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Energy cost and parmesan cheese. An overview in the different energy fluxes needed to produce a parmesan wheel

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Abstract. Agriculture is responsible for up to 30% of the greenhouse gases emission, and cattle breeding is the main contributor making up almost 10% of the total. For this reason, this sector is a key player toward a complete decarbonization. To take the proper action to reduce climate impact of cattle breeding, it is necessary to know the energy requirements of the industry. This work focuses on the energy mapping of a parmesan cheese production, with reference to an agricultural company situated in Modena province with about six hundred animals. Knowing the electrical and thermal energy requirements to produce a wheel of cheese gives the possibility to the farmers to identify and reduce the energy wastage as well as starting the implementation of a strategy for fossil fuel substitution. In this study, a comprehensive monitoring campaign is presented together with the proposal of some possible improvements. The analysis showed that, considering the actual situation, about 64 kWh of electrical energy and 94 kWh of thermal energy are needed to produce a parmesan cheese wheel, while the fuel used to feed the agricultural machinery (e.g., tractors) accounts for around 174 kWh. In this context, the implementation of biogas and solar photovoltaic can greatly contribute to reduce the dependence on fossil fuels.

1. Introduction

Agriculture is responsible for up to 30% of the anthropogenic greenhouse gases emission, and cattle breeding contributes for about one third of the emission related to agriculture [1] and therefore the decarbonization of this sector is crucial in the fight against global warming.

To take the proper actions, it is important to know the factors affecting the emission of greenhouse gases in the atmosphere. Cattle breeding can be responsible for different categories of environmental impact such as eutrophication, nonrenewable energy use, land occupation, biodiversity loss etc. [1].

This work is focused only on the mapping of the energy needed to produce a wheel (approximately 40 kg) of parmesan cheese, namely Parmigiano-Reggiano, a Protected Designation of Origin produced in five provinces on the south bank of the Po River in Italy [1]. A medium-large size farm with cheese factory for the parmesan production situated in Modena province with about 350 lactating cows has been monitored to study its energy consumptions. The knowledge of the various energy expenditures for the cheese production is mandatory for an effective identification and reduction of the energy wastage. Furthermore, the implementation of a strategy for the substitution of fossil fuel can take place only with cognizance of the process energy requirement. To produce Parmigiano-Reggiano at least 50% of forage dry matter must be supplied by forage produced on the land of the farm and at least 75% of forage dry matter must be supplied by forage grown in the area of production of this cheese [2]. The considered farm produces 60% of the feed necessary for cow nutrition while concentrated feed, that constitutes about 40% of the feed, is purchased externally. The energy needed to produce this remaining 40% was not considered. Along with the results, some proposals to improve the environmental impact of the process are suggested in relation to the form of energy needed.

2. Material and methods

The production process of parmesan cheese has been investigated with reference to the energy requirements of the various stages. The requirements have been identified through an examination campaign of all the most significant equipment used in the process together with the help of the farmer for the utilization rate (annual operating hours) identification. The nominal powers were found out through an inspection of the nameplate data of the equipment. It was important to differentiate the electrical energy needs from the thermal ones because the strategies for an effective decarbonization of them can be different. From Table 1 to Table 7 the most significant equipment used in the cheese production process are summarized, allocated by energy cost center, showing their nominal power with an estimate of the annual operating hours. The energy source (electric, LPG or diesel) is also reported.

Table 1. Cheese factory equipment

Number	Machinery	Nominal power *P* [kW]	Operating hours *t* [h]	Energy source
1	Steam boiler	700.00	730	Diesel
1	Milk refrigerator A	12.0	2920	Electric
1	Water chiller vats	4.80	4380	Electric
1	Cream refrigerator	4.60	4380	Electric
1	Renner Fridge	0.50	4380	Electric
1	Diesel burner	1.72	730	Electric
1	Industrial Fermenter	0.50	1460	Electric
1	Electric boiler A	1.20	365	Electric

Table 2. Milking parlor equipment

Number	Machinery	Nominal power *P* [kW]	Operating hours *t* [h]	Energy source
1	LPG Boiler 1	35.00	2500	LPG
2	Vacuum blower A	7.10	2920	Electric
1	Pasteurizer	7.10	1460	Electric
2	Electric boiler A	1.20	1095	Electric
1	Electric boiler B	2.40	1095	Electric
1	Vacuum blower B	3.00	730	Electric
1	Milk refrigerator B	1.30	1460	Electric
1	Washing machine	1.76	730	Electric
1	Water softener	0.01	8760	Electric

Table 3. Stable equipment

Number	Machinery	Nominal power *P* [kW]	Operating hours *t* [h]	Energy source
38	Heat lamp for calves	0.25	1600	Electric
18	Fan A	1.00	2400	Electric
24	Fan B	0.57	2400	Electric
100	Lamp	0.04	4380	Electric
30	Fan C	0.09	1095	Electric

Table 4. Cheese warehouse equipment

Number	Machinery	Nominal power *P* [kW]	Operating hours *t* [h]	Energy source
1	Automatic electronic cheese scraping – turning machines	9.00	2080	Electric
1	LPG Boiler 2	15.00	1000	LPG
1	Air conditioning system A	5.50	1800	Electric
1	Cold Room	1.12	4380	Electric
1	Automatic cheese loading/unloading machine	7.17	260	Electric

Table 5. Offices equipment

Number	Machinery	Nominal power *P* [kW]	Operating hours *t* [h]	Energy source
5	Air conditioning system B	2.94	300	Electric
1	Air conditioning system C	2.69	300	Electric
1	Air conditioning system D	7.36	300	Electric

Table 6. Slurry treatment equipment

Number	Machinery	Nominal power *P* [kW]	Operating hours *t* [h]	Energy source
1	Compressor Systems	7.50	8760	Electric
1	Screw press separator	7.50	2373	Electric
1	Pump A	5.50	1460	Electric
1	Pump B	18.50	312	Electric
5	Oil pump	3.00	183	Electric

Table 7. Mill sector equipment

Number	Machinery	Nominal power *P* [kW]	Operating hours *t* [h]	Energy source
1	Graincrusher	9.00	139	Electric
1	Mill	5.90	286	Electric
1	Compressor	3.00	364	Electric

The annual amount of energy (E) for each cost center has been calculated with the equation:

$$E_{cost\ center\ n} = \sum_{i=1}^{m} P_{machinery\ i} \cdot t_{machinery\ i} \quad (1)$$

where t indicates the estimated annual operating hours of the machinery and P is its nominal power. Regarding the energy needed for field operations, identified as the cost center “Field”, they were clustered considering the annual diesel purchase bill of the company and subtracting from it the energy needed for the diesel boiler of the cheese factory (Equation 2).

$$E_{Field} = m_{diesel} \cdot LHV_{diesel} - P_{boiler} \cdot t_{boiler} \quad (2)$$

where *m* indicates the annual mass amount of purchased diesel, *LHV* indicates the diesel lower heating value (11.83 kWh kg^{-1} [3]), and *P* indicates the boiler nominal power. Another cost center called "Others" has been introduced to contain all the electric utilities that are not listed in the previous tables due their small size and/or the difficulties in the assessment of their annual consumption, such as outdoor lighting, workshop tools, inaccessible equipment (submersible pumps) etc.

The "Others" cost center has been roughly estimated considering the electric energy bill provided by the farmer. Dividing the various energy consumption in terms of the different functional areas and equipment is a well-known strategy [4] and it is useful to identify the energy process with the higher impact. The calculated energy costs were discriminated according to both the energy source and the utility typology (electric, thermal, and field). Most of the machinery reported in the tables were considered electric utilities, to differentiate them from thermal utilities the aim of which is to provide heat, and from field utilities (for field operation). It is important to note that when the goal of a machinery is to subtract heat (such as a refrigerator unit or air conditioning) they were here considered as electric utilities. Knowing the number of parmesan cheese wheels produced annually it was possible to calculate the various specific energy costs for each wheel. In relation to the form of energy needed some proposals to improve the environmental impact of the process are suggested eventually.

3. Results

From Table 8 to Table 14 the various energy costs divided by cost center and machinery are summarized considering the most significant equipment used in the cheese production process, reporting the utility typology (electric or thermal).

Table 8. Cheese Factory annual energy consumption

Number	Machinery	*E* [MWh]	Utilities typology
1	Steam boiler	511.00	Thermal
1	Milk refrigerator A	35.00	Electric
1	Water chiller vats	21.00	Electric
1	Cream refrigerator	20.10	Electric
1	Renner Fridge	2.19	Electric
1	Diesel burner	1.26	Electric
1	Industrial Fermenter	0.73	Electric
1	Electric boiler A	0.44	Thermal

Table 9. Milking Parlor annual energy consumption

Number	Machinery	*E* [MWh]	Utilities typology
1	LPG Boiler 1	25.50	Thermal
2	Vacuum blower A	41.50	Electric
1	Pasteurizer	10.40	Thermal
2	Electric boiler A	2.63	Thermal
1	Electric boiler B	2.63	Thermal
1	Vacuum blower B	2.19	Electric
1	Milk refrigerator B	1.90	Electric
1	Washing machine	1.29	Electric
1	Water softener	0.09	Electric

Table 10. Stable annual energy consumption

Number	Machinery	*E* [MWh]	Utilities typology
38	Heat lamp for calves	15.20	Thermal
18	Fan A	43.20	Electric
24	Fan B	32.60	Electric
100	Lamp	15.80	Electric
30	Fan C	2.96	Electric

Table 11. Cheese warehouse annual energy consumption

Number	Machinery	*E* [MWh]	Utilities typology
1	Automatic electronic cheese scraping – turning machines	18.70	Electric
1	LPG Boiler 2	1.50	Thermal
1	Air conditioning system A	9.90	Electric
1	Cold Room	4.91	Electric
1	Automatic cheese loading/unloading machine	1.86	Electric

Table 12. Offices annual energy consumption

Number	Machinery	*E* [MWh]	Utilities typology
5	Air conditioning system B	4.42	Electric
1	Air conditioning system C	0.81	Electric
1	Air conditioning system D	2.21	Electric

Table 13. Slurry treatment facilities annual energy consumption

Number	Machinery	*E* [MWh]	Utilities typology
1	Compressor Systems	65.70	Electric
1	Screw press separator	17.80	Electric
1	Pump A	8.03	Electric
1	Pump B	5.77	Electric
5	Oil pump	2.74	Electric

Table 14. Mill sector annual energy consumption

Number	Machinery	*E* [MWh]	Utilities typology
1	Graincrusher	1.25	Electric
1	Mill	1.69	Electric
1	Compressor	1.09	Electric

The annual consumption due to the field operations resulted in 1200 MWh while the energy consumption of the “Others” cost center has been assumed in 100 MWh. Figure 1 shows the specific energy consumption of each parmesan wheel divided in terms of energy source. At present, between 6700 and 6800 parmesan wheels are produced annually resulting in an energy cost of about 336 kWh per wheel.

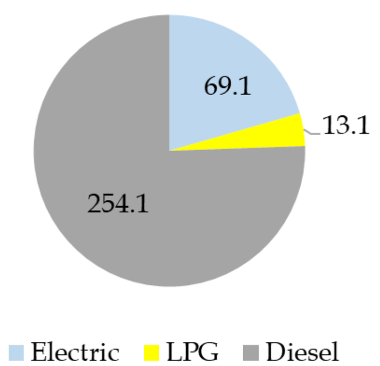

Figure 1. Specific energy cost by source [kWh/wheel]

As it is possible to see from the figure, the main source of energy employed for the cheese production process is diesel, for about two-thirds of the total, corresponding to about 21.5 kg of diesel used for each parmesan wheel. Field equipment typically uses diesel engines [5], however vehicles electrification has increased in the last years [6] therefore a mitigation of farm carbon footprint is possible [7] especially with agrovoltaic implementation [8]. Figure 2 depicts the energy consumptions grouped according to the utility typology.

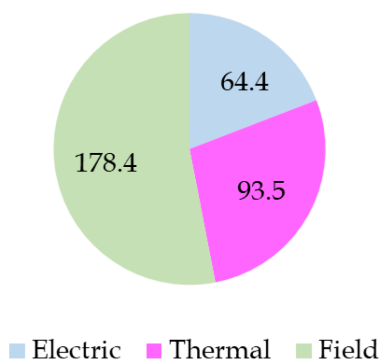

Figure 2. Specific energy cost by typology [kWh/wheel]

Field operations fueled through diesel require more than 50% of the energy needed for the process, followed by the thermal utilities. Last are electric utilities. Increasing the electric fraction as well as renewable generation can be effective for decarbonization [9].

Figure 3 presents the various electric utilities divided by cost center.

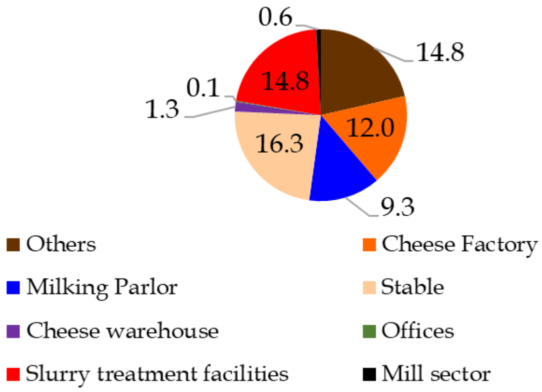

Figure 3. Specific electric energy cost by cost center [kWh/wheel]

Stable and slurry treatment facilities are the cost center with the highest electric energy demand. The "Others" cost center should not be considered totally independent but rather a fraction of it should be spread over the other cost centers.

Figure 4 shows that almost all the thermal requirements of the process are related to the cheese factory (≈ 81%) and the milking parlor (≈ 16%).

Figure 5 presents the thermal energy demands in terms of energy source.

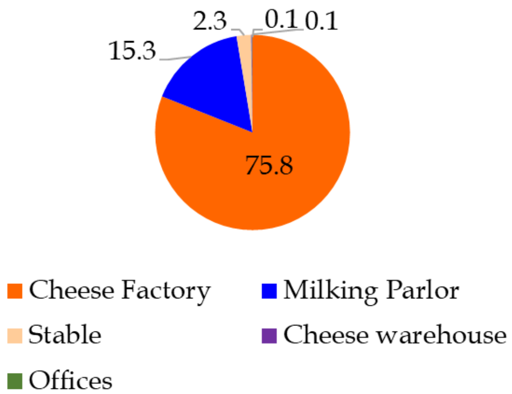

Figure 4. Specific thermal energy cost by cost center [kWh/wheel]

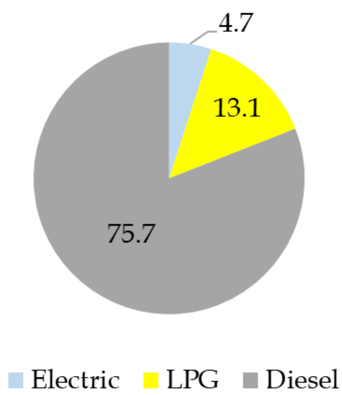

Figure 5. Specific thermal energy cost by source [kWh/wheel]

It is possible to see that diesel satisfies most of the thermal needs of the process. However, considering that every kg of burned diesel releases about 3.106 kg of CO_2 [10], every kWh obtained from diesel (upstream of any possible efficiency coefficient) results in a CO_2 emission of 265 g. On the other hand, 245 g are emitted for every kWh obtained burning LPG [11].

Therefore, increasing the use of LPG and reducing the diesel one could slightly improve the carbon footprint of the process. Furthermore, 2.75 kg of CO_2 are released every kg of methane that is burned [12], and its LHV is 13.90 kWh kg^{-1} [13], therefore 198 g of CO_2 are released for kWh obtained. For this reason, an even greater reduction of carbon dioxide emission would be possible substituting both diesel and LPG with methane. It is necessary to specify that this simple estimation does not consider the life cycles of the considered fuels.

Another possible strategy to improve the carbon footprint of the process would be a biogas power plant implementation. Production of biogas from anaerobic digestion of livestock waste has multiple advantages such as being a renewable energy source that does not depend on external elements (wind or sunlight) and improve the quality of livestock wastewater thanks to the conversion of the organic nitrogen into inorganic nitrogen (more bio-available for the plants) [14].

The considered farm is not self-sufficient concerning concentrate feed that constitutes about 40% of the animal's diet. However, even if this work considers only the energy consumption directly related to the company activities it is possible to affirm that another action that can be implemented to reduce its environmental impact is the production on-farm of the concentrate feed [1], as a consequence of the reduction of the transportation needed, even if it would result in an increase of farm energy consumption.

4. Conclusion

This work provides an energy mapping of the parmesan cheese production process with reference to a medium-large farm dividing its consumption in terms of typology of utility and energy source. The results show that for each wheel around 336 kWh are consumed and about two third of the entire process is performed exploiting diesel, that is used not only for field operation but also for most of the thermal needs such as the cheese factory steam boiler. Some improvements for the reduction of the carbon footprint of the company are suggested such as the increase in the share of the electric energy, the switch from diesel to LPG or methane, and the biogas and agrovoltaic implementation.

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