-Data Analyses of energy use in 3 feed factories-

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Abstract

In order to be able to reduce energy consumption of feed factories, several parameters must be known (registered if possible or estimated when missing). These parameters can be used to calculate the net Specific Mechanical Energy (SME) and Specific Thermal Energy (STE). Data were provided by A, B and C. The analyses made in this project focused on the net SME of the expander or BOA, of the press, of the process (expander/BOA+press) and on the STE of the conditioner. Based on these analyses, possible reduction of energy consumption were estimated. When considering SME and STE values per production line and/or per type of feed the most often produced in the factories, it was observed that:

- Net SME values are mainly between 10 to 20 kWh/t. This corresponds to the expected values when producing pigs feed while this is quite high compared to the literature data for poultry feed.
- Opportunities exist to reduce energy consumption. For example, optimization of the capacity values, of the meal temperature or of the use of the machine can help to reduce the SME and STE.
- In the analyses conducted with the available data, the potential energy reduction by taking off the most consuming runs was different within the factories. For example, when deleting up to 10% of the most consuming runs on a thermal or mechanical point of view, STE was more efficiently saved than SME at A: up to 18% of thermal energy could be saved compared to maximum 13 % of mechanical energy saved. This was the opposite at B (15% of thermal energy saved vs. 21% of mechanical energy saved). At C, up to 12% of mechanical energy could be saved when deleting 10% of the most consuming runs on a mechanical point of view. Saving of thermal energy could not be estimated because of the wide spread of the values.

It was therefore concluded that they are some opportunities to reduce the energy consumption. It was also concluding that by taking of a small part of the most consuming runs, an important part of energy use (up to 20 %) could be saved.

1 Introduction

1.1 Context

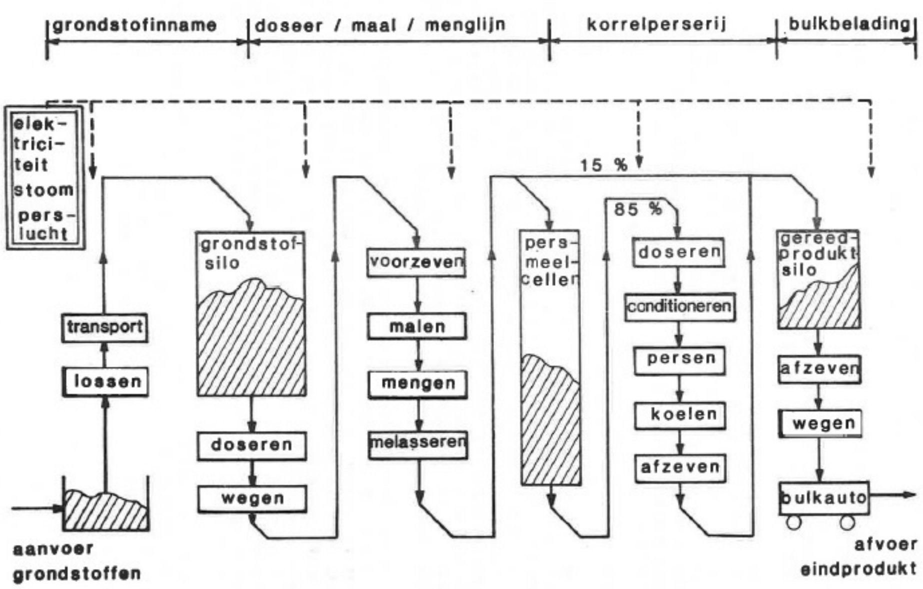
In the Netherlands, about 80 feed manufacturers and members of Nevedi (The Dutch Feed Industry Association) produced 13.4 million tons of feed in 2012. Three big feed manufacturers produced 60% of the feed. About 40 % of the feed is produced for pigs, 30% as ruminant feed and 30% as poultry feed [NEVEDI, 2013]. In the manufacture of feed, as for other production process industry, energy input is high: in average, the production of one ton of feed requires about 35 kWh [Beumer, 1986]. In order to decrease the CO_2 footprint of processing, there is a desire to improve the energy efficiency of the feed production process [Liang et al., 2011]. That is why the government is looking for possibilities to perform energy savings in the feed manufacturing industry.

The input of energy of a process is defined in two forms:

- Specific Mechanical Energy (SME): represents the energy transfer from the main drive motor to the compounding process by mass of material [Dreiblatt, Canedo, 2012]. It corresponds to electrical energy.
- Specific Thermal Energy (STE): represents the energy transfer from heat sources (as steam injection) to the material [Janssen et al., 2002].

As illustrated in Figure 1, feed manufacturing is characterized by the use of mechanical energy for milling, mixing, pre-conditioning, pelleting en cooling. Mechanical energy and thermal energy, in the form of steam, is used for pre-conditioning and pelleting the feed.

Figure 1: Schema of feed manufacturing [Beumer, 1986].



Pelleting is the process requiring the most energy. Normal values for the consumption of energy (in kWh/t) are given in Table 1.

Table 1: Energy consumption (kWh/t) indications for pelleted materials [Beumer, 1986]

Type of feed	Energy consumption (kWh/t)
Poultry	6 to 14
Pig	9 to 24
Dairy Cattle	11 to 23
Other	18 to 30

Conditioning recommendations for pelleting are given in Table 2 for various (animal feed) ration.

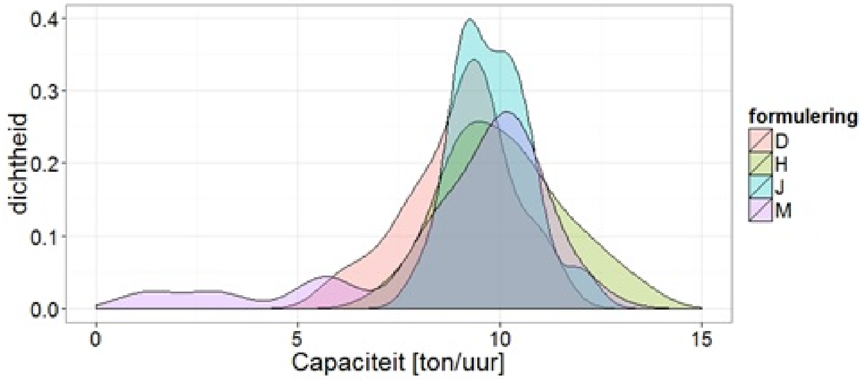
Table 2: Steam conditioning recommendations for different diets (modified after [Payne, 1978] and [Maier and Gardecki, 1992])

Ration type	Specific component	Recommended steam pressure (kPa)	Final meal temperature ($^{\circ}C$)
High starch feed	50 - 80 % starch from cereals or tapioca	102	80 - 85
Dairy rations	high fiber, 12 - 16 % protein	442	60 - 65
High protein, supplements and concentrates	25 - 45 % protein	442	80
Heat sensitive	5 - 25 % dry milk powder, sugar and/or whey	102	<55
Urea containing rations	Urea 6 - 30 %	442	-

From previous work performed at Zetadec, it is known that differences in processing conditions between lines and feed formulations are present. For example, temperature of the feed and capacity of the production lines may vary a lot for the same formulation (see the example in Figure 2) [Thomas, 2012]. Consequently, SME and STE values will also vary. From the figure, it appears that the production capacities of the different formulations have a remarkable variation. In order to produce the same feed, capacities of 8 to 12 kWh/t are measured. On an energy and technical point of view, higher capacities are wished.

From these observations, it can be deduced that by registering detailed data, calculations of the SME and STE may yield relevant information to be able to optimize the energy use of a process in the future [Liang et al., 2011].

Figure 2: Variation in capacity (in ton/hour) for 4 different ruminant feed formulation, measured during 3 months [Thomas, 2012].



1.2 Objectives

The purpose of this project is to make an inventory of the various possibilities existing to be able to optimize the energy consumption in the feed manufacturing industry. This is performed in 3 steps:

1. To perform an analyse about the variability present in the process when producing feed;
2. From this data, to make aware the manufacturers about this existing variability;
3. During meetings and workshops with the feed manufacturing industry, to share the knowledge gained from this project in order to target a reduction in energy consumption in this sector.

This report is a summary of the research performed on the energy consumption in the feed manufacturing industry. The purposes of this first step of the project are:

- To be able to extract variables indicating the level and variability of energy used for various processes and feed formulation present in a feed factory. This focus on:
  - Capacity,
  - Electrical energy consumption, calculated as Specific Mechanical Energy (SME), in kWh/t,
  - Thermal energy consumption, representing the use of steam, called Specific Thermal Energy (STE), in kWh/t.
- To estimate what would be the possible reduction of energy used when taking off a certain percentage of the most energy consuming runs.

As pelleting is the most consuming part in the manufacture of feed, the data collected are concerning this part of the process.

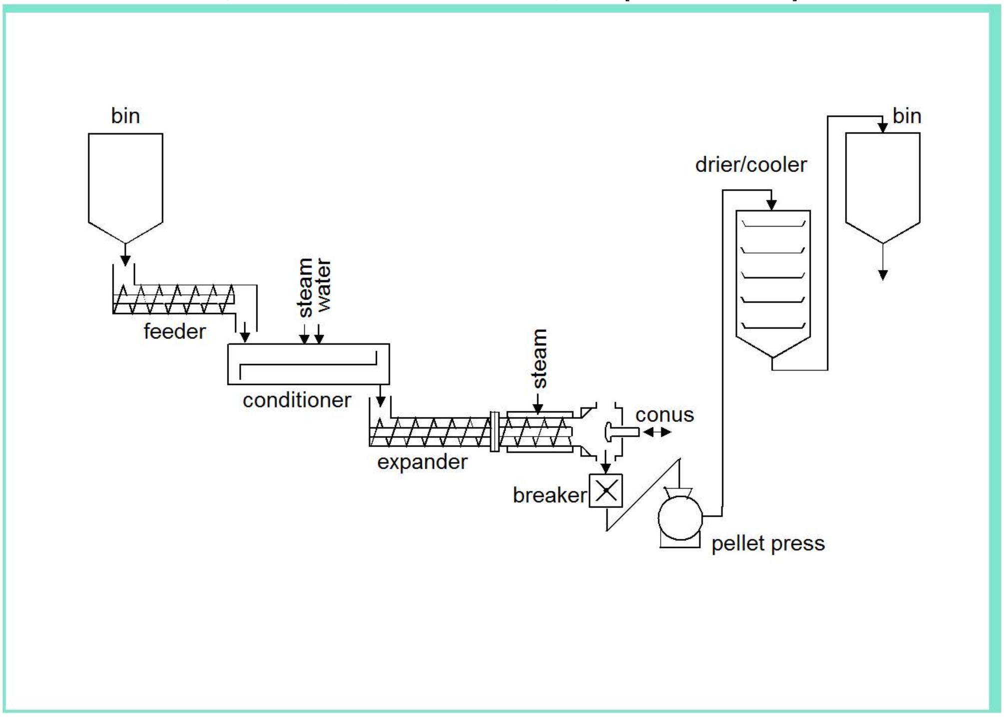
This report is based on the data provided by 3 feed factories. Based on the data from various feed companies with different levels of production, it is possible to get an idea of where and how the energy consumption could be better monitored and eventually reduced.

2 Materials en methods

2.1 Data available

Data from production runs of poultry feed, pig feed or both were stored by 3 feed companies, renamed A, B and C respectively. Data were stored in Excel files. The Excel data were transferred to the R software (version 15.3). Because the heat treatment and the pelleting process are the most consuming parts of a pelleting line, the data linked with the conditioner, the expander treatment (at A and C) or BOA treatment (at B) and the press were considered as relevant (see Figure 3). Other data were excluded as they were irrelevant for this project.

Figure 3: Lay-out of a pelleting line [Thomas, 1998].



Some information (as code for formula's) were made anonymous by using a R function which creates a combination of letter and/or numbers for the various confidential data. Extra data were communicated by the factories to Zetadec if needed. It was sometimes necessary to estimate some extra data. This was then done by Zetadec in discussion with the factories.

2.2 Calculations performed

2.2.1 Selection of the data

In some cases, few batches were saved within the same run resulting in several measurements for a same run. Thus, an average of the measurements was calculated using the generic function of R. This was performed in order to get one value per run. Then, where possible, the 20 most frequent produced formula's were selected to be compared per production line and per type of feed.

Depending on the feed factories, the data sent were mainly logged in 2013, or from 2012; on 2 to 4 pelleting lines. This resulted in a different amount of data considered in the analyses, as summarized in Table 3.

Table 3: Summary of the data used in the analyses

Factory	Species targeted	Agglomeration apparatus	Logging Period Start	End	Pelleting lines	Runs considered
A	Poultry	Expander+press	1-1-2013	26-4-2013	4	1682
B	Pigs	BOA+press	8-3-2013	29-5-2013	2	22
C	Poultry+pigs	Expander+press	1-1-2012	2-1-2013	3	4125

2.2.2 Specific Mechanical and Thermal Energies

For each run, the specific mechanical and thermal energies were calculated. The resulting data were analysed for the 20 selected formula's.

- Estimation of the net SME (Specific Mechanical Energy) based on [Anyonye, Badifu, 2007] and Watt's law:
  - from Amperes to kW: $\boxed{kW(A, V, \omega) = \frac{A \cdot V \cdot \sqrt{3} \cdot \omega}{1000}.}$
    - A: difference of amperes (full load-idle load),
    - V: voltage,
    - $\sqrt{3}$: rotating current factor,
    - ω: power factor or efficiency of the system,
    - kW: average power measured during the production of one run.
  - From kW and capacity to net SME: $\boxed{SME(kW, tph) = \frac{kW}{ton \cdot hour}}$
    - kW: as described above,
    - capacity: in tons per hour.

$$\Longrightarrow \boxed{SME(kWh, ton) = \frac{kWh}{ton}}$$

Specific Mechanical Energy indications for various pelleted materials were presented in Table 1. They varied from 6 to 30 kWh/t. Based on these indications, data resulting in SME values below 0 kWh/t or above 30 kWh/t were considered as unlikely and were excluded.

- Estimation of the quantity of STE (Specific Thermal energy) for the 20 most frequent formula's is calculated as follow:
  - Thermal energy is caused by steam addition, so there is only one STE value in the process
  - $\boxed{STE(\Delta T) = \Delta T \cdot (M_w \cdot CP_w + M_s \cdot CP_s) \cdot \frac{1000}{3600}}$
    - ΔT: difference of temperatures measured due to steam addition (Temperature of the feed before the expander-T_{mixer})
    - M_w: weight fraction of water, M_s: weight fraction of solid materials
    - CP_w: heat capacity of water ($4.2 \frac{kJ}{kg \cdot K}$), CP_s: heat capacity of the mix of solids:
      - Carbohydrate: $1.22 \frac{kJ}{kg \cdot K}$
      - Protein: $1.9 \frac{kJ}{kg \cdot K}$
      - Fat: $1.9 \frac{kJ}{kg \cdot K}$
      - Ash: $0.84 \frac{kJ}{kg \cdot K}$

        $\Rightarrow CP_{feed}$: $\approx 1.8 \frac{kJ}{kg \cdot K}$ [Beumer, 1987]

  Data resulting in STE values below 0 kWh/t were considered as unlikely and were excluded.

2.2.3 Statistics and plotting of the energy values

The values used in these analyses mainly result from the average of data of few measurements. From the values from the expander/BOA treatment and/or pelleting process by production line, calculations were performed to get:

- the mean
- the low and the high value of the 95% confidence interval (CI.low and CI.high), calculated as follow: $\boxed{CI = mean \pm qnorm(0.975) * SD/\sqrt{n}}$,
  - using the quantile function *qnorm* of R,
  - *SD* is the standard deviation,
  - and n is the number of values available.
- the delta value calculated from the range of the 95% confidence interval, calculated as: Delta=CI.high-CI.low
- number of values available (n).

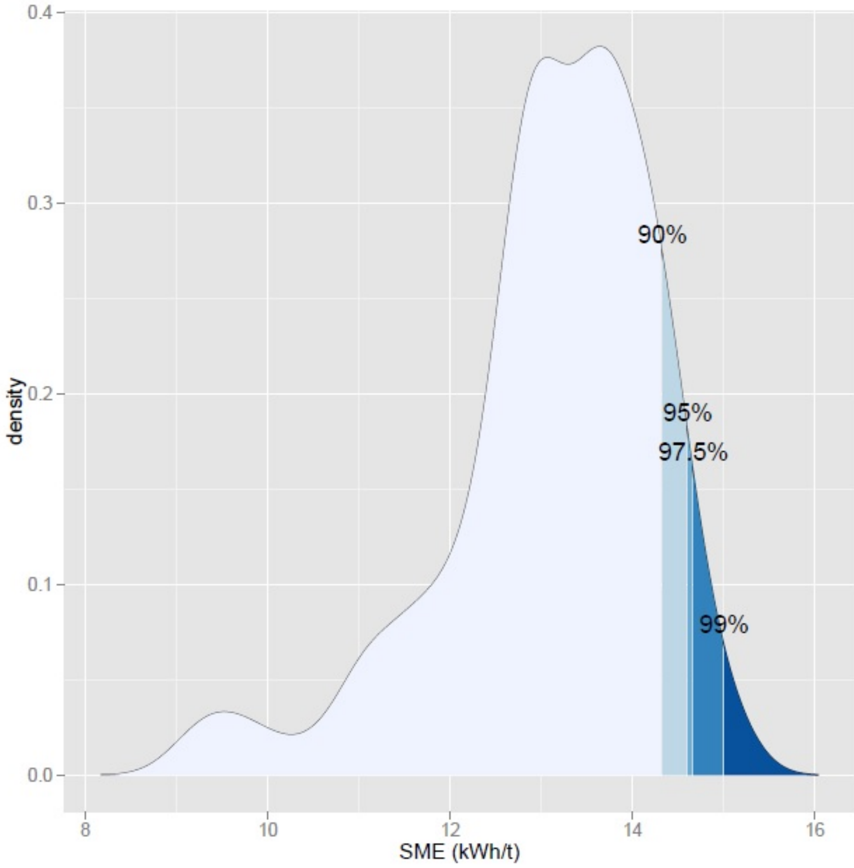
In order to give an overview of the variation present in the feed factories, 2 formula's frequently run in the factories were selected as example. Based on the calculated values, density plots are used to show the distribution of the energy values per production line and/or per type of feed.

2.3 Estimation of energy reduction

For the 20 most often produced formula's, specific energy values corresponding to a specific interval of a cumulative distribution curve (= quantiles) were calculated for various probabilities using the generic function *quantile* of R. For example, for a given probability of 5%, the associated quantile value was calculated for SME and/or STE for each feed, on each production line. This

means that 5% of the runs of a specific feed on a specific line has an energy use above the found value. An example is illustrated in Figure 4. The following probabilities: 1, 2.5, 5, 10 % were used.
By knowing the energy consumption and the tonnage produced with the concerned runs, it is possible to estimate the part of the energy that could be saved by not performing these specific runs at those energy levels.

Figure 4: Graphic example of selection of the most consuming runs: 90, 95, 97.5 and 99% quantiles are given. They are used in calculating the potential energy reduction possibilities.



3 Results

3.1 Capacity

As we can see from Table 4 and Figures 5 and 6, mean capacities values of the selected formula's are varying from about 10 to 16 t/h. These values are higher than the capacities reported in the past by [Beumer, 1986] which varied from about 3 to 14 t/h. If we consider the formula's that were run more than 100 times, the mean capacity of a specific formula may vary until about ± 1 t/h.

Type.feed	Company	code	Mean	CI_low	CI_high	Delta	n
Pigs	B	1	10.47	9.30	11.63	2.33	7
Pigs	B	2	11.29	9.67	12.91	3.24	9
Pigs	C	221	15.96	15.89	16.04	0.15	1396
Poultry	A	18	13.67	13.31	14.02	0.71	123
Poultry	A	26	13.97	13.57	14.37	0.80	112
Poultry	C	041	15.43	15.28	15.58	0.30	403

Table 4: Summary of capacity values (t/h, with 95% CI).

In Figure 7, we can see low SME values (around 5 kWh/t). This may be due to the fact that the expander is used as a conveying screw. If we focus on the value above 5 kWh/t, we can see that energy consumption tends to decrease with higher capacities, as it was already shown in the past ([Beumer, 1986]). Thus, if the mean capacity is 1 t/h lower, the production is less efficient on a energy point of view.

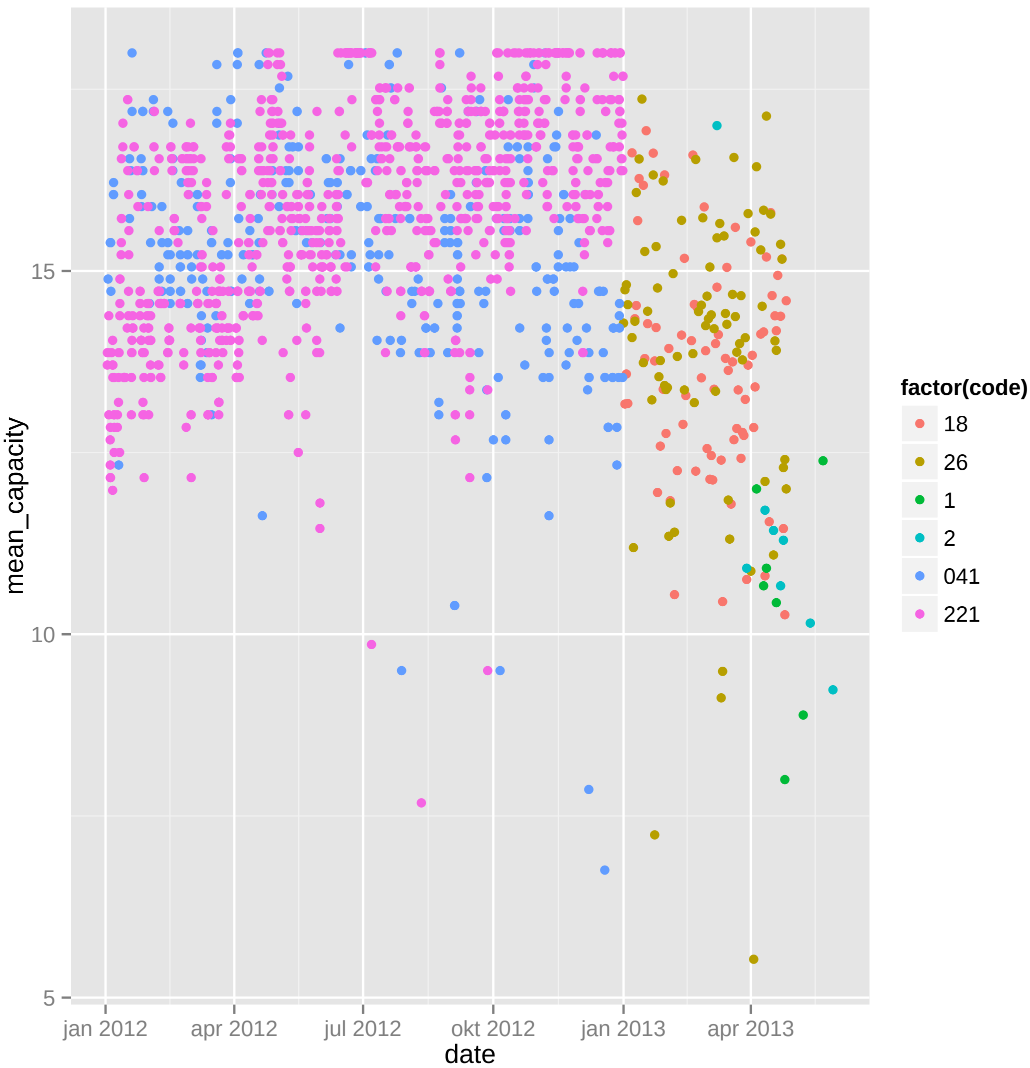


Figure 5: Time-plot of the capacity values.

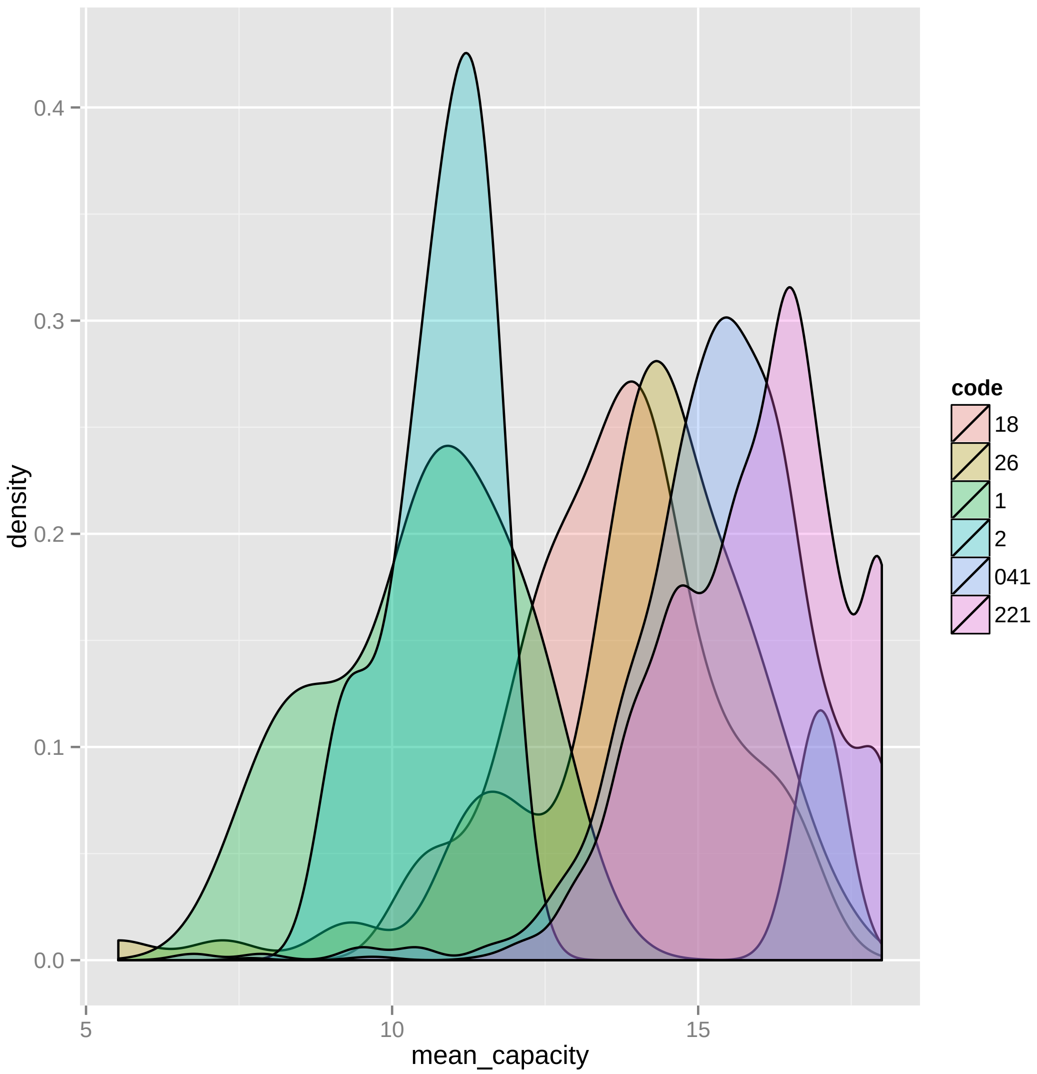


Figure 6: Density plot of the capacity values.

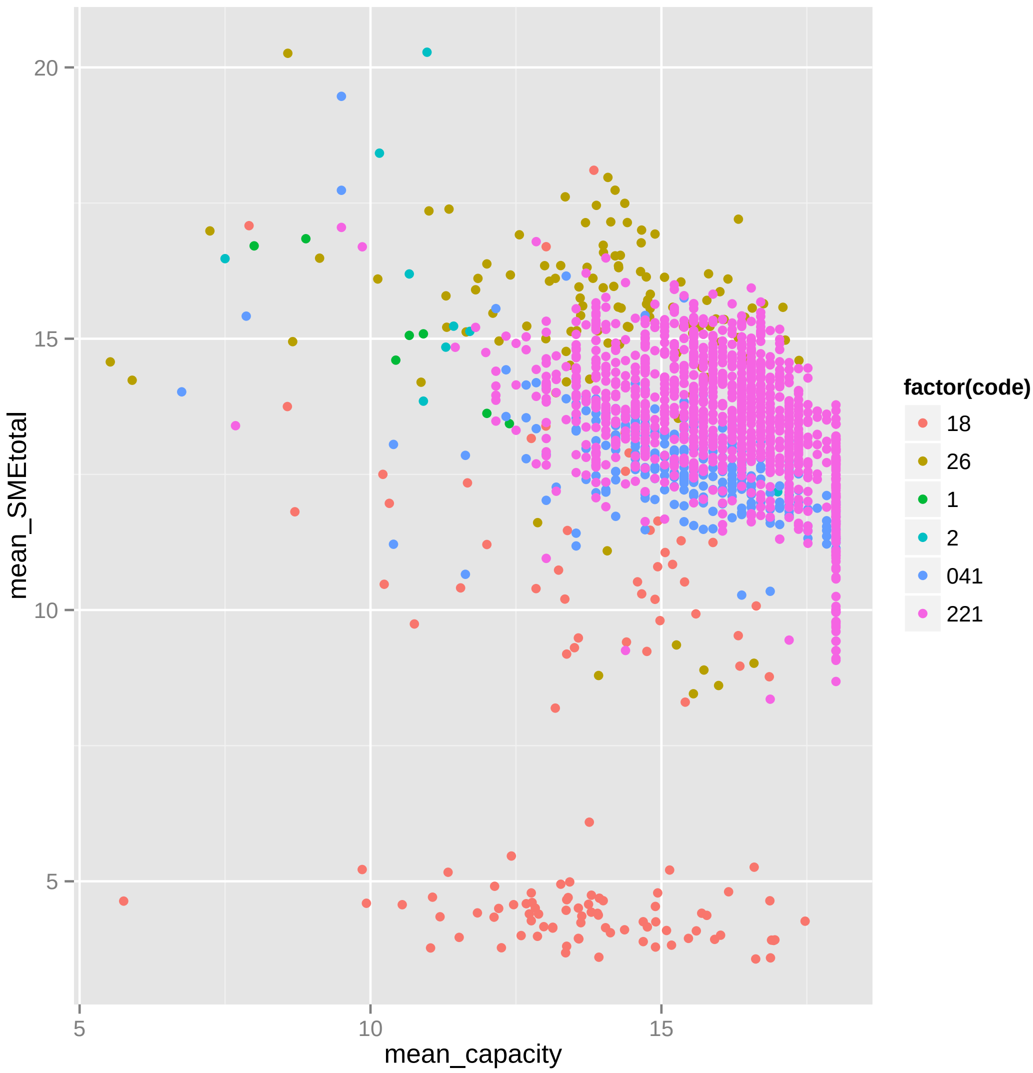


Figure 7: Link between energy consumption (kWh/t) and capacity (t/h)

3.2 SME plots

3.2.1 Variation of SME values

As we can see in Table 5, SME values in the pelleting process are quite variable. These variations will be detailed in the following sections.

Table 5: Peaks and range of SME values (in kWh/t) by feed factories

Factory	Species targeted	Agglomeration apparatus	SME Expander/BOA		SME press		SME process	
			peaks	range	peaks	range	peaks	range
A	Poultry	Expander+press	1; 7.5	1-11	3; 9	1-15	4.5; 15	2-20
B	Pigs	BOA+press	9	8-11	5; 8	4-10	15; 17	12-20
C	Poultry; pigs	Expander+press	9	3-10	5	3-9	13	9-16

3.2.2 SME expander/BOA

Values of SME of the expander or BOA treatment are widely distributed. The range of calculated SME values varies from ≈ 1 to 15 kWh/t. Most of the values are between 5 and 10 kWh/t for the expander treatment and 8 to 11 kWh/t for the BOA treatment. When considering the values per type of feed, 2 peaks of values are sometimes present. The peaks and the range of most of the values of SME of the expander or of the BOA are summarized by feed factory in Table 5.

When considering the formula's frequently produced, we can see from Table 6 and Figures 8 and 9 that mean SME values for expander or BOA treatments are varying from about 6 to 10 kWh/t (3 to 9 kWh/t for the expander and 9 to 10 kWh/t for the BOA).
The low SME values (<5 kWh/t) are maybe due to setting parameters as seen before. It can be that the expander is used as a conveying screw. We can see in Figure 8, that this may be the case for the formula 18 until April 2013. After that, the values are higher (above 5 kWh/t), suggesting the use of new parameters or a re-calibration of the machine.

Type.feed	Company	code	Mean	CI_low	CI_high	Delta	n
Pigs	B	1	10.09	8.71	11.47	2.76	7
Pigs	B	2	9.47	8.80	10.13	1.33	9
Pigs	C	221	8.53	8.48	8.57	0.09	1396
Poultry	A	18	3.33	2.75	3.91	1.16	123
Poultry	A	26	7.58	7.38	7.78	0.41	112
Poultry	C	041	6.26	6.21	6.31	0.10	403

Table 6: Summary of SME values of the expander (kWh/t), with 95% CI.

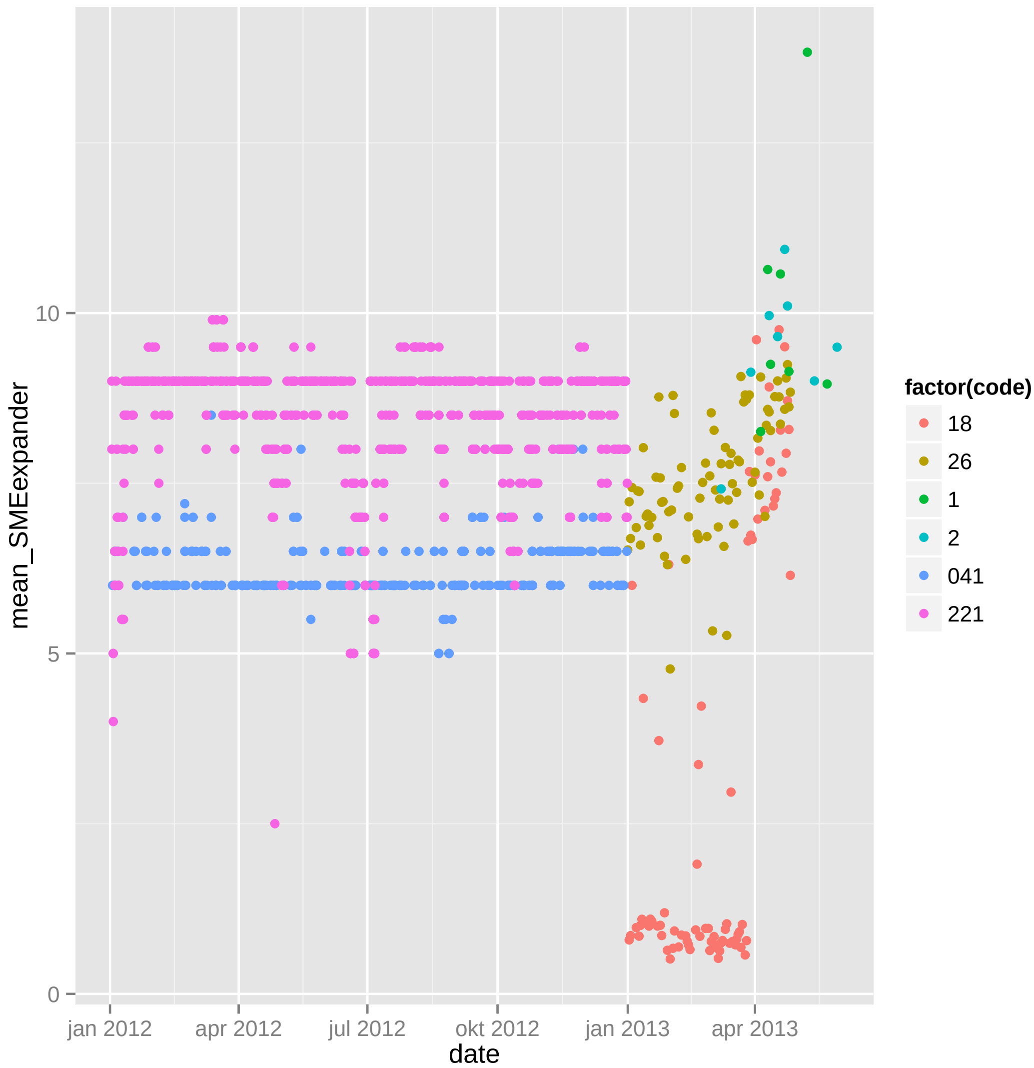


Figure 8: Time-plot of the SME values of the expander/BOA.

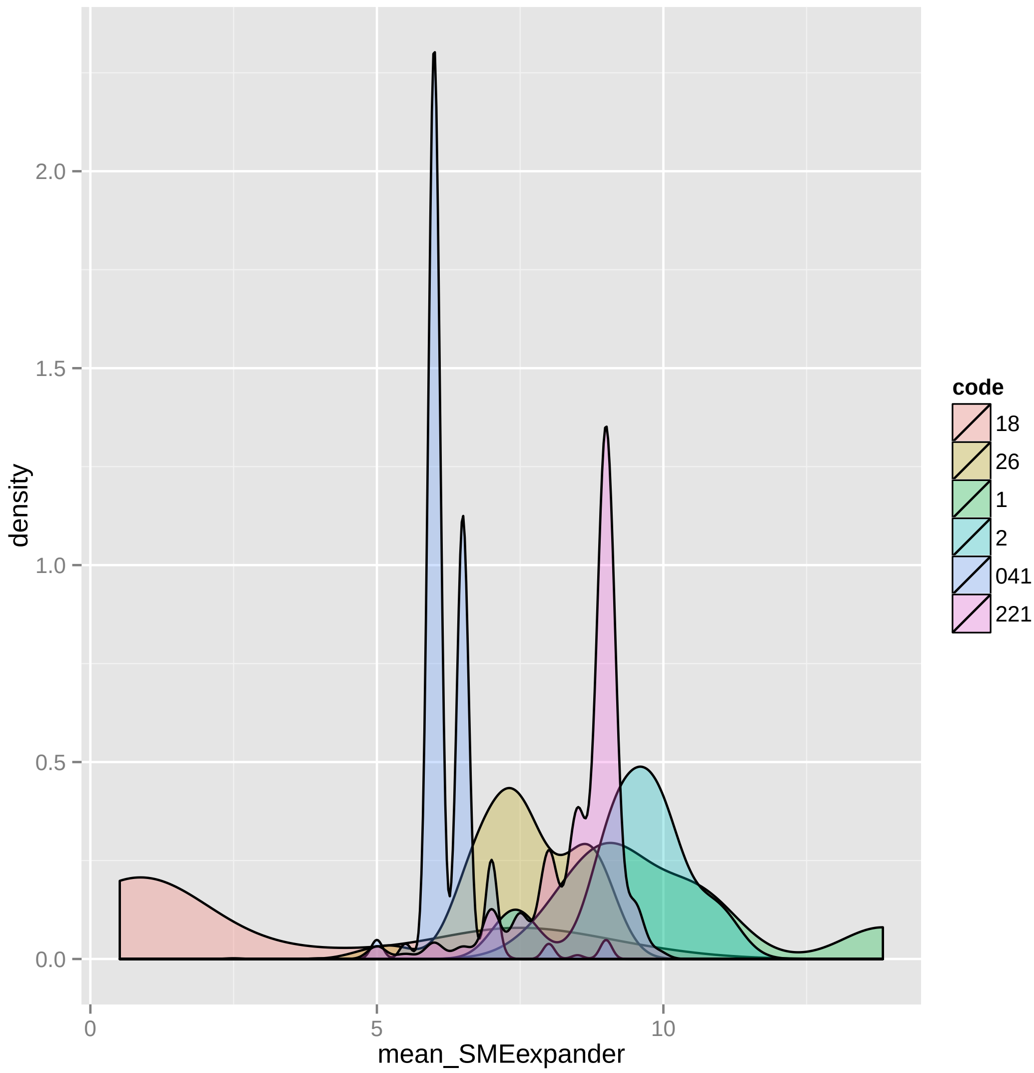


Figure 9: Density plot of SME values of the expander/BOA.

3.2.3 SME press

When much data are present (as in the case of C), it seems that the SME values of the press are closed to about 5 kWh/t. These values are more spread and higher (about 9 kWh/t) for production line 2 to 4 at A. On the contrary, this is very low for production line 1 ($\approx$ 3 kWh/t). For B, the 2 production lines give really different values, ranging from 4 to 10 kWh/t. The peaks and the range of most of the values of SME of the press are summarized by feed factory in Table 5.
When looking at the most produced formula's, we can see from Table 7 and Figures 10 and 9, that mean SME values of the press are varying from about 3 to 8 kWh/t.

Type.feed	Company	code	Mean	CI_low	CI_high	Delta	n
Pigs	B	1	4.96	3.87	6.05	2.18	7
Pigs	B	2	6.38	4.99	7.77	2.78	9
Pigs	C	221	5.01	4.96	5.05	0.09	1396
Poultry	A	18	3.61	3.40	3.82	0.42	123
Poultry	A	26	7.73	7.43	8.04	0.61	112
Poultry	C	041	6.41	6.34	6.48	0.14	403

Table 7: Summary of SME values of the press (kWh/t), with 95% CI.

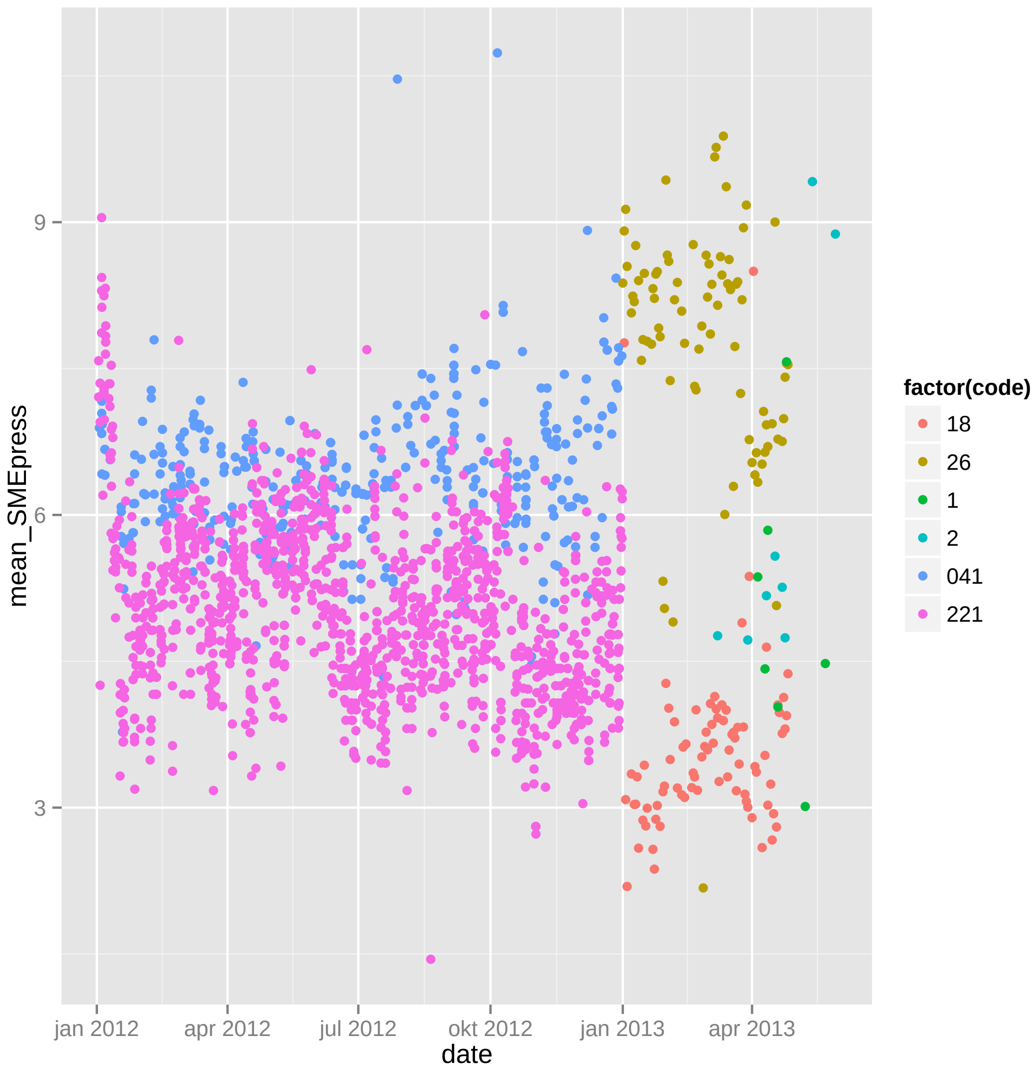


Figure 10: Time-plot of the SME values of the press.

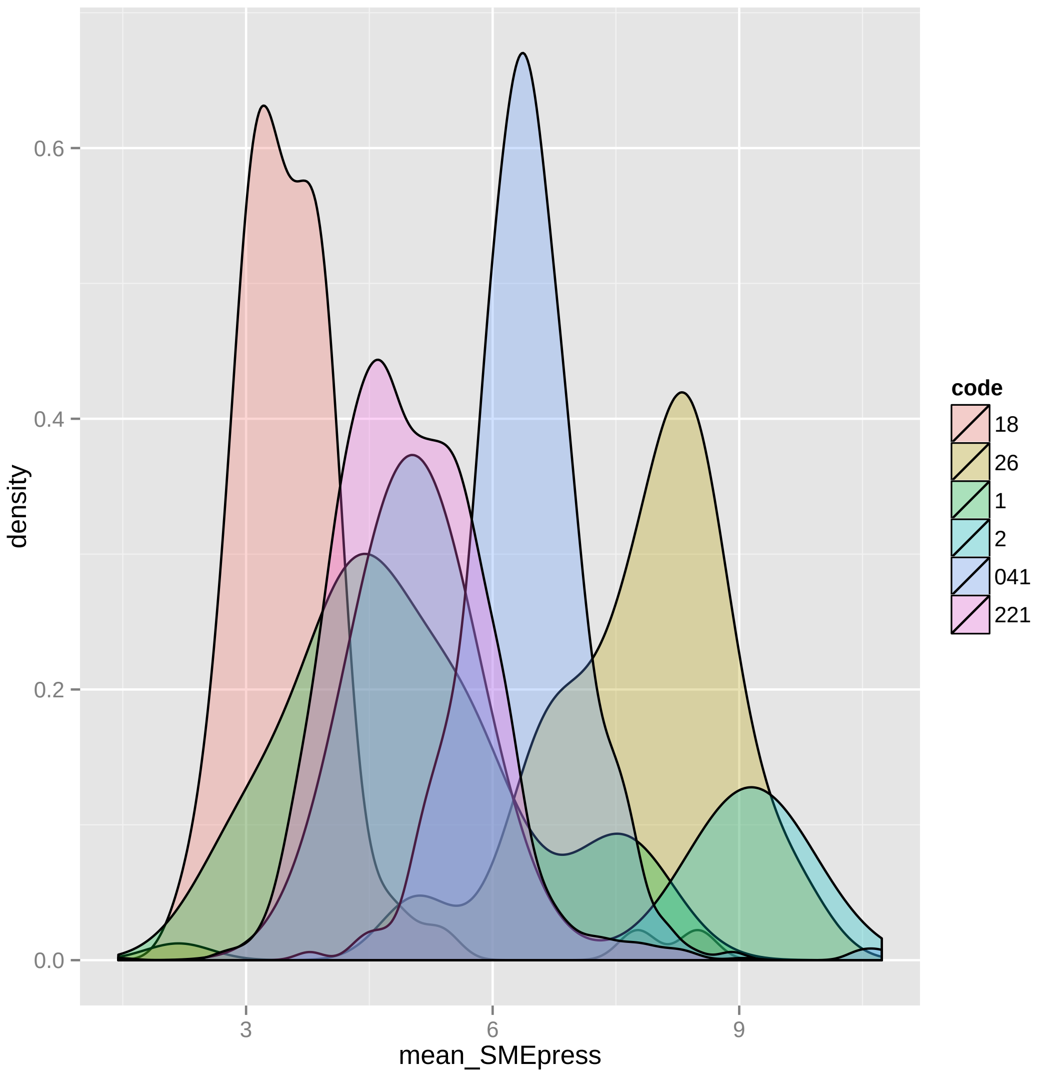


Figure 11: Density plot of the SME values of the press.

3.2.4 Total SME

As for SME values of the press, SME values of the pelleting process for C seem to be closed to $\approx$ 13 kWh/t. For the other factories, the SME values mainly range from 10 to 20 kWh/t with lower values for production line 1 of A. The peaks and the range of most of the values of SME of the pelleting process are summarized by feed factory in Table 5.
As we can see from Table 8 and Figures 12 and 13, mean SME values of the pelleting process for the most produced formula's are varying from about 7 to 16 kWh/t. This large variation is a result of the low SME values of the expander described previously.
When looking at the type of feed, these values are in line with the indications reported by [Beumer, 1986] (see Table 1).

Type.feed	Company	code	Mean	CI_low	CI_high	Delta	n
Pigs	B	1	15.05	14.06	16.05	1.99	7
Pigs	B	2	15.85	14.28	17.41	3.14	9
Pigs	C	221	13.54	13.47	13.60	0.12	1396
Poultry	A	18	6.94	6.31	7.58	1.27	123
Poultry	A	26	15.31	14.95	15.67	0.72	112
Poultry	C	041	12.67	12.58	12.76	0.18	403

Table 8: Summary of SME values of the pelleting process (kWh/t), with 95% CI.

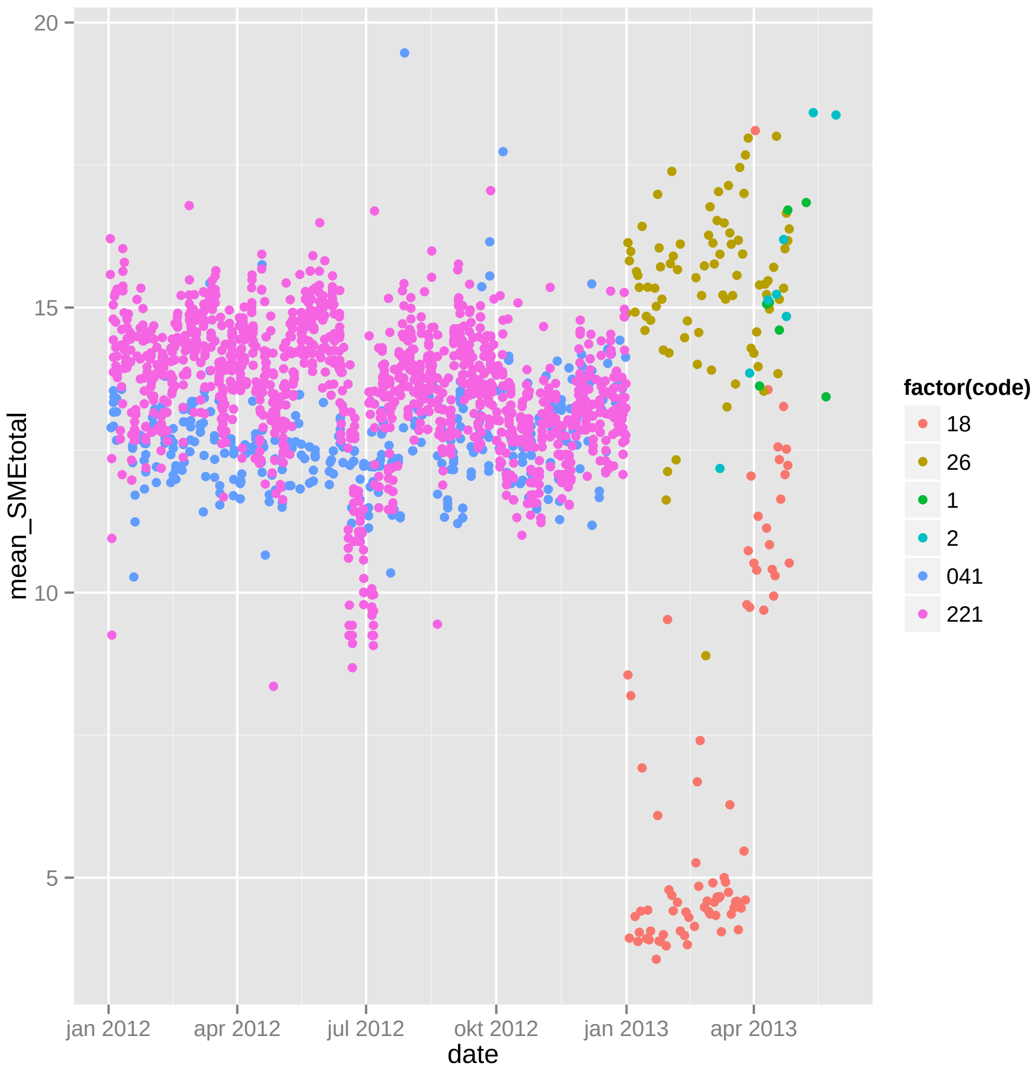


Figure 12: Time-plot of the total SME values.

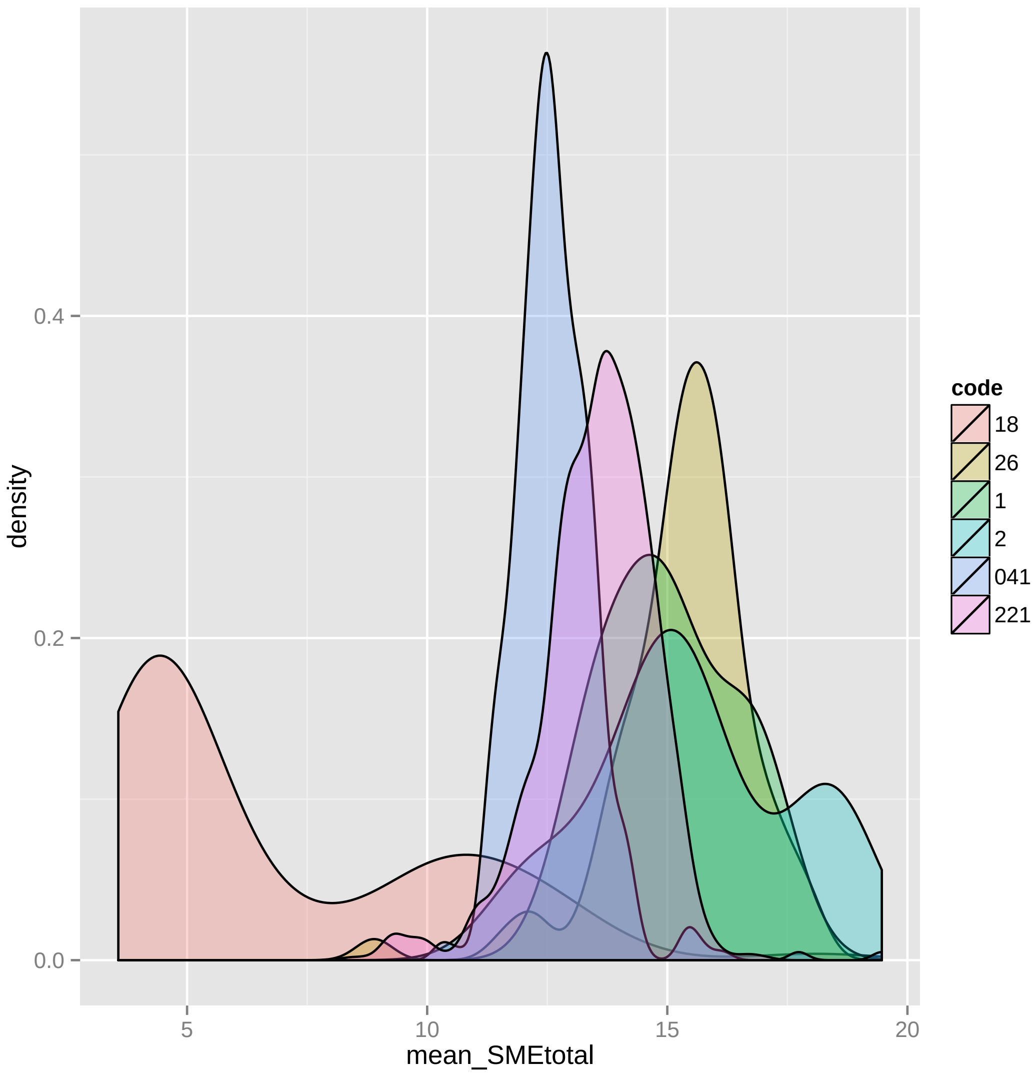


Figure 13: Density plot of the total SME values.

3.3 STE plot

About STE values, they are mainly between 15 to 40 kWh/t for A, about 15 to 30 kWh/t for C and 12 to 18 kWh/t for B. The STE values from C are distributed in various peaks due to temperatures differences varying mainly by step of 5°C.
The peaks and the range of most of the values of STE are summarized by feed factory in Table 9.

Table 9: Peaks and range of STE values (in kWh/t) by feed factories

Factory	Species targeted	Agglomeration apparatus	STE	
			peaks	range
A	Poultry	Expander+press	17; 31	15-40
B	Pigs	BOA+press	13; 15.5	12-18
C	Poultry; pigs	Expander+press	25	17.5-27.5

When considering the most produced formula's (see Table 10 and Figures 14 and 9), the STE values are varying from about 14 to 28 kWh/t. The STE values of Formula 041 are mainly 25 kWh/t resulting in a very low confidence interval. This formula is run many time through the year and is a good example that STE values can be kept constant.

Type.feed	Company	code	Mean	CI_low	CI_high	Delta	n
Pigs	B	1	14.96	13.63	16.29	2.66	7
Pigs	B	2	15.08	14.00	16.16	2.15	9
Pigs	C	221	26.38	26.30	26.46	0.16	1396
Poultry	A	18	22.11	20.55	23.67	3.11	123
Poultry	A	26	27.64	27.03	28.25	1.22	112
Poultry	C	041	25.03	25.00	25.07	0.07	403

Table 10: Summary of STE values (kWh/t).

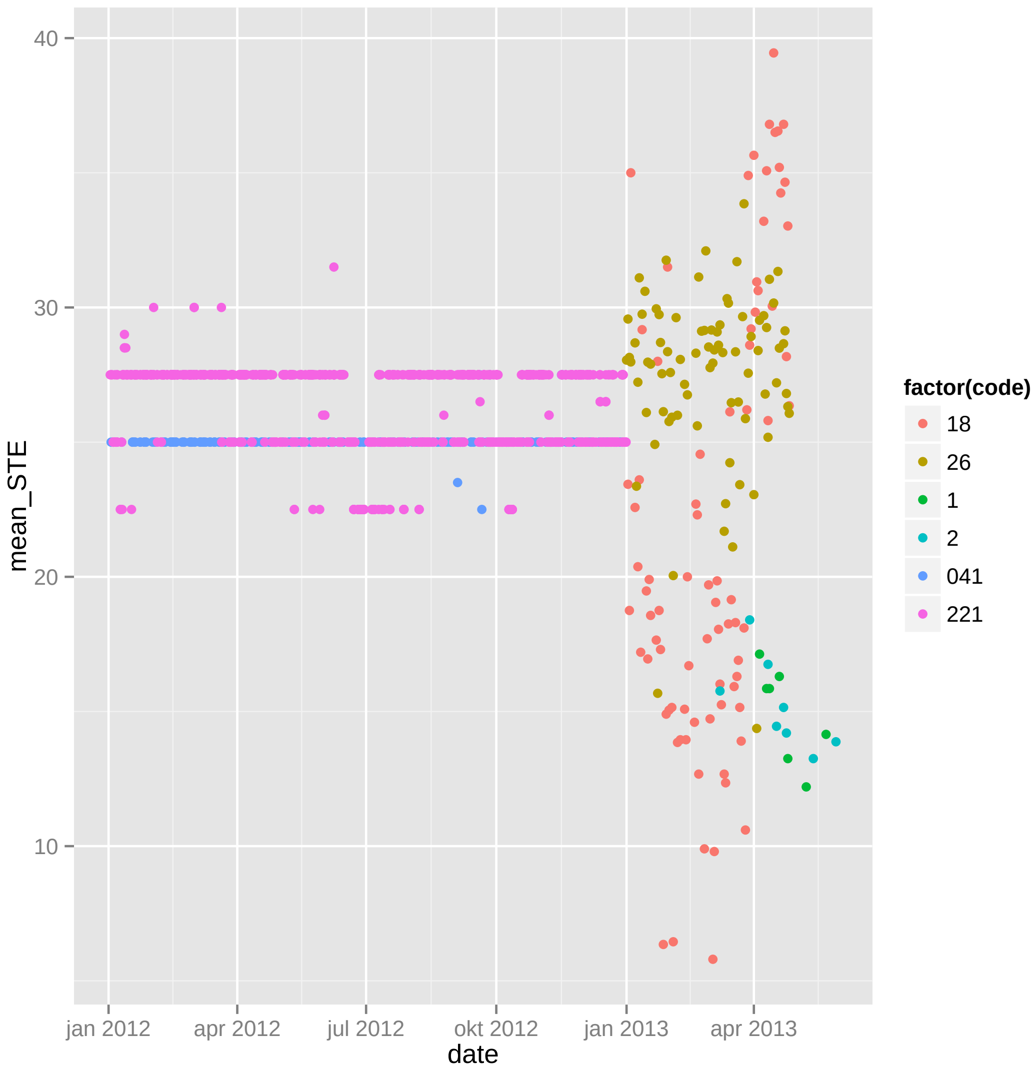


Figure 14: Time-plot of the STE values.

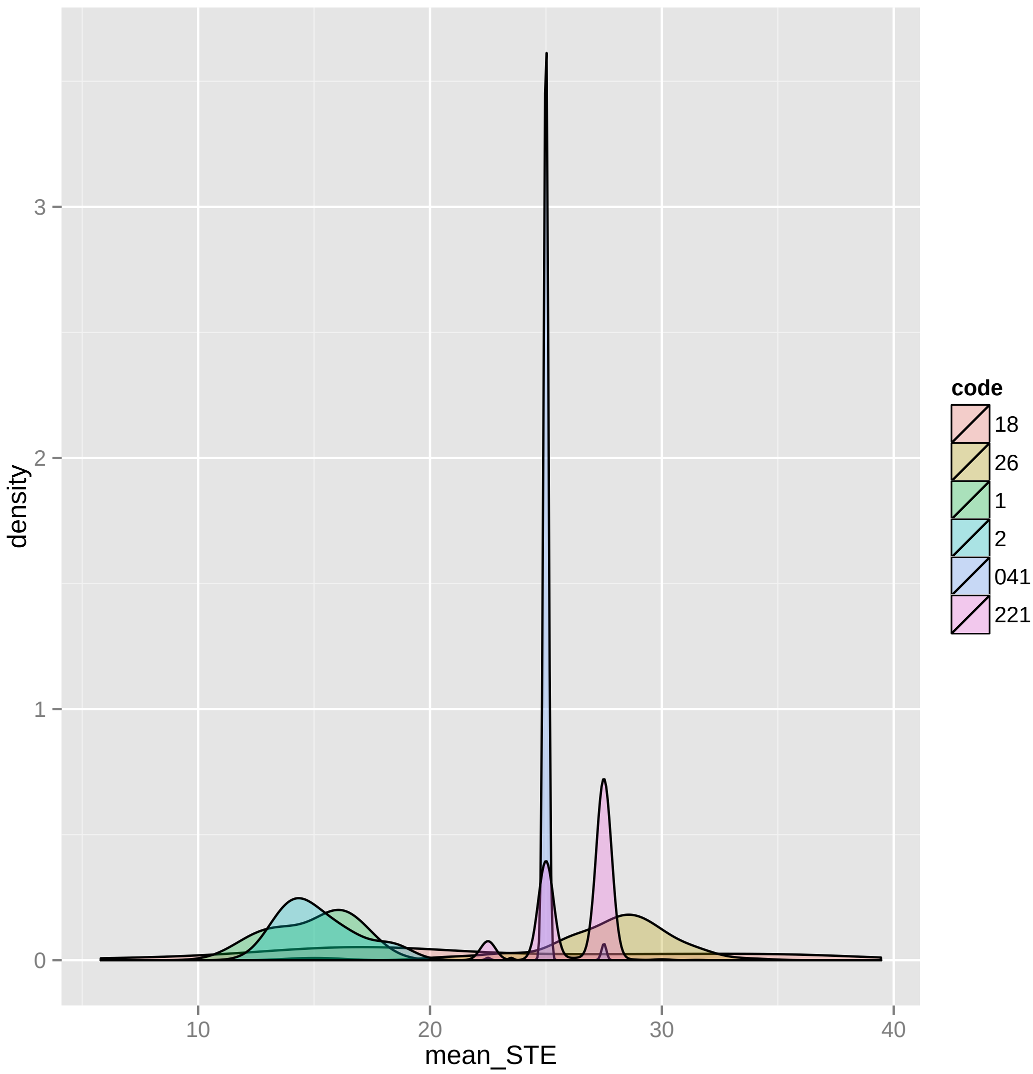


Figure 15: Density plot of the STE values.

3.4 Estimation of energy reduction

3.4.1 SME reduction

Calculation of possible reduction of SME use was based on the quantiles method. As we can see in Table 11, when taking off a certain amount of the most consuming runs, about the same amount of mechanical energy use can be saved at A and C. At B, due to the amount of data available, no matter the part of the runs taken off, the part of energy saved was calculated to be about 21% in this study.

Table 11: Percentage of mechanical energy possible to save when taking off a certain percentage of the most consuming runs

Factory	Species targeted	Agglomeration apparatus	% of runs taken off			
			1	2.5	5	10
A	Poultry	Expander+press	3	4	7	13
B	Pigs	BOA+press	21	21	21	21
C	Poultry; pigs	Expander+press	2	3	6	12

3.4.2 STE reduction

Calculation of possible reduction of STE use was also based on the quantiles method. As summarized in Table 12, no matter the part of runs deleted at B, the reduction of thermal energy was estimated to be $\approx$ 15%. For A, for each percent of runs taken off, at least about 2 percent of energy could be saved. Because of the variations by steps of 2.5 kWh/t of the STE values at C, it was not possible to estimate properly for this factory what would be the consequence of deleting some runs on the energy consumption.

Table 12: Percentage of thermal energy possible to save when taking off a certain percentage of the most consuming runs

Factory	Species targeted	Agglomeration apparatus	% of runs taken off			
			1	2.5	5	10
A	Poultry	Expander+press	6	8	11	18
B	Pigs	BOA+press	15	15	15	15
C	Poultry; pigs	Expander+press	-	-	-	-

4 Discussion

4.1 Observation from the results

It is clear from this study that variations exist in the measured data. By considering formula's run more than 100 times, we could observe that energy consumption could be lower by optimizing the capacity.
We also observed that the SME values of the expander for a specific formula changed within the year from a low value (<5kWh/t) to higher values. This reveals that the use of the expander changed. For example, it may have first been used as a conveying screw, which would explain the low SME values. Another possibility is that the machine and/or the meters have been re-calibrated or a specific parameter have been adapted. For example, if the form of the feed or the dimensions of the pellet change, the SME values will change :

- mash feed requires less energy than pellets,
- pellets with a high Length/ Diameter ratio (LD ratio) require more energy than pellets having a low LD ratio as more compression forces are needed to produce these long pellets.

Also, the function of the type of feed produced is important as cleaning feed is produced to decontaminate the production line and may have a different set-up requiring less energy than another type of feed.
Finally, the operators may have an impact on the energy values by changing some parameters. For example, one operator wants to have a meal temperature of 80 $°C$ while another operator sets the parameters to get a meal temperature of 85 $°C$. However, if this difference of 5 $°C$ would be smaller, more adapted and lower meal temperatures could be obtained, reducing the STE values.
It is thus important to be aware of the influence of these different factors on the SME and STE values of the pelleting process.
For net SME values, as described in Table 1, the expected ranges of consumption values are 6 to 14 for poultry feed and 9 to 24 for pig feed. In this study, the net SME values are mainly between 10 to 20 kWh/t, no matter the type of feed produced. This shows that a possible reduction of energy use may be possible when producing poultry feed.
It is also interesting to look at the difference between net and gross SME values. However, many values were communicated as net results, without knowing the idle load values. It was then not always possible to estimate this ratio. When possible, it was calculated that this ratio was close to about 50% (± 10%). This means that 50 % of the energy use would be needed to make the process running empty. Thus, on an energy point of view, the shorter the machines are running empty, the more efficient it is.

Because of missing information, it is difficult to estimate properly a potential energy reduction in the feed factories. However, it was noticed that the effect of taking off a certain part of the most consuming runs was different for each factory:

- It was more efficient to delete the consuming runs from a thermal point of view at A: for each percent of runs deleted, about the double percentage of energy could be saved.
- Contrary to A, at B, it is more efficient to take off the most consuming runs from a mechanical point of view as a bigger part of energy could be saved (21 % saved) compared to saving energy by taking off the most consuming runs on a thermal point of view (15 % of energy saved).

- For C, only effect on SME use could be properly estimated: taking off one percent of the most consuming runs would result in saving about the equivalent percentage of mechanical energy use.

4.2 Recommendations

In a future step, it is obvious that more data and background information are relevant to determine properly the potential energy reduction. Based on more data, analyses on specific parameters can be conducted with decision trees in order to determine the most influencing factors on the energy use. These factors of importance can be of different nature :

- Production line parameters: as set-up used, specific use targeted.
- Feed parameters: as shape, size, type.
- External factors: as seasonal effect, operators influence.

Also, it is important to remember that there is a balance relation between STE and SME use. Indeed, when comparing SME of the process and STE values, as described in Table 13, 1 to 2 times more thermal energy is used compared to mechanical energy. However, if less steam is used, STE will decrease but SME may increase as more energy may be needed to achieve an equivalent pellet quality.

Table 13: Ratio STE/SME

Factory	Species targeted	Agglomeration apparatus	ratio STE/SME
A	Poultry	Expander+press	2.3
B	Pigs	BOA+press	1
C	Poultry; pigs	Expander+press	2

5 Conclusion

To conclude, the ranges of the energy consumption calculated in this study are quite variable. For poultry feed, they seem to be higher than what was found in the literature. However, this study shows that it exists some opportunities to target an energy reduction in the feed manufacturing industry. For example, optimization of some production parameters can contribute to the reduction of energy consumption:

- the higher the capacity is, the lower the SME should be;
- the more adapted and lower the meal temperature is, the lower the STE can be;
- the more appropriate the use of equipment is (shorter empty run, use of conveying screw instead of use of expander, calibrations of the machines, etc.), the more efficient the process becomes.

When applying some of these optimization examples, it is then possible to reduce energy consumption. In order to get an estimation of a possible energy saving, this study showed that up to 20% of the energy used could be saved by deleting less than 10% of the most consuming runs.

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