	1 brewery	39.6	MJ/hl	2010	[28]
	Austria	n.a.	21.6–90	MJ/hl	2010	[28]
	Austria	n.a.	46.08	MJ/hl	2010	[20, 28]
total energy demand for a specific amount of beer	Europe	n.a.	116.8	MJ/hl	2012	[26]
	worldwide	225 breweries	207	MJ/hl	2012	[18]
	worldwide	143 breweries	229	MJ/hl	2008	[18]
	UK	n.a.	161	MJ/hl	2006	[27]
	worldwide	158 breweries	239	MJ/hl	2004	[18]
	worldwide	86 breweries	271	MJ/hl	2000	[18]

- heat (machine specific) [kJ/h];
- water demand (machine specific) [m³/h];
- pressured air demand (machine specific) [m³/h];
- gas demand (machine specific) (CO_2) [m³/h].

- Energy management and optimisation efforts:
  - energy manager/energy management system/DIN ISO 50001;
  - share of energy cost on total production costs;
  - realised energy-optimisation strategies;
  - planed energy-optimisation strategies.

- Data regarding production planning:
  - number of filling days;
  - number of grade chances per week;
  - number of cleaning units per week;
  - detailed information about cleaning (type, duration and energy demand).

The machines and the machine-specific parts of the questions were selected according to DIN 8784 [35]. Single parts of the questions were customised for every machine type (e.g. water and heat demand for cleaning machines). The respondents of the questionnaire could choose between different types of bottling lines (PET, glass, returnable, non-returnable) to increase usability. All information was provided voluntarily, and single questions could be omitted. Before publication, the questions were validated by a number of selected companies in a pretest. The survey was available online for 1 year and >550 bottling companies were informed by letter with a written version of the survey. The questions were detailed, leading to an average editing time of >30 minutes. 33 questionnaires were completed to a degree of 15%–95%, representing approximately 2% of the German beverage-bottling industry.

The results of the survey are mainly presented as boxplot diagrams, as recommended in the literature for group studies [36]. The data are presented in quartiles. Each quartile includes 25% of the values. For example, the third quartile includes the values of the total nominations that fall between 50% to 75% of the maximum. The centre of the boxplot is the median. In contrast with the arithmetic average, the median is not located at the geometric centre of the boxplot but indicates where half of the values have already been mentioned (see schematic drawing in Figure 2).

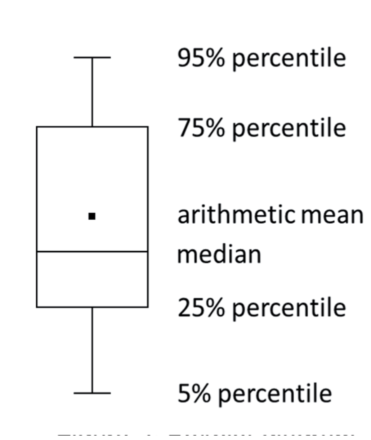

Fig. 2 Boxplot diagram

4 Results

4.1 Characterisation of participants

All companies provided data for their most frequently used bottling line. Not every question was answered by every company. All companies who entered details for this study use returnable glass bottles, which is characteristic for the German beverage market. Some companies additionally are producing cans (number of companies n = 9) or non-returnable glass bottles (n = 8), PET bottles (n = 6, n = 4 for single use, n = 2 for returnable bottles), or kegs (n = 7). The collected energy and media data were related to returnable glass bottles. The annual output of the companies was between 700 hl/a and 1,900,000 hl/a. The machine speeds varied from 2,200 to 72,000 bottles/h and 300 to 4,000 crates/h. All companies surveyed provided general data for the filling machine (n = 33) of their bottling plant, most of them for bottle-cleaning machines (n = 31), packers (n = 30) and depackers (n = 31) and crate washers (n = 30), some for palletisers (n = 26), labelers (n = 25), depalettisers (n = 21), pasteurisers (n = 14) and a few for tray packers (n = 7) or stretch blow moulders (n = 1). The machines were mainly younger than 15 years (see Figure 4 at page 92).

In this survey, the median nominal speed for the lead machine filler is 28 000 bottles/h (see Figure 5 at page 92). Questions concerning the detailed demand behaviour of the machines were answered by a smaller number of companies. With increasing level of detail, the number of answers decreased (see Figure 3 at page 91). Although an average of over 50% of the companies gave information about the installed load of single machines, only one third of them made an entry in the field of the electrical power demand in operating time and only 25% for standby times.

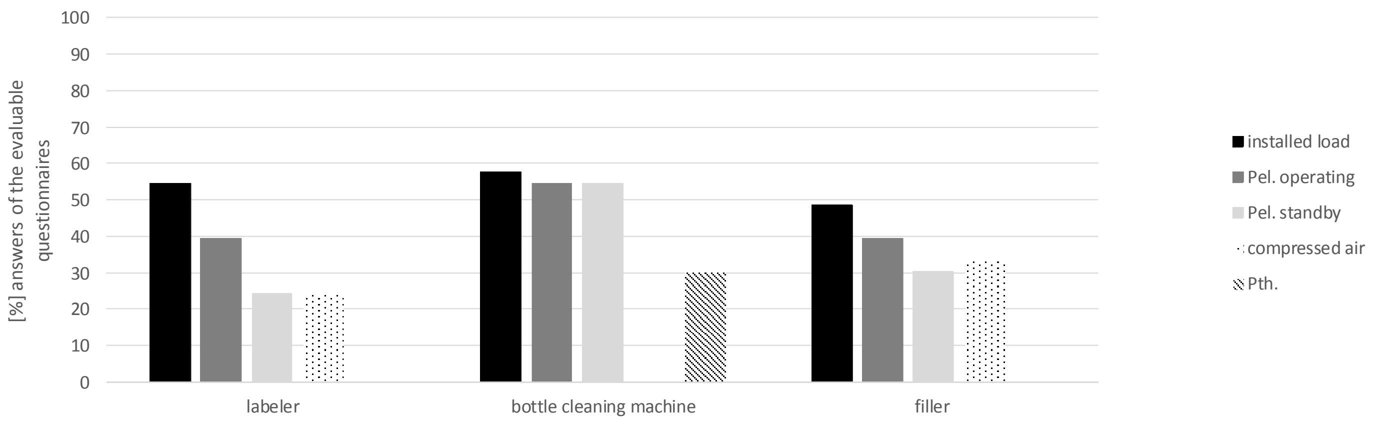

Fig. 3 Percent of detailed answers regarding detailed energy and media demand of machines

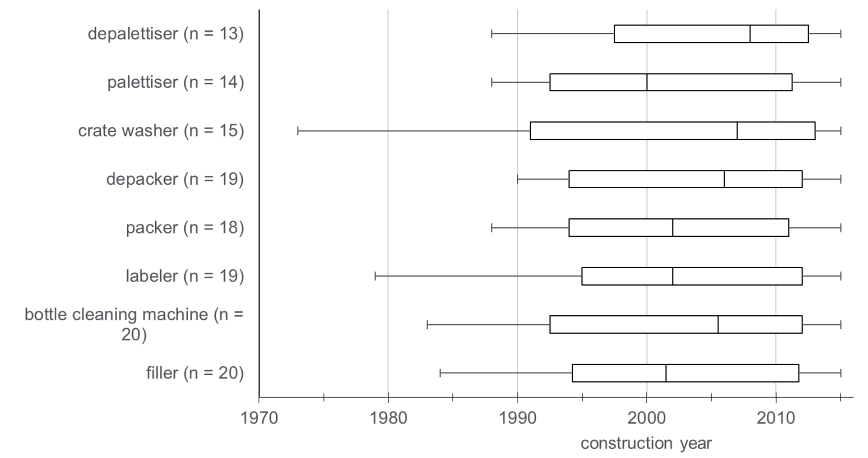

Fig. 4 Characterisation of participants: Boxplot diagram of machine age: approximately 75% of answers included the year of construction of the machine

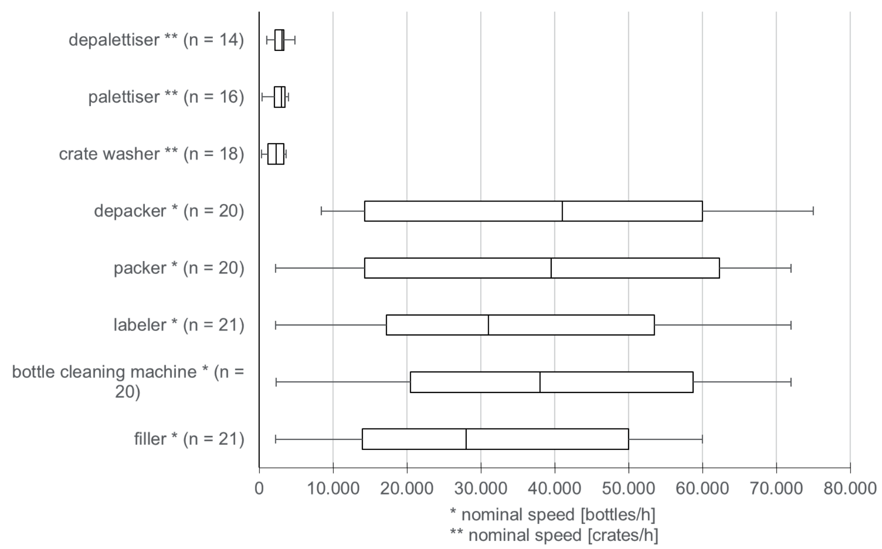

Fig. 5 Characterisation of participants: Boxplot diagram of nominal speed of machines

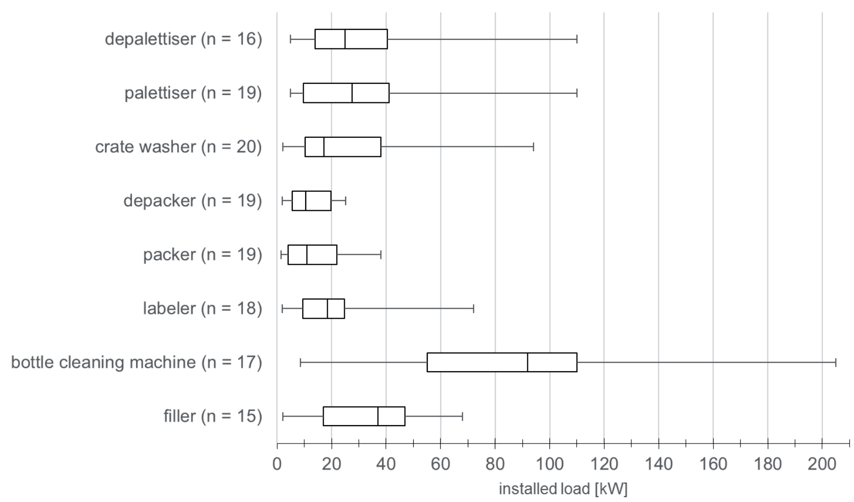

Fig. 6 Installed load on machine level

4.2 Installed load and electrical energy demand at machine level

The installed load of the individual machines is usually known because it is stated in the machine specification. Nevertheless, only half of the participants provided information on this topic. Figure 6 shows the installed load for individual machines. More than 50 % of the participants specified a value for the installed load of the individual machines. The bottle-cleaning machines have the highest installed load, followed by the fillers, the palettising machines and the crate washers. A wide range of values were returned for the bottle-cleaning machines. Figure 7 shows the correlation between the nominal speed of the machines and the installed load of the machines for the example of a labeler, a filler and a bottle-cleaning machine. The installed load increases with increasing machine speed. The plots show a linear correlation between machine speed and installed load.

Only limited data were provided for pasteurisation machines. Machines with a nominal speed of 3,200–5,000 bottles/h have an installed load of 25–120 kW. The demand during operating is 42–97 kW. A single value of 57 kW was specified for standby (approximately 60 % of the demand during operation). No pertinent information was collected for stretch blow moulders or mixers.

Figure 8 shows the data for the electrical energy demand at the machine level during operating. The bottle-cleaning machine has the highest electrical energy demand. The order of the other machines is consistent with the data for the installed load. The values for the bottle-cleaning machine, the filler and the labeler for demand during operation range from 18 % to 98 % of the installed load (average is 57 %).

Figure 9 (see page 94) shows the correlation for the electrical power demand during operating and the nominal machine speed. Beside the crate washers, that show a clear trend to an increasing electrical energy demand with increasing machine speed but a poor linear fit ($R^2 = 0.28$), for the other main consumer a linear correlation between the electrical energy demand and the nominal machine speed was found (see Figure 9 at page 94).

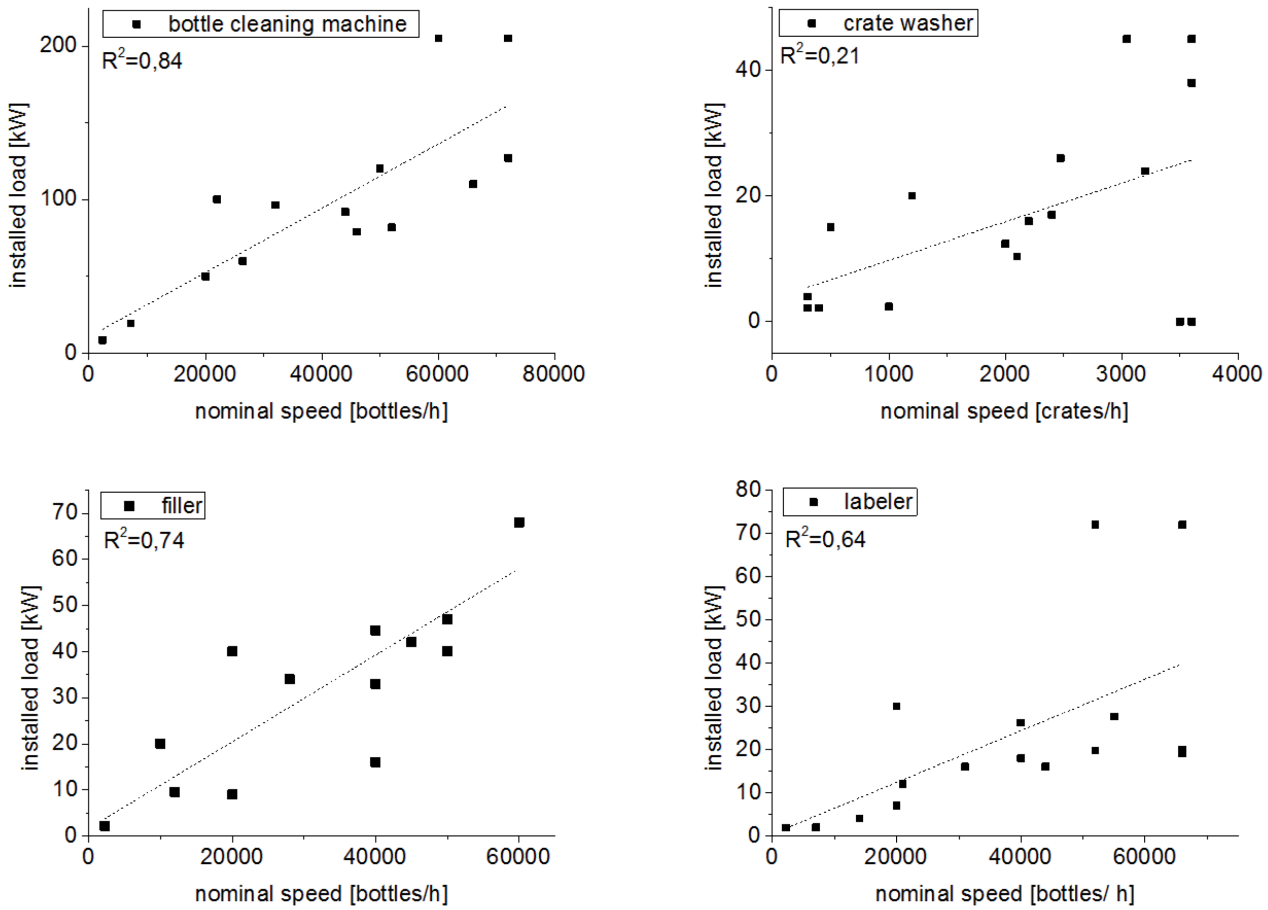

Fig. 7 Correlation between nominal machine speed and installed load

The electrical power demand during standby is shown in Figure 10 (see page 94). The demand of the bottle-cleaning machine ranges from 1 % to 78 % (mean: 34 %) of the demand during operation. For the filler the analogous range is 1 %–74 % (mean: 21 %) and for the labeler it is 3 %–70 % (mean: 29 %). For the bottle-cleaning machine, the standby values exceed the values during operation of most of the other machines mentioned.

Figure 11 (see page 95) shows the demand during standby for the four main consumers. No linear correlation between the machine speed and the energy demand was found for the considered machines (bottle cleaning machine, labeler, crate washer, filler). The figures for all machines show a trend to an increased demand in dependence to an increasing machine speed. The enlarged sample size might bring more information here.

4.3 Heat and media demand at machine level

Concerning the media demand, one third of the companies provided information on the demand of compressed air (see Figure 12 at page 95). The values for the labeler and the filler are widely distributed. For the labeler no direct linear correlation appeared between machine speed and demand of compressed air, but there is a tendency that machines with a higher nominal speed consume more compressed air (all demands > 50 m^3/h caused by machines with a nominal speed above 45,000 bottles/h).

Furthermore, data were collected for heat demand of the bottle-cleaning machine and for fresh water demand for the bottle-cleaning

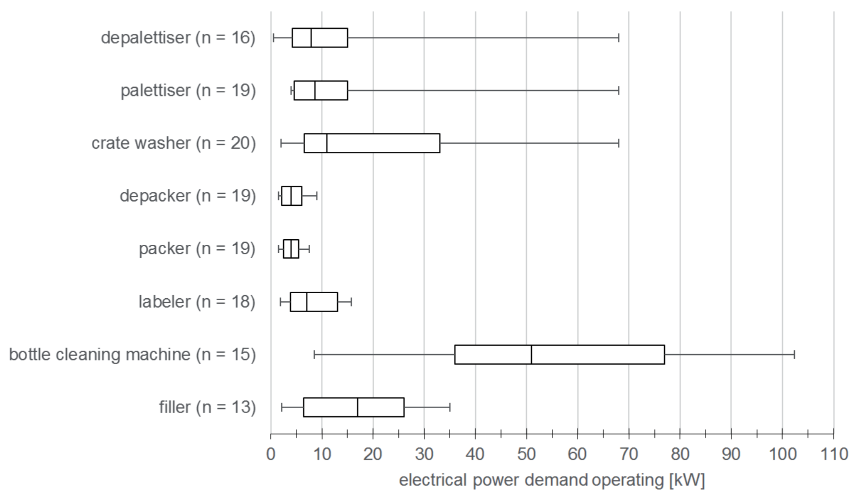

Fig. 8 Electrical power demand during operation

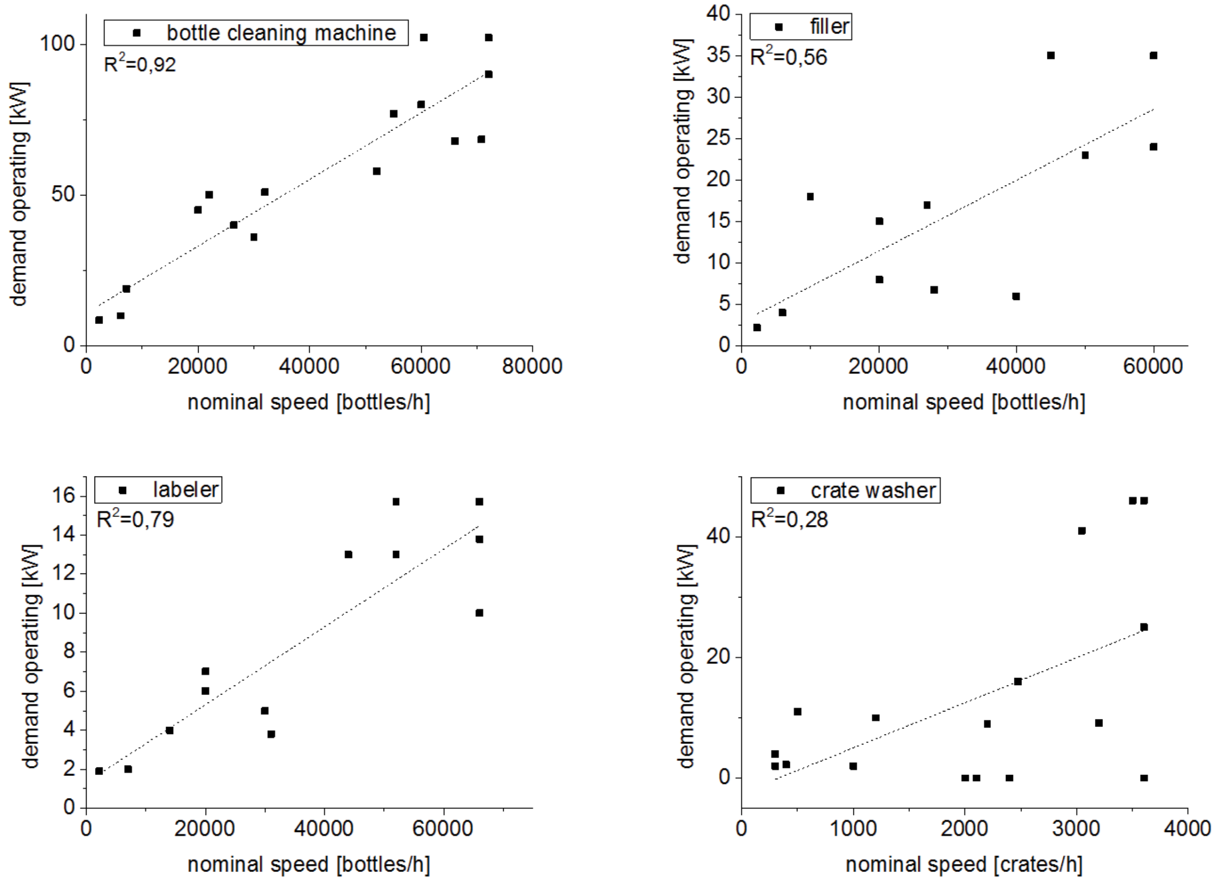

Fig. 9: Power demand during operating depending on the nominal speed of the machines for the main consumer, linear regression and coefficients of determination R^2

machine and the crate washer (see Figure 13 at page 96). All data were collected for the bottle size of 0.5l.

Less than 30 % of the companies provided data for heat demand of the bottle-cleaning machine. 75 % of the data fall between 25–80 kJ/bottle. No pertinent data were available for heat demand of the crate washer.

40 % of the companies listed fresh water demand of the bottle-cleaning machine between 140 and 900 ml. The values are spread evenly over the nominal speed of the machines and the age of the machines, except for the highest value, which is related to a machine from the early 1980s with a significantly low machine speed. The water demand of the crate washer is not specified related to single crates but in [m³/h]. Figure 14 (see page 96) shows the fresh water demand for the example of the bottle cleaning machine related to the nominal speed and the year of construction. The fresh water demand for this data is not correlated to the construction year nor the nominal speed of the machines. For the linear regression a poor fit was found for both variables (nominal speed: $R^2 = 0.12$; machine age $R^2 = 0.05$, see Figure 14). For the machine age a trend to a slightly degreasing consumption during the years was found. Therefore a Q-Q-plot was made to consider the probability of the data. The values follow a nominal probability (not considering the single highest value).

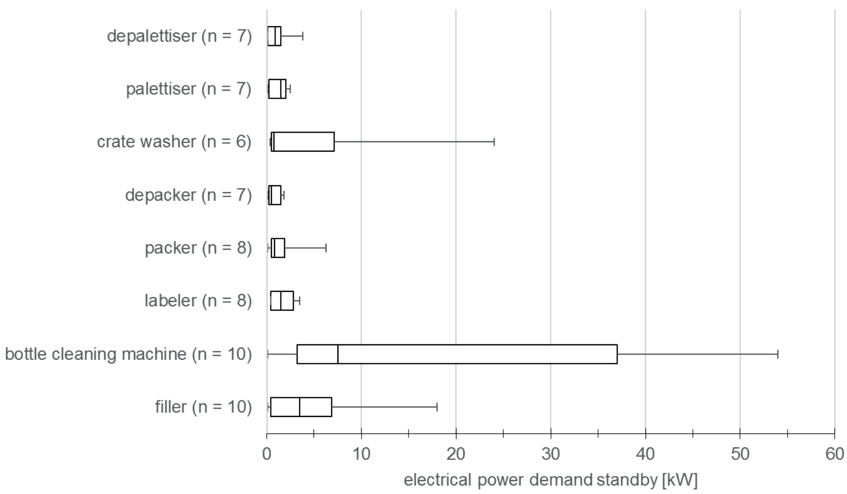

Fig. 10 Electrical power demand during standby.

4.4 Production planning and maintenance

Cleaning and maintenance are periodic processes that consume additional energy. No information about energy demand during cleaning and maintenance was found in the literature. The number of cleaning and maintenance steps is related to technological parameters and to production planning

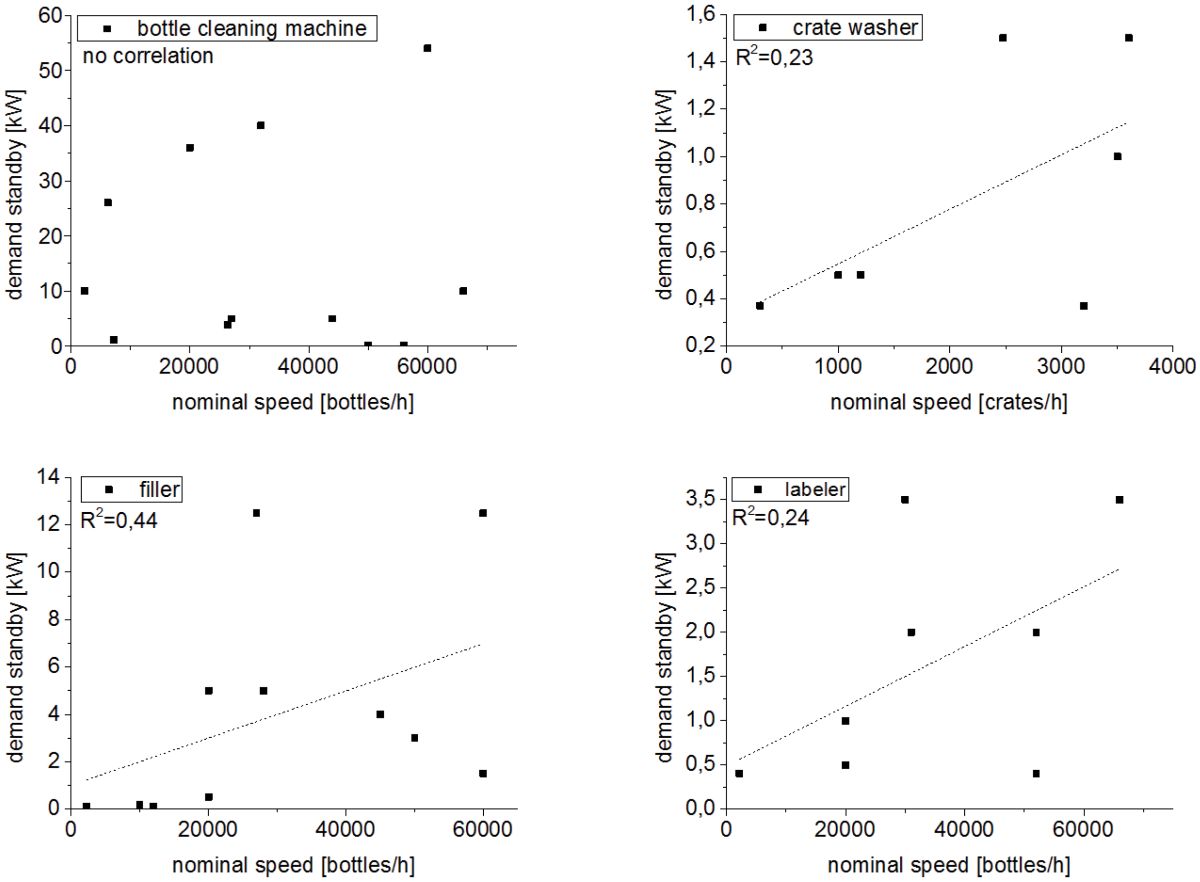

Fig. 11 Power demand during standby depending on the nominal speed of the machines for the main consumer, linear regression and coefficients of determination R^2

issues (i.e. number of articles per week). Therefore, data were collected specifying the product range and the production plans for a week. Figure 15 shows the product variety and the proportion of products filled within one production week. For breweries, this study finds a product range between 1 and 85 articles (median is 15 articles). For companies producing mineral water and juice, between 6 and 400 articles (median is 100 articles) were found.

No reliable data regarding the number of cleaning processes per week or the energy demand of single cleaning steps could be obtained from the questionnaires. Data relating to the duration of cleaning processes are summarised in figure 16 (see page 97). The data for external cleaning are widely spread because line structures and cleaning standards differ.

4.5 Energy management and present and future optimisation strategies

Of the surveyed companies, 50 % employ an energy manager, and 70 % run an energy management system. Approximately 40 % are certified according to ISO 50001. The year of the certification is predominantly (> 90 %) after 2012. More than 50 % were certified in 2014. Approximately half of the responses regarding energy cost as a share of total production cost is 0 % to 20 % (see Figure 17). More than 80 % of the respondents said they are already investing in energy-optimisation strategies, and over 80 % are planning to invest in energy-saving measures in the future. The companies provided information about current and future optimisation strategies for their bottling plants. The answers could be categorised to the following topics:

- Holistic thinking in cycles:
  - heat recovery (mainly bottle-cleaning machine and crate washer, cogeneration unit, product heating);
  - installation of heat exchanger.
- Replacement of equipment (investment in new machines and technology):

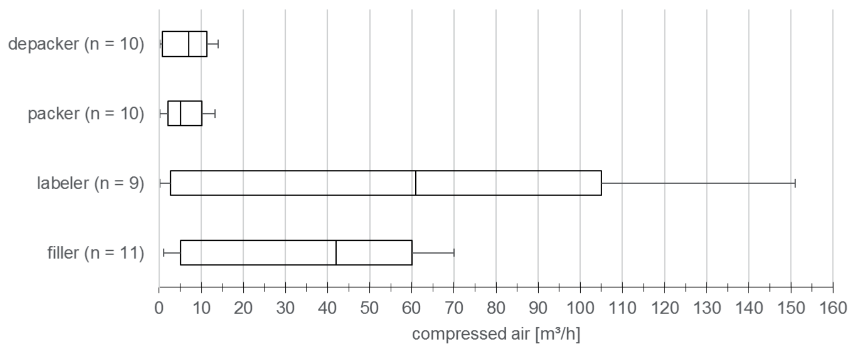

Fig. 12 Compressed-air demand

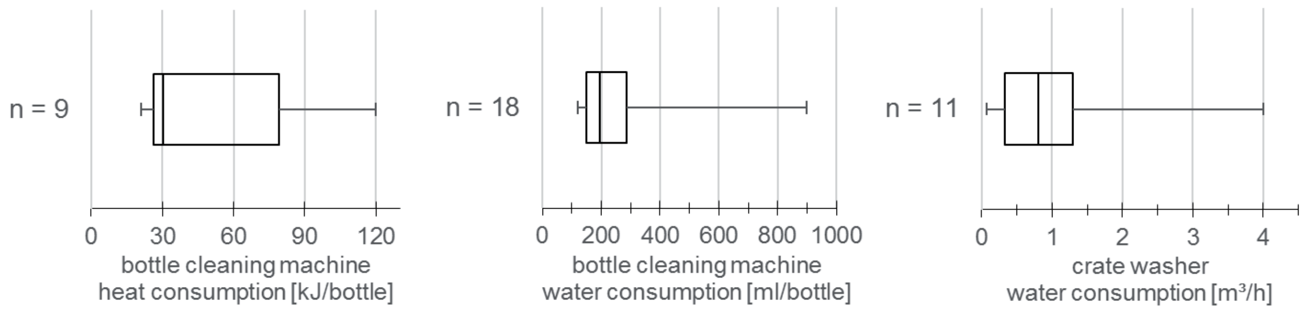

Fig. 13 Heat and fresh water demand of bottle-cleaning machines and crate washer

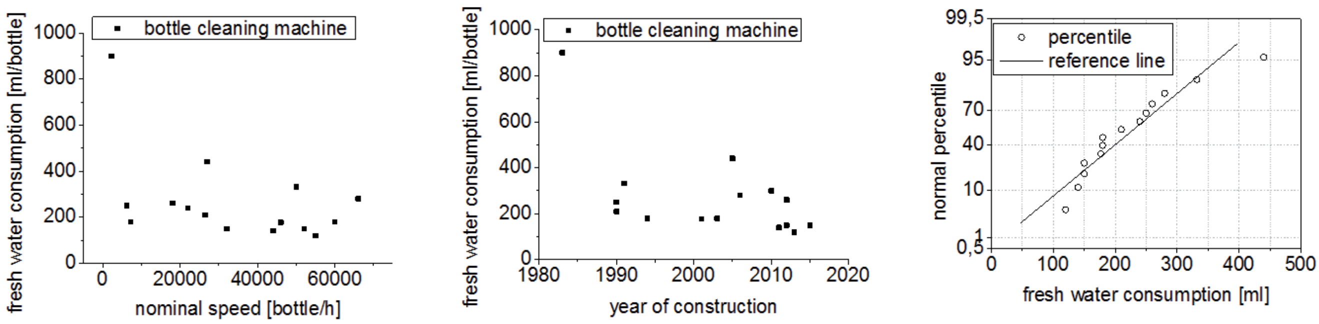

Fig. 14 Fresh water consumption of the bottle cleaning machine related to nominal speed and construction year and Q-Q-plot for normal probability without the single value of 900ml/bottle (µ = 222.07; Sigma = 87.14)

- general replacement of machines and equipment (filler, bottle-cleaning machines);
- replacement of parts: mainly pumps and electric drives and controls (frequency converter, permanent magnet motors).

- Optimisation of existing equipment and processes:
  - compressed-air supply, leakage management;
  - water and chemical demand (e.g. clocked fresh water spraying for the bottle-cleaning machine);
  - improved insulation of machine parts and pipes and valves;
  - temperature reduction lye at the bottle-cleaning machine.

- Structural measures:
  - data acquisition;
  - production planning;
  - reduction of short term downtimes.
- Building technology:
  - modern lighting (LED).

- Use of renewable energy:
  - photovoltaics;
  - solar thermal energy.

5 Discussion

This study provides information on energy and media demand for bottling plants at the machine level and further information about energy management systems and optimisation considerations. For most questions a limited number of reliable data were collected. The quantity of the collected data must be reviewed critically in terms of further statistical analysis and general statement regarding the demand of bottling machines. This is due to the limited sample size compared to the total numbers of German beverage bottling companies. The data show interesting trends and a demand for more detailed, validated data as a basis for future optimisation considerations.

The values for installed load (electrical power) are usually provided in the specification documents. The low response rate for this question may indicate that the values are not known by the production manager. A gap exists between the installed load and demand during operation times due to peak load demand. Based

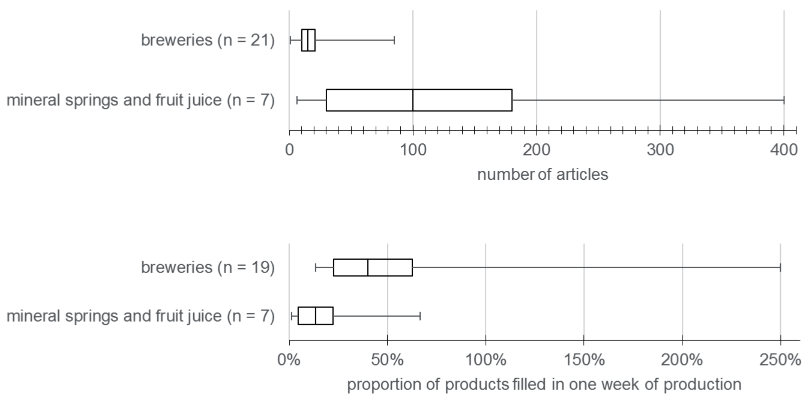

Fig. 15 Ratio of number of total products to products filled in one week of production

on the available data, no conclusion can be drawn about whether the machines have a higher installed load than needed. Data from figure 7 indicates that a linear correlation exists for most machines between the nominal speed of the machines and their installed load. For the bottle cleaning machine a linear correlation was found between the nominal machine speed and the electrical energy demand during operating and standby times. For all these machines beside the crate washer a linear correlation was found for the electrical energy demand during operating and the nominal machine speed. No correlation was found between the nominal machine speed and the electrical energy demand standby times for the labeler, the crate washer and the filler. The missing linear correlation might indicate optimisation potentials due to different shut down strategies. As the sample size for the standby demand is small, there should be further investigations on the energy consumption behaviour during standby times to find saving potentials.

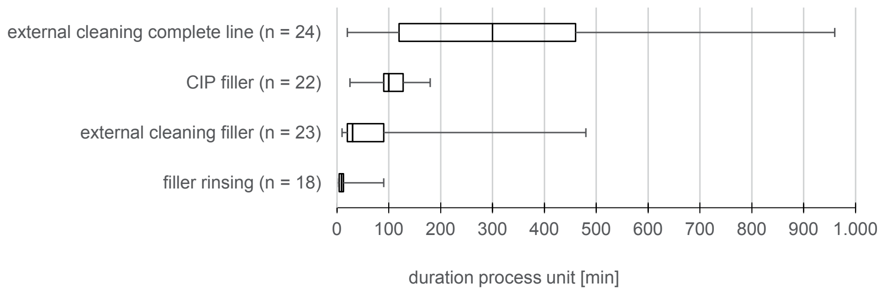

Fig. 16 Duration of various cleaning processes

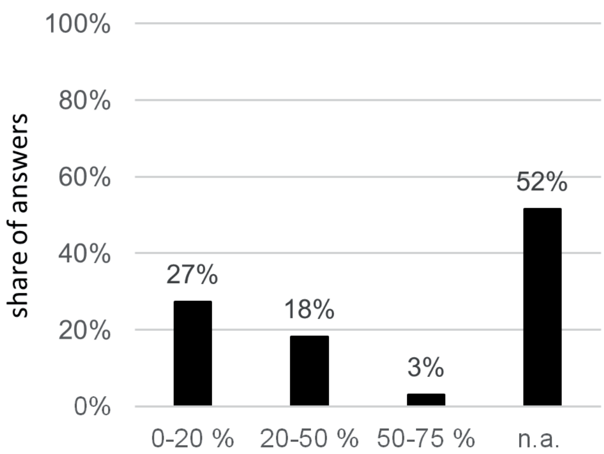

Fig. 17 Share of energy costs on total costs of production

Figure 18 compares the few data published in the 1980s with the data from the present study. Most data for installed load are in the same range. The data indicate a shift toward a higher installed load, which may be caused by the increased degree of automation since the 1980s.

Data for fresh water demand were provided for bottle-cleaning machines and crate washers. The highest fresh water demand of 900 ml/bottle for a bottle-cleaning machine was from a machine from the early 1980s with a low nominal output. Based on the data a water demand below 300 ml/bottle is state of the art today. The arithmetic average of the data (excluding the single highest demand 900 ml/bottle) is 220 ml/bottle. Four participants specified a fresh water demand significantly above average. It is expected that there is a number of bottling plants remaining with water demand significantly greater than the state of the art. No correlation was found between the fresh water consumption and the machine age or the nominal speed of the machines. It can be assumed, that the fresh water consumption of the older machines might be optimised in the last years resulting in fresh water consumptions camparable to modern machines. The data provided for crate washers are expressed in [m³/h]. The drawback of this approach is that no possibility exists to draw conclusions on production-related actions that might indicate potential improvements. Few data were provided for heat demand of bottle-cleaning machines. A value of 25–80 kJ/bottle was indicated for 50 % of the machines. No data were available for the heat demand of the crate washer. Modern crate washers are often interlinked with bottle-cleaning machines to reuse the heat.

The data concerning the production planning and the product variety show that several product changes occur per week, resulting in cleaning and change-over processes, which also require energy and media. Therefore, energy demand of the resulting cleaning and change-over processes should be considered for the specific and total energy consideration. No participant gave detailed information about energy demand for the different cleaning units. Although product availability is prioritised, demand should be traced back

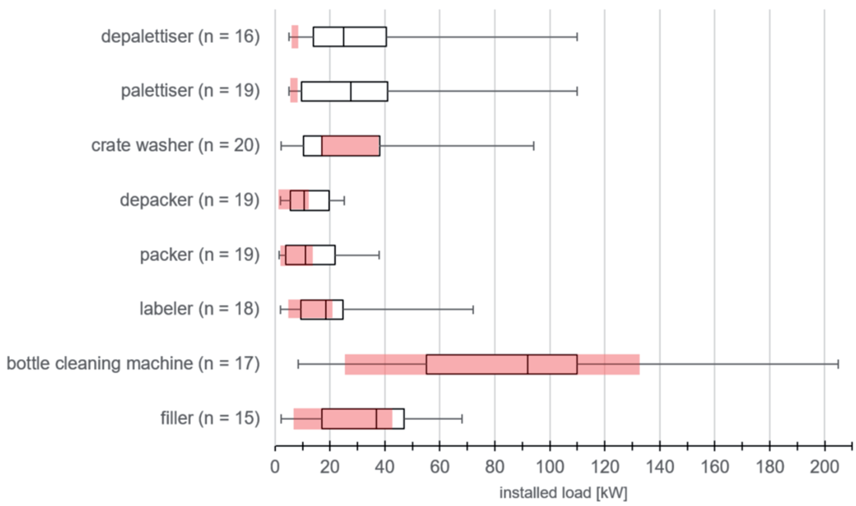

Fig. 18 Comparison of results of present study with publish data [5] for installed load of bottling machines. The values for installed load the bottle cleaning machines published by Zimmermann [37] are between 11–24 KW for a low nominal speed of the machines (4000–6600 bottles/h) and not include in this figure

to the source to include energy and performance considerations into production planning. While specific product-related energy performance indicators (e.g. kW/bottle) are suitable for economic considerations, a cause-related approach (e.g. operation-state-based demand) would give more information for optimisation approaches.

Several energy-optimisation approaches are already implemented or planned for industrial applications, as discussed in section 4.5. Given more detailed energy data, it is believed that even more energy savings can be identified.

The focus of this study is on the machine level. Conveyer technology was not included because of its variable structure and to keep the number of questions to a minimum. For future considerations, data for the demand of the conveyer systems would be of interest because several electrical drives (often more than 100) are used for bottle, crate and palette transport.

Although the survey was sent to numerous German bottling companies, the response rate was low due to the high effort of filling out the questionnaire. Furthermore, relatively few companies provided data for the requested level of detail. Nevertheless the data are interesting indicators for energy demands on machine level, showing that detailed measurements might help to identify energy saving potentials. Only a few answers were given to questions concerning the detailed machine demand structure. It is expected that only few companies already measure energy data at this high level of detail. Furthermore, no industry-accepted definition for standby demand exists at the moment. With further knowledge of the production plan, machine efficiency and utilisation factor operational state related energy consumption values can be used for calculation of specific energy waste or specific energy costs. Significant feedback from production managers regarding this question indicted an interest in this type of consideration as a method to identify optimisation potential and to reduce life cycle costs. The available data collected in this study show that the electrical power demand during standby for bottle-cleaning machines are high and exceed the demand of most other machines during operation.

6 Conclusion

The results obtained in this study provide an overview of the energy and media demand of the German bottling industry. General statements regarding the energy demand of bottling machines are missing, due to the limited number of samples. The main consumers are identified and concrete demand data are obtained for a limited number of plants. For some demand values a linear correlation to the nominal speed of the machines were found. Companies running bottling plants can use the data from this study as a basic benchmark against which to compare their existing equipment and as a reference for new machine purchases. The data confirm that optimisation should focus on electrical demand because every machine in a bottling plant uses this expensive type of energy. Optimizations of bottle-cleaning machines should also be given special attention. Because only few, less detailed values are published and because the number of data provided herein is limited, further effort is required to establish a reliable branch database. Although efforts are already underway to improve energy efficiency, significant potential remains to be exploited by further investigations. The results of this study can be used as basic research for future studies on the detailed energy demand behaviour, accompanied by further data acquisition, to find generic models describing state-related energy demand for cause-related allocation of demand and detailed optimisation strategies.

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