World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:8, No:4, 2014

Assessment of Energy Use and Energy Efficiency in Two Portuguese Slaughterhouses

M. Feliciano, F. Rodrigues, A. Gonçalves, J. M. R. C. A. Santos, V. Leite

Abstract**—**With the objective of characterizing the profile and performance of energy use by slaughterhouses, surveys and audits were performed in two different facilities located in the northeastern region of Portugal. Energy consumption from multiple energy sources was assessed monthly, along with production and costs, for the same reference year. Gathered data was analyzed to identify and quantify the main consuming processes and to estimate energy efficiency indicators for benchmarking purposes. Main results show differences between the two slaughterhouses concerning energy sources, consumption by source and sector, and global energy efficiency. Electricity is the most used source in both slaughterhouses with a contribution of around 50%, being essentially used for meat processing and refrigeration. Natural gas, in slaughterhouse A, and pellets, in slaughterhouse B, used for heating water take the second place, with a mean contribution of about 45%. On average, a 62 kgoe/t specific energy consumption (SEC) was found, although with differences between slaughterhouses. A prominent negative correlation between SEC and carcass production was found specially in slaughterhouse A. Estimated Specific Energy Cost and Greenhouse Gases Intensity (GHGI) show mean values of about 50 €/t and 1.8 tCO_2e/toe, respectively. Main results show that there is a significant margin for improving energy efficiency and therefore lowering costs in this type of non-energy intensive industries.

Keywords**—**Meat industry, energy intensity, energy efficiency, GHG emissions.

I. Introduction

ENERGY is a key factor to the global economy and the welfare of human population [1], [2]. Its strong connection to multiple economic, social and environmental issues makes energy a key element for sustainable development [3]. In the industrial sector, energy is nowadays acquiring special relevance in the decision-making structure of many world industries [4]. The widespread acceptance of the eco-efficiency concept by the industrial sector shows the increase of its awareness to reduce energy consumption and improve environmental performance [5], [6]. In fact, saving energy contributes to a more efficient production, increases competitiveness, enhances innovative capacity and allows industries to respond to environmental requirements imposed by law, market and society in general.

Despite general progresses in promoting sustainable energy policies, there has been a global increase in energy consumption in recent years [7]. This trend has been largely driven by the rapid development of emerging economies and it is likely to continue in the near future. Portugal, until 2005, faced a similar situation, as there was an increase in energy intensity when compared to the EU27 average. This unfavorable trend has been reversed over the last five years, but the development of more ambitious and dynamic efforts in promoting energy efficiency and energy saving still remains a priority in all sectors of society, and it is particularly relevant to highly competitive sectors such as the food industry.

Food industry is the second largest manufacturing sector in Europe, with a 12.2% market share and 14.5% of the total manufacturing turnover [8]. Among food industry worldwide, meat industry is a growing sector accounting for about 65% of the global food production [9]. Although most meat industries are non-intensive energy consumers, improving energy efficiency of industrial processes is one of the most important options for lowering the dependence on fossil fuels, while lowering costs and greenhouse gas emissions. Many studies (e.g. [10]–[12]) show that it is possible to reduce the energy consumption in meat industries, either by applying adequate strategies or by implementing some adjustments to existent processes.

The Inovenergy Project - Energy Efficiency in the Food Industry Sector was launched in 2011 with the objective of surveying and analyzing energy use, providing technical support, and thus promoting efficiency measures in six food industry subsectors: meat, fish, dairy, wine, fruit & vegetables and food conservation & distribution. Portuguese food industry is the largest of the manufacturing industry sectors, accounting for a 13.7% market share and with net sales of over 10 thousand million Euros in 2012 [13]. The meat industry is one of the most important areas within the Portuguese food sector and has been growing over the last decade [14], [15]. This article addresses an energy study conducted within the framework of the aforementioned project at two slaughterhouses, with the main purpose of assessing energy performance of this type of meat industry facilities.

II. Brief Description of Slaughterhouse Processes

The EU defines slaughterhouses as any premises, including facilities for moving or lairaging animals, used for the commercial slaughter of animals, as solipeds, ruminants, pigs, rabbits and poultry [16]. They can be specialized in a specific livestock, such as pigs, cattle, sheep, goats or rabbits, or they

M. Feliciano is with CIMO Research Center, Escola Superior Agrária do Instituto Politécnico de Bragança, Campus de Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal (corresponding author to provide phone: +351273303339; e-mail: msabenca@ipb.pt).

F. Rodrigues, J.M.R.C.A. Santos and A. Gonçalves are with CIMO Research Center, Escola Superior Agrária do Instituto Politécnico de Bragança, Campus de Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal (e-mail: fjmrodrigues@gmail.com, ajg@ipb.pt, josesantos@ipb.pt).

V. Leite is with Escola Superior de Tecnologia e Gestão do Instituto Politécnico de Bragança, Campus de Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal (e-mail: avtl@ipb.pt).

can be polyvalent.

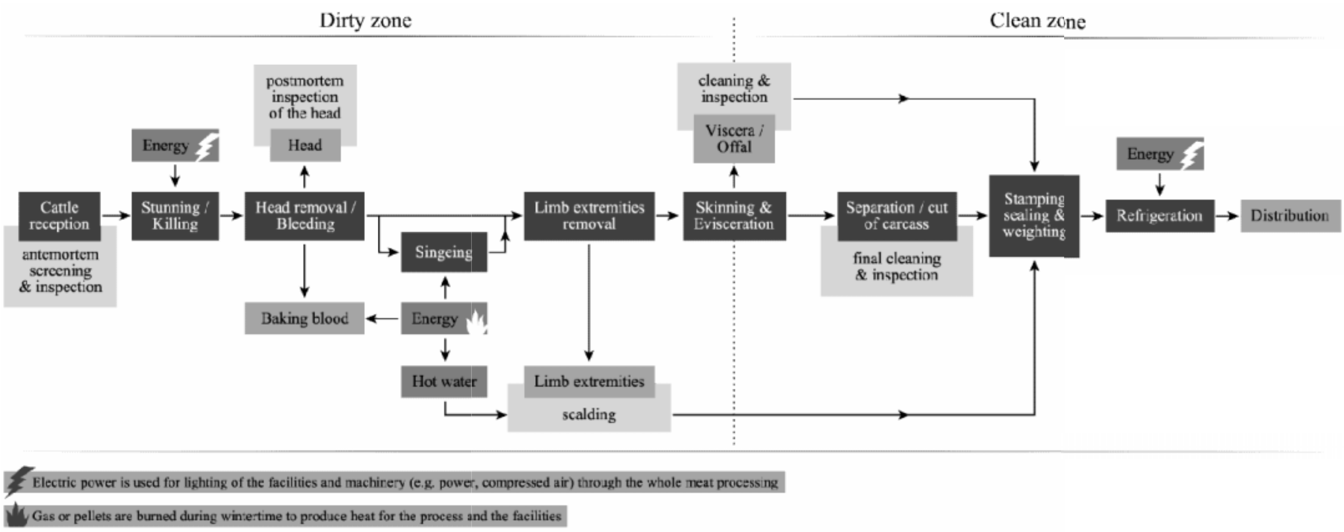

Fig. 1 General schematic of the process of meat production at a slaughterhouse

Slaughterhouses receive and process live animals into meat carcasses and by-products, such as blood, fat, meat scraps and bones, white and red offal and leather. By-products can also be processed on-site. Fig. 1 shows the main slaughterhouse processes, from the arrival of the animal, until its carcass is matured and ready for distribution and consumption. Typically, the slaughterhouse's processes are organized into two physical zones: the first one, named the dirty zone, concerns mostly the killing of the animal and the removal of its interior elements (organs and fluids); the second zone, named the clean zone, is dedicated to the preparation of both the carcass and viscera/offal for consumption. The evisceration is the process that usually defines the zones.

Energy supply is required to assure various processes, such as the killing (that requires an electric shock) or the singeing of some specific kinds of meat (e.g. pork), which requires gas, or other sources of energy to produce hot water for the scalding. Electric power is also used for illuminating facilities and to power the machinery along the production line, including the generation of compressed air. Energy supplies will also be necessary for cleaning and wastewater treatment. Other energy sources, such as natural gas or pellets, are usually burned in boilers to produce heat in order to bake the blood and to warm up the facilities, particularly during the cold weather. By the end of the process, meat and other goods are stored in cooling chambers which require electricity.

III. Methodology

The study was performed with the collaboration of two polyvalent slaughterhouses located in the northeastern region of Portugal, hereinafter referred to as SA and SB. Both industries slaughter cattle, goats, sheep and pigs, following a semi-automated slaughtering procedure. Both industries have similar installed capacity, but SA is slaughtering annually about 6,300 heads (cattle 41%; goats 12% sheep 40%; pigs 7%) and SB about 6,100 heads (cattle 45%; goats and sheep 40%; pigs 15%). Slaughtering processes differ significantly depending on the type of animal but in general follow the different stages illustrated in Fig. 1. Concerning the carcasses preparation, they are split, usually in two pieces, washed, stored in refrigerated chambers and then delivered to slaughterhouses' customers. Sometimes, carcasses can be further split according to the requisites of the final product, packed and stored until delivery.

The study methodology consisted in two different stages: an initial stage for surveying information on general industry characteristics (e.g. dimension, annual turnover, etc.), type, costs and amount of energy inputs, raw material and annual production; a second stage involving energy audits in the facilities, with the purpose of identifying and quantifying the major consuming processes, as well as pointing out energy inefficiencies. Finally, the gathered information was analyzed and used to estimate energy efficiency indicators (EEIs) widely employed for benchmarking purposes (Table I).

TABLE I
Indicators Used to Assess the Energy Efficiency of the Slaughterhouses

EEI	Formula	Terms
Specific energy consumption, SEC	$SEC = \frac{\sum Q_s}{P}$	Q_s, quantity of energy from source *s* [kgoe]; *P*, volume of production [ton].
Specific energy cost, SECost	$SECost = \frac{\sum C_s}{P}$	C_s, costs with energy from source *s* [€]; *P*, volume of production [ton].
GHG intensity, GHGI[a]	$GHGI = \frac{\sum E_s}{\sum Q_s}$	E_s, emission of CO_2 equivalent from energy source *s* [tons of CO_2e]; Q_s, quantity of energy from source *s* [toe].

[a] GHG (Greenhouse Gases) intensity is based on carbon dioxide equivalent emissions.

These EEIs are based on both the physical amount of the output (e.g. energy per unit of production and GHG intensity) and its economic value (e.g. specific energy cost). They were used due to their adequacy in evaluating the energy efficiency in manufacturing processes [17]–[20] including the meat industry [21].

The consumption for each energy source was examined monthly to assess its variation during a full calendar year in both slaughterhouses. A cost analysis was also performed with up-to-date energy prices for Portugal, to evaluate the EEI values and to assess the possible reduction of expenses. In order to determine the EEI values, the production was also evaluated for the same period. The study also provided information on the energy use per section/equipment so that specific cost reduction strategies could be presented (an aspect to be reported in further publications).

IV. Results

A. Energy Use

Fig. 2 shows the use of energy by both slaughterhouses, also identifying the consumption by source and by subsector. The annual energy consumption is 31 toe and 43 toe, for SA and SB respectively. According to the Portuguese legislation they are both non-energy intensive industries since their total annual energy consumption is below 500 tons of oil equivalent (toe).

Electricity and natural gas are the most used energy sources in SA, while SB relies on electricity and pellets for more than 90% of its total primary energy supply. The distribution of electric power per sector is similar in both organizations. In both cases, industrial cold, used for meat storage, is the main electricity consumer weighting around 50%, in line with findings reported for other European countries [21], followed by other production processes, compressed air production and lighting.

At SA, natural gas, used as fuel for hot heating generation required for processing animal parts and sterilizing utensils, represents 42% of the total energy consumption. The thermal energy in SB is provided by two wood pellets boilers. Wood pellets represent about 46% of total primary energy. Propane gas is also used in SB for singeing swine skins, being also used as a backup fuel in the boilers.

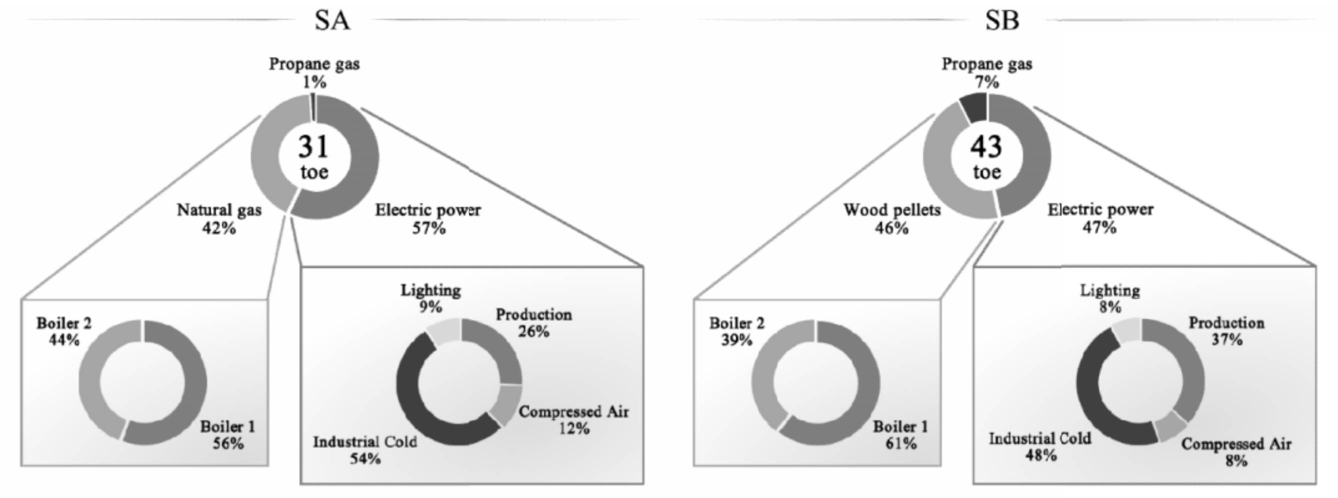

Fig. 2 Energy use for both slaughterhouses: consumption by source and by sector.

B. Production and Energy Use

Fig. 3 (a) depicts the monthly production and energy use evolution for both slaughterhouses. Production corresponds to dress weight carcass in tonnes. Production and energy use exhibit distinct annual profiles in each slaughterhouse. Concerning energy use, SB exhibits a higher fluctuation along the year (std value of 0.72 toe) with a marked increase in consumption during the summer months, especially in August. SA shows a near constant energy consumption throughout the year, with a standard deviation of 0.23 toe. Annual meat production is similar in both slaughterhouses, but SB has more irregular slaughtering rates than those observed in SA, which may be attributed to its location in a mostly rural county, where animal slaughter is demanded for the manufacture of traditional products such as smoked ham and sausages.

In order to better understand the relationship between energy use and production, an analysis based on the Energy Specific Consumption Indicator (SEC) was also performed. As shown in Fig. 3 (b), SEC decreases as production increases, being this relationship well evident for SA. At SB, the SEC ranges from 54 to 86 kgoe/t throughout the year, with only a slight tendency to decrease inversely to meat production. Correlation coefficients show that the linear model explains 93% (SA) and 33% (SB) of the data. Moreover, the main results also show differences around 10 kgoe/t (56 kgoe/t for SA and 66 kgoe/t for SB) between slaughterhouses. Ramírez et al. [21] report similar SEC values regarding primary energy and typical technologies for the late 1990s, such as 33.2 kgoe (cattle) or 50.1 kgoe (pork) per tonne of dress carcass weight.

C. Energy Use and Cost

Regarding the energy costs, SB spends about 1.1 times more than SA. However, based on the analysis of the SECost indicator (Fig. 3 (c)), it is evident that SB is more efficient for the typical productions. The energy cost per ton of meat is on average 1.06 times higher in SA (51.13 €/t) than it is in SB (48.03 €/t). For the most prevailing monthly productions, which are in the range 40-60 t/month, SB processes the same amount of meat with lower costs than SA, approximately 1/4 less.. The relationship found between SECost and production clearly shows that SA can substantially increase its efficiency by increasing its production.

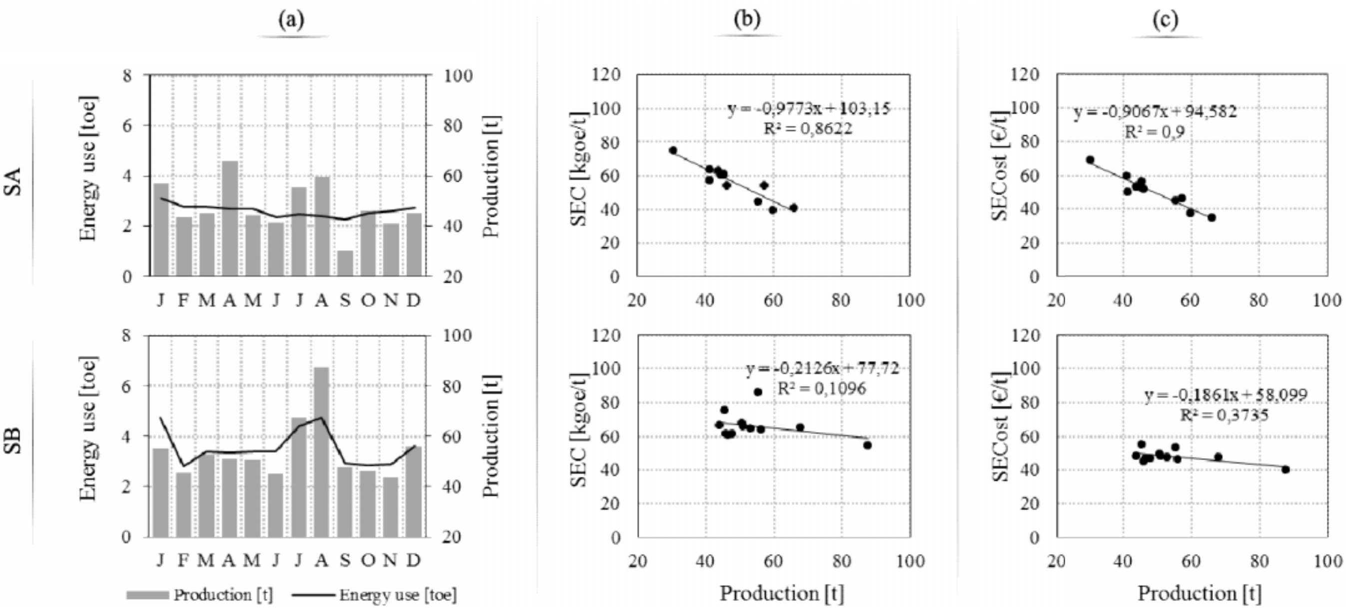

Fig. 3 Main results of the study conducted at slaughterhouses A and B: (a) Monthly energy consumption and meat production; (b) linear correlation between SEC and meat production; (c) linear correlation between SECost and meat production

D. GHG Emissions and Energy Use

The CO_2 equivalent emissions (CO_2e) were determined for each slaughterhouse, per energy source (see Fig. 4), using the conversions shown in Table II. Wood pellets as a biomass fuel are considered as carbon neutral [22]–[25], but GHG emissions from its combustion were also accounted for in the analysis.

TABLE II
CONVERSION FACTORS USED TO DETERMINE THE EQUIVALENT EMISSIONS OF CO_2

Energy source	Conversion/emission factor	Reference
Electric power[a]	1 kWh - 0.47 kg CO_2e	
Natural gas	1 kg - 1.077 kgoe - 2.89 kg CO_2e	[26]
Propane gas	1 kg - 1.099 kgoe - 2.90 kg CO_2e	
Wood pellets	1 kg - 0.401 kgoe – 0.746 kg CO_2e	[26], [27]

[a]Considering an efficiency of 40% on converting primary into final energy.

Main results show that SA emits less GHG, a total of 75 tCO_2e, than SB with 88 tCO_2e, when emissions from burning pellets are accounted for (Fig. 4), leading to GHG intensities of 2.4 tCO_2e/toe for SA and 2.05 tCO_2e/toe for SB. However, considering that carbon dioxide emitted from pellets combustion in SB is recycled into biomass as it grows, net CO_2e emissions from SB will drop to about 59%, lowering the GHG intensity of SB to 1.21 tCO_2e/toe. Even though SB uses more energy, its direct contribution for the radiative forcing is lower than those estimated for SA.

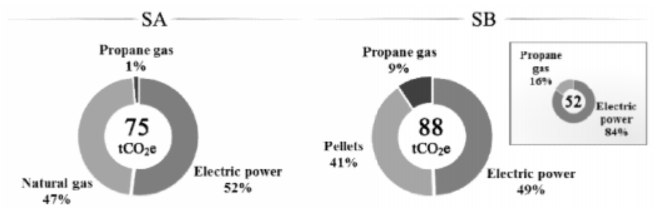

Fig. 4 CO_2 equivalent emissions, total and per sector, for each slaughterhouse

V. CONCLUSIONS

The energy surveys and energy audits performed in this study allowed for the definition of energy consumption profiles in both slaughterhouses. The main consumers in slaughterhouses were also identified and quantified. Monthly analysis of EEIs proved to be an important source of information due to the seasonality associated to this type of industries. SEC values showed that SA has a lower energy consumption per tonne of meat produced, while processing a lower amount, and it gets even lower when production increases. An identical reading was found for the cost, which also decreases when production rises. Therefore, results suggest that there is an increase in efficiency as the facility gets closer to its full capacity.

Regarding CO_2e emissions, it is expectable that the more energy is consumed, the more greenhouse gases are emitted.

Considering every energy source is not carbon neutral, SA can be considered as more efficient in terms of CO_2e emissions. However, when using biomass or a biomass derived fuel (e.g. pellets), accountable emissions decrease considerably, thus lowering GHG intensity.

Main results show that there is a relevant potential margin for improving energy efficiency and lowering costs in any slaughterhouse of the region. Therefore, Portuguese meat sector which is strongly dependent on meat imports can benefit from a better energy management throughout the whole meat production chain, including the slaughtering.

The representativeness of this study is low at the national context, but even so it represents an important contribution to fill in the significant gap existing in Portugal and in other parts of the world concerning energy evaluation in non-energy intensive companies. This study can also be a helpful contribution to raise awareness for energy efficiency and environmental optimization at slaughterhouses and other food industries.

Acknowledgment

This research was co-funded by the project INOVENERGY (Energy Efficiency in the Food Industry sector, FCOMP-05-0128-FEDER-018642).

The authors gratefully acknowledge the involved slaughterhouses for providing relevant data for this study.

References

[1] D.I. Stern, "The Role of Energy in Economic Growth". CCEP working paper 3.10. Centre for Climate Economics & Policy. Crawford School of Economics and Government, the Australian National University, Canberra, 2010.

[2] R.U. Ayres, J.C.J.M. van den Bergh, D. Lindenberger, B. Warr, "The underestimated contribution of energy to economic growth", *Structural Change and Economic Dynamics*, 27, pp. 79-88, 2013.

[3] A.K. Jorgenson, A. Alekseyko, V. Giedraitis, "Energy consumption, human well-being and economic development in central and eastern European nations: A cautionary tale of sustainability", *Energy Policy*, 66, pp. 419-427, 2014.

[4] K. Tanaka, "Review of policies and measures for energy efficiency in industry sector", *Energy Policy*, 39(10), pp. 6532-6550, 2011.

[5] S. Schmidheiny with the Business Council on Sustainable Development, "Changing course: a global business perspective on development and the environment", ISBN: 978-0-262-69153-6, MIT Press, 1992.

[6] V. Magueijo, M.C. Fernandes, H.A. Matos, C.P. Nunes, J.P. Calau, J. Carneiro, F. Oliveira, "Energy efficiency measures applicable to the Portuguese industry: a brief technological framework", ISBN: 978-972-8646-18-9, ADENE - Portuguese Agency for Energy, 2010.

[7] EIA, "International Energy Outlook 2013", U.S. Energy Information Administration, Office of Energy Analysis, U.S. Department of Energy, 2013.

[8] CEC, Commission staff working document "European industry in a changing world, updated sectorial overview 2009", SEC document, Commission of the European Communities, 1999.

[9] FAOSTAT, "FAO Statistical Yearbook 2013: World Food and Agriculture", ISSN: 2225-7373, Food and Agriculture Organization of the United Nations, Rome, Italy, 2013.

[10] A. Fritzson, T. Berntsson, "Efficient energy use in a slaughter and meat processing plant – opportunities for process integration", *Journal of Food Engineering, 7*6 (4), pp. 594-604, 2006.

[11] A. Fritzson, T. Berntsson, "Energy efficiency in the slaughter and meat processing industry – opportunities for improvements in future energy markets", *Journal of Food Engineering*, 77 (4), pp. 792-802, 2006.

[12] M. Alcázar-Ortega, C. Álvarez-Bel, G. Escrivá-Escrivá, A. Domijan, "Evaluation and assessment of demand response potential applied to the meat industry", *Applied Energy*, 92, pp. 84-91, 2012.

[13] INE, I.P, "Estatísticas da Produção Industrial 2012", ISBN: 978-989-25-0201-4, Instituto Nacional de Estatística, I.P., Lisboa, Portugal, 2013, from www.ine.pt.

[14] INE, I.P, "Estatísticas Agrícolas 2000", ISBN: 972-673-526-2, Instituto Nacional de Estatística, I.P., Lisboa, Portugal, 2001, from www.ine.pt.

[15] INE, I.P, "Estatísticas Agrícolas 2012", ISBN: 978-989-25-0198-7, Instituto Nacional de Estatística, I.P., Lisboa, Portugal, 2013, from www.ine.pt.

[16] Council Directive 93/119/EC, of 22 December 1993, on the protection of animals at the time of slaughter or killing, Official Journal of the European Communities, OJ L 340, pp. 21-34, (31/12/1993).

[17] B. Hyman, T. Reed, "Energy intensity of manufacturing processes", *Energy*, 20(7), pp. 593-606, 1995.

[18] S.L. Freeman, M.J. Niefer, J.M. Roop, "Measuring industrial energy intensity: practical issues and problems", *Energy Policy*, 25(7-9), pp. 703-714, 1997.

[19] X. Olsthoorn, D. Tyteca, W. Wehrmeyer, M. Wagner, "Environmental indicators for business: a review of the literature and standardisation methods", *Journal of Cleaner Production*, 9(5), pp. 453-463, 2001.

[20] D. Maxime, M. Marcotte, Y. Arcand, "Development of eco-efficiency indicators for the Canadian food and beverage industry", *Journal of Cleaner Production*, 14 (6-7), pp. 636-648, 2006.

[21] C.A. Ramírez, M. Patel, K. Blok, "How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries". *Energy*, 31(12), pp. 2047-2063, 2006.

[22] R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, D.J. Dokken, "Land Use, Land-Use Change, and Forestry Special Report", ISBN: 92-9169-114-3, Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, 2000.

[23] B. Wahlund, J. Yan, M. Westermark, "Increasing biomass utilisation in energy systems: a comparative study of CO_2 reduction and cost for different bioenergy processing options", *Biomass and Bioenergy*, 26(6), pp. 531-544, 2004.

[24] A.K.P. Raymer, "A comparison of avoided greenhouse gas emissions when using different kinds of wood energy", *Biomass and Bioenergy*, 30(7), pp. 605-617, 2006.

[25] H.K. Sjølie, B. Solberg, "Greenhouse gas emission impacts of use of Norwegian wood pellets: a sensitivity analysis", *Environmental Science & Policy*, 14(8), pp. 1028-1040, 2011.

[26] PEA, Portuguese environment Agency, "Portuguese National Inventory Report on Greenhouse Gases, 1990 – 2011", Amadora, Portugal, 2013.

[27] A.P. Fernandes, C. Alves, C. Gonçalves, L. Tarelho, C. Pio, C. Schimdl, H. Bauer, "Emission factors from residential combustion appliances burning Portuguese biomass fuels", *Journal of Environmental Monitoring*, 13, pp. 3196-3206, 2011.