LUIZ PAULO DE LIMA

SUSTAINABILITY IN THE BRAZILIAN DAIRY INDUSTRY: ENERGY EFFICIENCY AND BULK WATER CHARGING

Thesis presented to the Universidade Federal de Viçosa as part of the requirements of the Graduate Program in Food Science and Technology to obtain the title of *Doctor Scientiae*.

Advisor: Antonio Fernandes de Carvalho

Co-advisors: Gustavo Bastos Braga
Ronaldo Perez

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Assent:

Luiz Paulo de Lima
Author

Antonio Fernandes de Carvalho
Advisor

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ABSTRACT

LIMA, Luiz Paulo de, D.Sc., Universidade Federal de Viçosa, February, 2020. **Sustainability in the Brazilian Dairy Industry: Energy Efficiency and Bulk Water Charging**. Advisor: Antonio Fernandes de Carvalho. Co-advisors: Gustavo Bastos Braga and Ronaldo Perez.

The increase in the average temperature of the Earth, the increase in the sea level and the scarcity of water resources are just some of the environmental phenomena that have demonstrated the importance of mitigating or compensating the impacts of human actions, such as those of industrial activities. However, industrial activities are also responsible for generating jobs, wealth and food. In Brazil, the dairy sector represents the second largest segment within the food industry. Thus, considering its relevance and, consequently, its ability to impact the environment, this thesis aimed to conduct an investigation on aspects of its sustainability: (i) analysis of the energy matrix and energy efficiency of the Brazilian dairy industry; and (ii) evaluation of the impact of charging for the bulk water use in the dairy industry. The first part of this thesis was conducted based on data collected through a questionnaire, applied to managers of Brazilian dairy industries. The data come from 37 cheese producing establishments, distributed among the Brazilian regions. They were analyzed using descriptive statistics and data envelopment analysis. In the second part of this thesis it was development a case study for a dairy industry that produces mozzarella cheese. In this case, the data were analyzed using descriptive statistics. Among the results obtained, it was observed that firewood is the most used fuel in the generation of thermal energy, while diesel is the most used in the generation of electricity. There was greater efficiency of scale (76.1%) than pure technical efficiency (48.4%). However, dairy products have a low level of energy efficiency (34.9%). Regarding the use of water, the price increase related to charging by its use was low (from 0.04 to 0.09% of production costs), indicating that this cost can be absorbed by the industries. However, it should be noted that these values are relevant to the implementation of several actions to improving the quantity and quality of water. There is a future perspective of a more rational use of the natural resources in the Brazilian dairy industry. However, it should occur gradually from the entry of new more competitive dairy establishments, and from the development of policies associated with the internalization of environmental impacts caused by users/polluters.

Keywords: Energy matrix. Food industry. Milk processing. Natural resources. Water pricing.

RESUMO

LIMA, Luiz Paulo de, D.Sc., Universidade Federal de Viçosa, fevereiro de 2020. **Sustentabilidade na Indústria de Laticínios do Brasil: Eficiência Energética e Cobrança pelo Uso da Água**. Orientador: Antonio Fernandes de Carvalho. Coorientadores: Gustavo Bastos Braga e Ronaldo Perez.

O aumento da temperatura média da Terra, do nível do mar e a escassez de recursos hídricos são apenas alguns dos fenômenos ambientais que demonstram a importância de mitigar ou compensar os impactos provenientes de ações antrópicas, como aqueles das atividades industriais. No entanto, as atividades industriais também são responsáveis pela geração de empregos, riquezas e alimentos. No Brasil, o setor de laticínios representa o segundo maior segmento dentro da indústria de alimentos. Dessa forma, considerando a sua relevância e, consequentemente, a sua capacidade de impactar o meio ambiente, esta tese objetivou realizar uma investigação sobre aspectos de sua sustentabilidade: (i) análise da matriz energética e da eficiência energética da indústria de laticínios brasileira; e (ii) avaliação do impacto da cobrança pelo uso da água bruta na indústria de laticínios. A primeira parte desta tese foi conduzida a partir de dados coletados realizada por meio de um questionário, aplicado a gestores de indústrias de laticínios brasileiras. Os dados são provenientes de 37 estabelecimentos produtores de queijo, distribuídos entre as regiões brasileiras. Os dados foram analisados por estatística descritiva e análise de envoltória de dados. Já a segunda parte desta tese foi desenvolvida a partir de um estudo de caso para uma indústria de laticínios produtora de queijo muçarela. Neste caso, os dados foram analisados por estatística descritiva. Entre os resultados obtidos, observou-se que a lenha é o combustível mais utilizado na geração de energia térmica, enquanto o diesel o mais utilizado na geração de energia elétrica. Houve maior eficiência de escala (76,1%) do que eficiência técnica pura (48,4%). No entanto, os laticínios apresentam baixo nível de eficiência energética (34,9%). Com relação ao uso da água, o incremento de preço relacionado à cobrança pelo seu uso foi baixo (de 0,04 a 0,09% dos custos de produção), indicando que este custo pode ser absorvido pela indústria. Entretanto, cabe ressaltar que estes valores são relevantes para a implementação de diversas ações para a melhoria na quantidade e na qualidade da água. A perspectiva futura em relação à sustentabilidade na indústria leiteira brasileira é o uso mais racional dos recursos naturais. Isto deve ocorrer, gradualmente, a partir da entrada de novos estabelecimentos, mais competitivos, e do desenvolvimento de políticas associadas à internalização dos impactos ambientais causados pelos usuários/poluidores.

Palavras-chave: Indústria de alimentos. Matriz energética. Preço da água. Processamento de leite. Recursos naturais.

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1 GENERAL INTRODUCTION

"*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (UN, 1987, p. 41). The Brundtland Report, which set out the definition of what we denominated *sustainable development*, was published in 1987. Since then, phenomena such as rising average temperatures, melting glaciers, rising sea levels (IPCC, 2014; RIPPLE et al., 2020), scarcity of water resources (NOTARNICOLA et al., 2012), contamination of water and soil resources (MARQUES et al., 2007), loss of biodiversity, desertification (NOTARNICOLA et al., 2012), and many others, have become increasingly frequent.

At the same time, scientists have worked to understand the causes of these phenomena. Among the main agents identified, perhaps the main one, are the industrial activities (NOTARNICOLA et al., 2012; IPCC, 2014; RIPPLE et al., 2020). All industrial activity causes environmental impacts as, for example, those wicht are consequence of the fossil fuel consumption (LIMA et al., 2018), of the greenhouse gas emissions (HORTON et al., 2016), and of the solid waste and effluent generation (CHERUBINI et al., 2014). The environmental impacts, of course, are mainly associated with the portfolio and the size of the enterprise (LIMA, 2018).

At the same time, there are many economical instruments capable to mitigate/internalize environmental impacts from industrial activities, as: negotiation among agents, imposition of standards, pollution market, and taxations/subsidies (PEARCE and TURNER, 1990). In Brazil, the instruments more used are imposition of standards and taxations/subsidies. The imposition of standards, for example, are present in the National Solid Waste Policy (BRASIL, 2010) and in the effluent discharge conditions and standards (CONAMA, 2011), while the taxations and subsidies are present respectively in the National Water Resources Policy (BRASIL, 1997) and in the distribution of resources from the Tax on Circulation of Goods and Services – ICMS (in Portuguese) (PARANÁ, 1990).

According to 2017 data, the Brazilian food industry is the main manufacturing industry in terms of revenue (IBGE, 2019c). In 2018, the sector's revenues reached R$ 656.0 billion – 9.6% of the Brazilian Gross Domestic Product (ABIA, 2019). However, despite the existence of some studies on the Brazilian energy matrix (GOLDEMBERG et al., 2002; GOLDEMBERG and PRADO, 2010), there is a lack of studies on the characteristics of specific industrial sectors (LAMAS and GIACAGLIA, 2013), as dairy sector, and how the environmental impacts from these industries can be mitigated/internalized.

Within the food Brazilian industry, dairy industries represent the second most relevant sector in terms of revenue (ABIA, 2019),and Brazil is the third largest milk producer in the world, with production of 33.5 × 10^9 t, in 2017 (FAO, 2019). In addition, data from the Brazilian Institute of Geography and Statistics – IBGE (in Portuguese) indicate that over 70% of this milk is processed in dairy industries (IBGE, 2019a; 2019b).

According to Lima et al. (2017), Brazilian dairy industries are geographically distributed in a scattered form and have a diversified production profile. Thus, the potential environmental impacts from these activities can goal all Brazilian regions. Consequently, the analysis of the sustainability in the Brazilian dairy industry emerges as a potential case study. Therefore, this thesis objective is to analyze: (i) the energy mix and energy efficiency, and (ii) the charge for the bulk water use in the Brazilian dairy industry.

2 LITERATURE REVIEW

Environmental impacts of the food industry

According to Conselho Nacional do Meio Ambiente Resolution No. 1 of 1986 (CONAMA, 1986), environmental impact is: "(...) *any change in the physical, chemical and biological properties of the environment, caused by any form of matter or energy resulting from activities that directly or indirectly affect*:

I. *The health, safety and welfare of the population;*
II. *Social and economic activities;*
III. *The biota;*
IV. *The aesthetic and sanitary conditions of the environment;*
V. *The quality of environmental resources".*

For the ABNT NBR 14001 (ABNT, 2015), environmental impact can be defined as a "*change in the environment, both adverse and beneficial, wholly or partially resulting from the environmental aspects of an organization*".

Food production makes use of a large amount and variety of inputs (KORONEOS et al., 2005). And, like all industrial processes, it causes environmental impacts on air, water and/or soil (ABRE, 2006), throughout its entire production chain: production of raw materials, processing, distribution and disposal (CASTANHARI, 2013; DEL BORGHI et al., 2014). In research conducted on Irish farms, for example, Murphy et al. (2017) found that the production of 1 kg of milk requires, an average, 690 L of fresh water[1]. For yogurt production in a Spanish dairy[2], Vasilaki et al. (2016) found that 1 kg of yogurt produced consumes 204 L of water and emits 1.94 kg of CO_{2eq}.

In Brazil, Léis et al. (2015) found that the production of 1 kg of raw milk in the filed emits 0.535-0.778 kg of CO_{2eq}, depending on the dairy production systems. Campos et al. (2019) found that the production of 500 g of butter emits 2.91 kg of CO_{2eq}, and that the production of 500 g of margarine emits 0.63-2.69 kg of CO_{2eq}, depending on the region who soybeans are from[3]. Despite the previous examples, there are few case studies destined to cover the Brazilian food production. In addition, these studies are not focused on the impacts of the industrial chain, but in those from

[1] This study cover the consumption of soil moisture due to evapotranspiration, the consumption of ground and surface water, and the freshwater used for cultivation of crops for concentrate production, on-farm cultivation of grass or fodder and water required for animal husbandry and farm maintenance.
[2] Considering the impacts from milk production in the field to the final product in the industry.
[3] This study cover the impacts of the products produced from the field stage to its packed form.

agricultural production (CHERUBINI et al., 2014; MACIEL et al., 2016; CARDOSO et al., 2017; ZORTEA et al., 2017; CARDOSO et al., 2019).

Wastewater, soil nutrient loss, fertilizer leaching, deforestation, pesticide runoff, increased tropospheric ozone concentration and CH_4, N_2O and CO_2 emissions are some of the environmental aspects associated with food production (HORTON et al., 2016). These, in turn, are commonly associated with environmental impacts such as global climate change, water scarcity, decreased water and soil quality, loss of biodiversity, spread of "super weeds", and desertification (NOTARNICOLA et al., 2012). Food production is one of the segments that most contributes to our carbon- and energy-footprints. Global greenhouse gas emissions from agriculture, forestry and fisheries totaled 5.3 Gt CO_{2eq}, in 2011 (FAO, 2014). The China food industry, for example, accounted for the emission of about 140 Mt CO_{2eq}, in 2012 (LIN and XIE, 2015).

In order to reduce these impacts, the companies have focused themselves in the potential impacts of their activities, products and services aimed to review their strategies to cleaner technologies (BRANDLI et al., 2009). Among the factors that motivate companies to change their environmental policies are the society's awareness, the market pressure and the advancement of environmental legislation (BARBOSA JÚNIOR et al., 2008). Mello and Pawlowsky (2002) point out that the environmental issue has been incorporated into the analysis and the planning of the productive process of companies, being considered a possible competitive differential.

Consumers, in turn, are increasingly willing to purchase environmentally appealing products and services. According to research data conducted by Tetra Pak (2017), Brazilian consumers value recyclable products that contain environmental seals. However, the price difference between products and the lack of information about sustainable attributes are barriers of these products in the market. In a study with Brazilian consumers, Silva et al. (2017) found that sustainability labeling (seal and/or indication of organic, origin and quality, and sustainable agriculture) influenced the sensory acceptance of dark chocolate samples.

Energy use in the food industry

It is estimated that in 2017, the Brazilian industry was responsible for 32.9% of the energy consumed in Brazil, including the use of electricity as a fuel for the generation of either or both electricity and thermal energy. Food and beverage industries consumed 9.0% of this total (EPE, 2018). Specifically in food and beverage industries the main energy source were: sugar cane bagasse (73.7%), electricity (10.1%), and firewood (9.5%) (EPE, 2018).

In the food industry, the energy may be consumed in two different ways: through the use or generation of electricity, or through the production of thermal energy. While electricity is used for the operation of equipment and manufacturing facilities, thermal energy is used in heat systems to produce either or both hot water and steam (SAIDUR et al., 2010). In the last case, hot water and steam are generally produced in boilers fueled with oil, coal or gas, operating with a pressure between 900–1,100 kPa, and efficiency that varies from 80 to 92% (BYLUND, 1995).

According to Lima et al. (2018), the Brazilian dairy industries mainly use firewood for thermal energy generation. Despite being a renewable fuel source, it is considered less efficient than other renewable sources, such as woodchips and sugarcane (NASCIMENTO and BIAGGIONI, 2010). The largest use of the wood may be associated with the availability of planted forests (POTTMAIER et al., 2013). In 2015, Brazil had around 46.8 Mt of wood residues from the processing and forest harvesting industry (IBÁ, 2016). A considerable portion of these residues is left in the field to fertilize the soil and the other part, composed of woodchips, small firewood, sawdust and paper scraps, is used to generate energy by burning in boilers for steam and electricity for their industries but also other consumers, such as the food, agriculture, feed and textile industries.

On other hand, fuel diesel is the most used for electric power generation. Though it is more efficient than other energy sources, with a higher calorific value, the diesel is a non-renewable fuel (LIMA et al., 2018). Tsai et al. (2014) and Yang et al. (2015) mentioned that the advantages of the diesel engines in the generators are due to its output power and fuel efficiency, as regards calorific value.

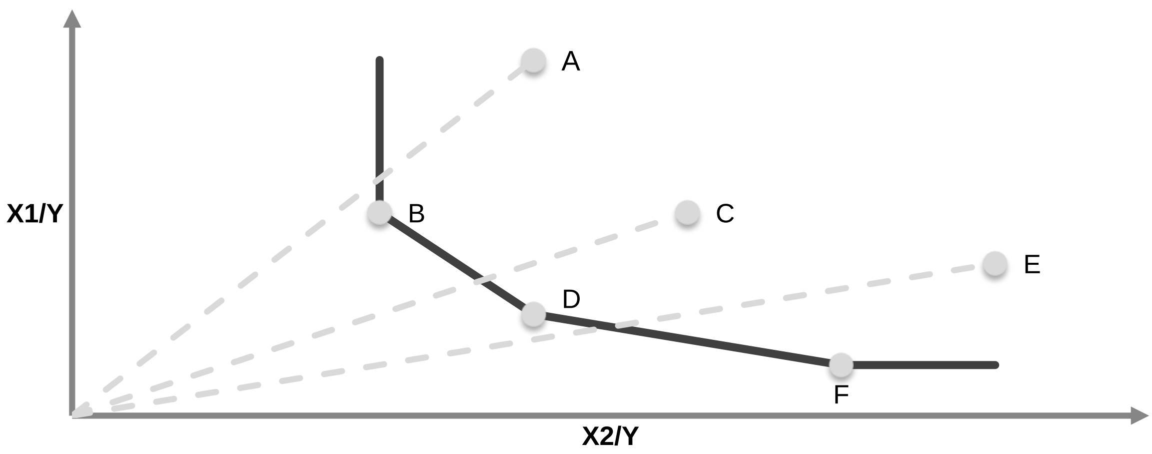
According to Liukkonen and Hiltunen (2014, p. 444), "*the type and amount of emission in energy boilers depend highly on the quality of the fuel used, for which changes in the fuel quality usually inflict changes in the emissions*". In this sense, the demand for alternative sources of fuels has grown. However, the determining factor in the search for new energy sources, renewable or not, is commonly only the economic aspect. As stated by Saidur et al. (2011), companies are continually looking for new fuels that are less expensive than the traditional ones.

Data envelopment analysis

The Data Envelopment Analysis – DEA models consist of a mathematical programming approach capable of measuring a relative relationship between different producers (decision-making units – DMUs), based on inputs and outputs (CHARNES et al., 1978). These models use of multi-factor productivity analysis to measure the relative efficiency of a homogeneous set of DMUs (CHARLES and ZEGARRA, 2014).

In DEA, the models can be input- or output-oriented. When output-oriented, the efficient DMU is one that maximizes the quantities of products produced from the consumption of a certain amount of inputs. When input-oriented, the efficient DMU is one that minimizes the quantities of inputs consumed from the production of a certain quantity of products (DIMARA et al., 2008). In input-oriented models, the efficient production frontier is convex in relation to the origin of the coordinated axes (Figure 1), while in output-oriented models this frontier is concave (FERREIRA and GOMES, 2009).

Figure 1. Illustration of the DMUs and the efficiency frontier for Data Envelopment Analysis of a product (Y) and two inputs (X_1 and X_2), with input-oriented, through constant returns to scale.



The efficiency frontier provides the identification of efficient DMUs that will serve as a reference for the other DMUs in the sample. Thus, it is possible to determine optimal values for the inputs and outputs of the DMUs present in the analysis, and to detect gaps in the use of resources or in the production of products (CHARLES and ZEGARRA, 2014). In this way, the models aim to find the best virtual DMU (from the radial projection of the DMUs at the efficiency frontier) for each DMU (original) in the sample. If the virtual DMU is better than the original one, the latter is considered inefficient (FERREIRA and GOMES, 2009). In Figure 1 DMUs B, D and F form the efficiency frontier. Then, these DMUs being taken as benchmarks for the others. Consequently, DMUs A, C and E are considered inefficient, since for each of them, it is possible to design a more efficient virtual DMU at the efficiency frontier.

It should be noted that the position on the frontier is a necessary condition, but not sufficient for efficiency. In addition to being on the efficiency frontier, there is a no-slack (waste) need in that DMU, which is characterized by the sum of slack variables equal to zero (SEIFORD and THRALL, 1990). In Figure 1, for example, it is possible to observe that the radial projection of DMU A on the frontier would give rise to a false-efficient DMU, since DMU B is able to obtain the same production (Y), with the same consumption of input X_2, but less consumption of input X_1. Therefore, more efficient.

The DEA model of Constant Returns to Scale – CRS emerged in 1978 (CHARNES et al., 1978). This model considers constant returns to scale and is therefore suitable for sets of DMUs that have similar sizes. The DEA model of Variable Returns to Scale – VRS emerged in 1984 (BANKER et al., 1984). This model considers variable returns of scale and, therefore, can be used for sets of DMUs that have variable sizes. Using the CRS model, a score is obtained for global technical efficiency. According to Farrel (1957), technical efficiency reflects the ability of a firm to obtain the maximum amount of products, given a set of inputs, or to consume the minimum of inputs, given a set of products. Through the VRS model it is possible to obtain a score for pure technical efficiency, comparing each DMU only with those that are similar in size (KHOSHROO et al., 2013). The ratio between the scores obtained for global technical efficiency and pure technical efficiency is provides the scale efficiency. According to Ferreira and Gomes (2009), scale efficiency is associated with the most adequate level of production for a given DMU, in agreement with technology adopted.

The CRS model input-oriented can be represented by the Linear Programming Problem 1 – LPP 1, illustrated in Table 1, while the VRS model input-oriented can be represented by LPP 2. LPP 3 is used for identify the DMU's scale return. In this case, it is imposed a condition of non-increasing ($N_1\lambda \leq 1$) or non-decreased ($N_1\lambda \geq 1$) returns to scale. Then, the pure technical efficiency scores generated are compared with those that are obtained using the model with variable returns to scale (SOUZA et al., 2011).

Table 1. Linear Programming Problems – LPP with constant returns and variables returns of scale, input-oriented

Item	LPP 1	LPP 2	LPP 3
Function	$min_{\phi,\lambda}\phi$	$min_{\phi,\lambda}\phi$	$min_{\phi,\lambda}\phi$
Restrictions	$\phi x_i - X\lambda \geq 0$ $Y\lambda - y_i \geq 0$ $\lambda \geq 0$	$\phi x_i - X\lambda \geq 0$ $Y\lambda - y_i \geq 0$ $N_1\lambda = 1$ $\lambda \geq 0$	$\phi x_i - X\lambda \geq 0$ $Y\lambda - y_i \geq 0$ $N_1\lambda \leq 1$ $\lambda \geq 0$

Source: Ferreira and Gomes (2009), adapted.

where: y_i is a vector (m x 1) of product quantity of the i-th DMU; x_i is a vector (k x 1) of input quantities of the i-th DMU; Y is a matrix (n x m) of products from the n DMUs; X is a matrix (n x k) of inputs from the n DMUs; λ is a vector (n x 1) of weights; ϕ is a scalar that has values less than or equal to 1 and indicates the technical efficiency score of the i-th DMU in relation to the others; and N_1 represents a vector (N x 1) of numbers ones. The calculation of (1 - ϕ) indicates the proportional reduction in the inputs that the i-th DMU can obtain, keeping the quantity of products constant. The linear programming problems must be solved n times, once for each DMU. Thus, there is a specific efficiency score for each production unit.

Water use in the food industry

Water is a vital resource for life on the planet and essential for many man-made processes (CARVALHO et al., 2012), such as food production (FAGGION et al., 2009). Industrial activities are responsible for 17% of all water consumed in Brazil (CNI, 2013a) and, according to data from the National Water Agency – ANA (in Portuguese) (ANA, 2017a), the Food Products sector is responsible for 42% of total water consumed by industrial activities, while the beverage sector accounts for another 6%. According to Ramjeawon (2000), the food industry is one of the largest industrial sectors in the world and, although not considered the most impactful, it is capable of causing severe environmental pollution, if improperly designed or operated.

In the food industries, water is collected, used in production processes (steam production, ice and cold water production, brine production, detergent and sanitizer dilution, personal hygiene, etc.), treated and, later, returned to the water bodies. Thus, food industries are susceptible to the water context of the region in which they are installed and, as such, problems related to water availability can mean, among others, production losses and increased production costs (LIMA, 2018).

However, water collection is not the only impact generated by the food industry in relation to its use. In some cases, such as in beverage producing industries, a considerable part of the volume of water collected is incorporated into the product composition (CERVBRASIL, 2015). In addition, effluents generated by food industries, in general, even after proper treatment, may have high organic load and/or high concentration of other pollutants (e.g. nitrogen, phosphorus). Thus, the water available in the water bodies is also used to dilute this pollution, when the food industry effluents are disposed in them.

Water demand in industry is function of the type of product produced, the production technology adopted and other factors such as industrial management and plant maintenance (LIMA, 2018). According to Silva (2011), for example, larger dairies have a water consumption coefficient per liter of processed milk and chemical oxygen demand (COD) content present in the effluent lower than smaller dairies. In addition, the level of employee awareness tends to exert greater influence on the environmental aspects of smaller industries, as in general there is a greater need for manipulation (SILVA, 2011). Thus, water consumption per producing unit may vary widely (Table 2).

Despite the increasing participation of industry in total water demand and the impact of effluent discharges into water bodies, the role of water in the industrial sector is still a little studied subject in Brazil (FÉRES et al., 2005). According to data from the ANA (2017b), the demand by the water use in Brazil has grown by 80% in the last two decades, with a 30% growth projection by 2030. And, according to Féres et al. (2005) and ANA (2017a), there are few consistent data on water use in the industrial sector, which represents an obstacle to the characterization of industries in terms of water use and pollutant input to the basins. However, characterizing the industrial use of water is extremely important to assessing the impact of water resources management policies on the sector, such as the charging for water use and for pollution generated according to user-pays and polluter-pays (FÉRES et al., 2005).

Table 2. Volume of water collected, consumed and disposed, in m^3, by industrial activity

Industrial activity	Activity unit	Collection	Consumption	Effluent
Dairies	m³ of milk	1.1-2.0	-	1.6-2.2
Grinding, manufacture of starch and feed products	t produced	1.7-3.0	0.3-1.2	1.4-1.8
Manufacture of malt, beer and draft beer	m³ produced	4.0-5.4	0.8-1.2	3.2-4.3
Manufacture of vegetable and animal oils and fats	t of raw material	0.2-14	-	0.2-14
Non-alcoholic beverage manufacturing	m³ produced	1.4-3.0	0.9	0.5-2.1
Slaughtering pigs, poultry and other small animals	t of live animal	4.0-12.0	0.5-1.5	3.5-10.5
Sugar manufacturing and refining	t of processed sugarcane	8.0-35.0	8.0-35.0	-

Source: CNI (2013b).

Charging for bulk water use

In Brazil, several laws have been approved to preserve the environment as tools for controlling the environmental impact of industrial practices. The regulation of groundwater collection through the granting of concessions (BRASIL, 1997), the regulation of effluent discharge (CONAMA, 2011), the charging for the use of bulk water for economic purposes[4] (BRASIL, 1997), and the sanctions for those who violate legal norms (BRASIL, 1998; 2008) are just some of them. Other examples of advances in search of more sustainable practices are the latest organic agricultural expansion (IFOAM, 2019), the increase in the number of companies concerned with sustainable actions (BRANDLI et al., 2009) and the release of reports on sustainability by large companies.

In 1981, Law No. 6,938 defined the objectives of the National Environmental Policy (BRASIL, 1981). In its Art. 4, item VII, the referred Law imposed to the polluter and the predator the obligation to recover and/or to compensate the damages caused and, to the user, the contribution for the use of environmental resources for economic purposes. Subsequently, the Federal Constitution of 1988, underlined in its Art. 25 that all waters belong to the union and the states, being included in the category of public goods of common use (BRASIL, 1988). But only with the establishment of the National

[4] It should be noted that, in addition to the variations that exist between the charging amounts, due to the charging models adopted by the each River Basin Committee, in many parts (basins) of the country, this charge is non-existent.

Water Resources Policy, established by Law No. 9,433, that modern criteria were introduced into the Brazilian legal system, establishing, among other, that water is a natural resource limited and economic, social and ecological valuable, indicating to users its real value. In this sense there is the charge for the use of water resources, which has as objectives (BRASIL, 1997):

i) indicate the actual value of water to its user;
ii) encourage its rational use; and
iii) obtain resources for basin recover.

According to Correa (2016), charging for the bulk water use carries the concept that water is a public economic good and it is necessary to encourage the rationalization of its use. Thus, this charging can be considered an economic instrument with the objective of ensuring the sustainable management of this natural resource (CARRERA-FERNANDEZ, 1997; PEREIRA and TAVARES, 1999), and it is a good solution for the sustainable management of this natural resource. Especially considering the scarcity of the country's economic resources, which impacts its ability to police pollution, as well as to invest in the water bodies (PEREIRA and TAVARES, 1999).

Currently, charging for bulk water use follows the dominance of water between the states (Médio Paraíba do Sul/Rio de Janeiro, Mogi/São Paulo, Piranga/Minas Gerais, etc.) and the union (Paraíba do Sul, Rio Doce, São Francisco, etc.), being present in both. Models for charging for the use of bulk water for each installment (capture, consumption, release and transposition) follow the calculation structure (1). The mechanisms for charging for bulk water use and the amounts charged are discussed within each River Basin Committee among representatives of the various water user sectors, civil organizations and public authorities (ANA, 2014).

$$Amount\ charged = (Basis\ of\ calculation).(Unit\ price).(Coefficients) \qquad (1)$$

where *Amount charged* is the financial value of each installment (capture, consumption, release or transposition) corresponding to the charge for the use of water resources; *Basis of calculation* refers to the volume of water used for extraction, consumption, release (and/or dilution), or transposition; *Unit price* defines the unit financial value per m^3 of water use, based on the objectives of the collection instrument; and, the *Coefficients* aim to adapt the defined mechanisms to objectives, specificities of the basin or specific uses.

It is noteworthy that this charge is not a tax, rate, tariff or contribution, but a public price, because its mechanisms and values are negotiated through public debate within the River Basin Committees, and not by isolated decisions of governmental bodies (ANA, 2014). Moreover, the legislation establishes a specific destination for the collected resources: the recovery of the watersheds in which they are generated (ANA, 2017b). According to Law No. 9,433 (BRASIL, 1997), the funds collected from the charging should be applied primarily to the watershed in which they were generated, and should be used to: finance studies, programs, projects and works included in the Water Resources Plans; implementation and administrative costing of the organs and entities of the National Water Resources Management System (up to 7.5% of these expenses may be used); and, in projects and works that alter, in a manner considered beneficial to the community, the quality, the quantity and the flow regime of a water body.

Charging for the use of bulk water is based on the “polluter-pays” and “user-pays” principles. According to the “polluter-pays” principle, if everyone is entitled to a clean environment, the polluter must pay for the damage he has caused. If there is a social cost arising from a particular activity, it must be internalized or assumed by the entrepreneur. That is, if an industry carries on a certain activity and thereby causes pollution or degradation of a river, the cost of the pollution must be internalized by that industry. According to the “user-pays” principle, one pays for the use of bulk water to the detriment of others. In fact, the polluter is a user who uses this feature to dilute and transport effluents (GRANZIERA, 2000).

On the other hand, charging for the bulk water use has a direct impact on the productive sector, which is the increase in production costs (CARRERA-FERNANDEZ, 1997; PEREIRA and TAVARES, 1999; TIMOFIECSYK and PAWLOWSKY, 2003). It occurs due to the insertion of a cost that, until then, did not exist. Consequently, as food industry pass this cost to the consumer, there is a tendency for this economic instrument of environmental management to increase food prices (PEREIRA and TAVARES, 1999). To some extent, this should not indicate a problem, because the internalization of these costs can be associated with market corrections, which would goal a new balance (CARRERA-FERNANDEZ, 1997). However, it is necessary to consider that, in Brazil, 6.5% of the residents of permanent households in 2016 were in extreme poverty[5], according to the National Continuous Household Sample Survey (IBGE, 2017). The food price increases associated with charging for the use of bulk water tend to be felt in a greater proportion in the less favored economic classes (PEREIRA and TAVARES, 1999).

[5] Equivalent to US$ 1.90/d per capita income or consumption in purchasing power parity (IBGE, 2017).

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3 CHAPTER 1: THE ENERGY MIX AND ENERGY EFFICIENCY ANALYSIS FOR BRAZILIAN DAIRY INDUSTRY

THE ENERGY MIX AND ENERGY EFFICIENCY ANALYSIS FOR BRAZILIAN DAIRY INDUSTRY

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Luiz Paulo de Lima, Gabriel Browne de Deus Ribeiro, Ronaldo Perez

Abstract

This paper focuses on an analysis of the energy mix profile and energy efficiency of the Brazilian dairy industry. It investigates dairies' energy mix and energy efficiency and identifies some actions for a cleaner energy mix. Primary data from 37 dairy cheese-making establishments distributed among the Brazilian regions were obtained from online surveys. The results indicate that woodfuel plays a critical role, being the most used fuel in thermal energy generation, while diesel is dominant in electric generation. It also emphasizes that only 51% of the dairy establishments utilize electric energy generators. Other alternative biomass sources are still incipient in the sector, restricted to just 9.5% of the cases for thermal energy generation and no cases for electricity. Regarding the energy efficiency analysis, the results suggest dairies are more scale efficient than pure technical efficient. However, the dairies present a low energy efficiency level. There is no evidence that inefficiencies are differently distributed according to their size. These findings are important for government agencies, industry associations, scientists, universities and research institutes. High inefficiencies, regarding the use of electricity and thermal energy, are a key issue in sustainable bioenergy production.

Keywords: Energy efficiency. Food industry. Milk processing. Renewable fuel. Sustainability.

Introduction

In recent decades, the Brazilian population has started to consume more processed foods, representing 85% of the food consumed in 2012, which is up from 56% in the 1980s (CNI, 2012). Another change that occurred during this period relates to the awareness of reducing the emissions of greenhouse gases (CNI, 2007; Herbert and Krishnan, 2016), which has been highlighted as the main factor responsible for global warming (Feng and Wang, 2017; Pottmaier et al., 2013). The attention has been directed to the use of fossil fuels, considered the primary generators of greenhouse gases (Goldemberg and Tadeo Prado, 2010; Saidur et al., 2011).

According to ENERDATA (2016), from 2014, Brazil stands out as the tenth largest primary producer of total energy worldwide, generating 269 Mtoe (3,128 GWh), and is the seventh largest consumer of total energy worldwide, using 306 Mtoe (3,559 GWh). It is estimated that in 2014, the Brazilian industry was responsible for 87.5 Mtoe of the energy consumed (28.6% of the country's total), including the use of electricity as a fuel for the generation of either or both electricity and thermal energy. Food and beverage industries consumed 25.4% of this total, with much of this percentage (72.6%) originating from the bagasse and sugarcane straw burning, derived from sugar and ethanol producers with a cogeneration system (EPEE, 2015). The sector is also noted for its self-production of 794.5 ktoe (9,241 GWh) of electricity, equivalent to 9.8% of the total self-production in Brazil (MME, 2015).

In 2014, the dairy industry was among the three largest sectors of the food industry based on revenues (ABIA, 2016) highlighting its great importance. There is no data concerning the energy consumption profile associated with milk processing activities in Brazil. According to Lamas and Giacaglia (2013), it is common to find information on the Brazilian energy mix as a whole, although without taking into consideration the characteristics of each industry and its regionalism. Considering data of the 2014 processed milk volume from the Instituto Brasileiro de Geografia e Estatística (IBGE, 2017a), together with indicators calculated by previous studies (RAC/CP, 2002), this work can estimate that in that year, the Brazilian dairy industry consumed somewhere between 297.3 and 700.8 ktoe of energy (thermal and electrical). About 80% of the total energy consumed by the sector is thermal, while only 20% corresponds to electricity (Maganha, 2008). As Brazil produces more than 60% of its electricity from hydroelectricity (ANEEL, 2017; MME, 2015), the country modestly contributes to the sustainability of the dairy energy mix. The Brazilian dairy industry did not utilize bagasse/straw sugarcane or energy purchase contracts from sugarcane plants, raising questions about how these dairies supply their respective energy demand.

This study aims to characterize the energy mix of the Brazilian dairy industry and measure how efficiently they use these resources. The paper's principal contributions include the following three areas: (i) considering that there are no studies related to the Brazilian dairy industry energy mix, the primary data obtained is relevant and a valuable source of information for the sector; (ii) the development of an energy efficiency analysis provides complementary and relevant findings on cleaner energy; and, (iii) based on the research results, the survey also provides policy recommendations to ensure the sector uses energy in a more efficient, clean and renewable manner in the medium- and long-term.

Materials and methods

Data

The case of this study is the Brazilian dairy establishments registered in the Serviço de Inspeção Federal (SIF) by the Ministério da Agricultura, Pecuária e Abastecimento (MAPA), the government office responsible for industrial and food products registration. To guarantee the homogeneity of the sample, only cheese-making establishments were considered. The data was collected between November 2014 and January 2015, through online semi-structured questionnaires. The questionnaire is part of Master's thesis of the senior author, and it is available in Lima (2015). The questions were developed to obtain data about: produced products; industrial process and economic data.

Based on the information available about the establishments registered at the SIF in the MAPA site (category, company name, and address), this paper identified 1,188 establishments, divided into five categories according to MAPA (1952). Probabilistic sampling strata were used, in which each category was treated as a stratum and, in each category, a simple random sampling method was applied to select the elements.

Exploratory analysis

After collecting the data, an exploratory analysis was performed to check for blank answers and fill errors. Also, descriptive statistics was developed to evaluate the obtained responses and measure extrapolation capacity of the conclusions of the study.

Descriptive statistics (mean, median, minimum, maximum, standard deviation) were restricted to the general characterization of the sample, according to their profile, the use and spend of the energy resources, and the energy efficiency. In relation to the energy efficiency, a paired *t*-test was performed to verify significant differences between scale, technical and pure technical efficiencies at a 5% probability level. Data about energy profile and energy efficiency were crossed to verify concentration tendencies of energy inefficiencies in a specific group.

Efficiency analysis

The data envelopment analysis (DEA) is a non-parametrical technique to measure the relative efficiency of a homogeneous group of decision-making units (DMUs) with multiple inputs and outputs, through an efficient frontier (Charnes et al., 1978). A DMU (decision making unit) refers to the unit responsible for converting multiple inputs into outputs. In this paper, for example, each dairy establishment represents one DMU. This method allows estimating the efficiency without previous knowledge about the structural association between the inputs and outputs (Charles and Zegarra, 2014).

The model may be either input- or output-oriented. In the first instance, the goal is to identify the lowest levels of inputs to obtain the same levels of outputs. For the output-oriented model, the objective is to determine the highest levels of outputs that can be achieved with the current levels of inputs. Besides identifying the efficiency score of each DMU thought the efficiency production frontier, DEA enables each inefficient DMU to measure i) the portion of relative gap of each input (or output), when a gap represents any input that is over-used, or any output produced below the expected level, and ii) the DMUs that serve as the benchmark (Cristóbal et al., 2016;

Wang et al., 2017). It is important to note that in DEA, benchmark is a DMU reference of efficiency.

This paper used the DEA model with input orientation by the multi-phase method. The use of constant (Charnes et al., 1978) and variable (Banker et al., 1984) returns to scale methods provided a discrimination among the scale and pure technical efficiency scores.

In the light of input orientation, scale efficiency indicates how the production level of a DMU is near optimum, according to the technology used, while pure technical efficiency illustrates how well a specific DMU utilizes its inputs to generate the maximum possible outputs (Farrell, 1957). If a certain DMU is operating in a condition of increasing or decreasing returns to scale, it means that the DMU is not in its optimum scale. If a specific DMU has any gap, it suggests that the DMU still could reduce its input consumption without decreasing its output production.

Technical efficiency, which is obtained from the constant returns to scale method (Charnes et al., 1978), is the product of scale efficiency and pure technical efficiency, which are obtained from the variable returns to scale method (Banker et al., 1984).

The multi-stage method was used to nullify cases of falsely efficient DMUs (Coelli, 1998). The restriction of non-increasing returns to scale was used to find the scale operation of a DMU. The decision to use input orientation rather than output orientation was made because the increase in the output levels (processed milk volume) may not be desirable.

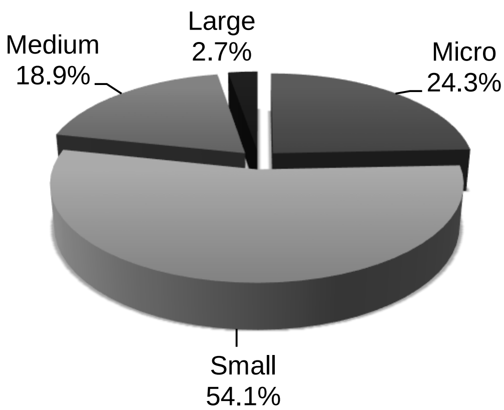
The output variable was the processed milk volume, while the input variables were the electricity and thermal energy spends. Considering these DMUs (dairies) are a homogeneous group, the DEA allows inferring how efficient they use energy to process raw milk. In this context, efficiency refers to how economically a specific DMU uses energy inputs compared to all other DMUs analyzed. Therefore, it is not about a thermodynamic efficiency, for example.

Results

Sample

A sample of 37 dairies was obtained, which is in accordance to the rule-of-thumb to use DEA. According to Banker et al. (1984), the number of DMUs should be at least three times the number of inputs and outputs combined. Conversely, Golany and Roll (1989) suggested that this relation should be at least five times. The dairies have an average of 22.65 years of operation with a standard deviation of 19.16 years. The oldest establishment has been operating for 105 years, while the youngest, only 2 years. The total milk collection of the establishments surveyed corresponds to 2.24 M L/d (only two managers did not inform those values), equivalent to 3.3% of the formal Brazilian milk collection in 2014 (24,747 M L of milk were processed in Brazil that year) (IBGE, 2017a). Considering the size (Table A.1), 78.4% (29) of the studied establishments are "Micro" or "Small Business" (Figure 1), which illustrates the high diversity and the large number of micro and small companies existing in Brazil, confirming the scenarios already reported by Ferreira et al. (2008) and Brunozi Júnior et al. (2012).

Figure 1. Establishment's classification per size.



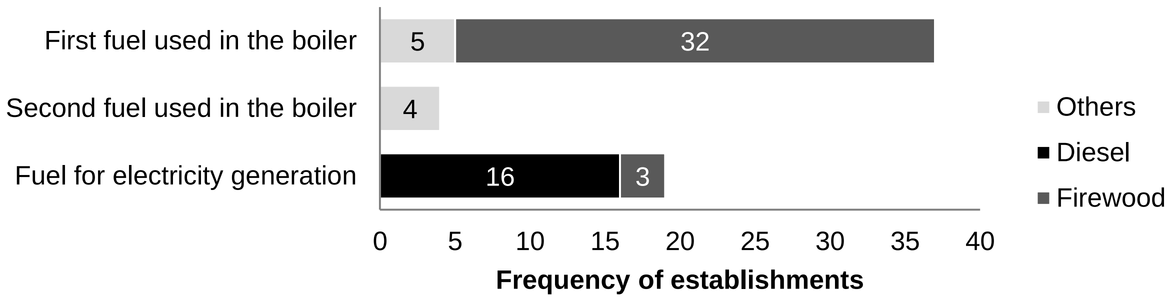
Energy mix

This study makes inferences about the Brazilian dairy industry using the data obtained from the sample, which is an important source to increase comprehension about the energy profile of the sector.

Regarding the thermal generation used fuel, all studied establishments have boiler steam generation and, of these, only 10.8% have more than one source of fuel for thermal generation. The firewood stands out as the prominent fuel in the burners of the boilers, followed by alternative sources (Figure 2). Managers cited fuel oil (3), briquette (3), natural gas (1), babaçu coconut (*Attalea* ssp.) (1), and plywood waste (1), as other alternative sources.

A little over half of the surveyed establishments (51.4%) use electricity generators. Diesel is the most utilized fuel. Three other dairy units were identified as using firewood for this purpose (Figure 2).

Figure 2. Fuel usage frequency for each purpose. The frequencies indicate, in each case, the number of establishments that use each type of fuel.



Regarding the thermal energy generation, the dairy industries mainly use firewood, which, despite being a renewable fuel source, it is considered less efficient than other renewable sources, such as woodchips and sugarcane (Nascimento and Biaggioni, 2010). As for electric power generation, the non-renewable fuel diesel is the most used, a non-ideal scenario from a sustainability standpoint, though diesel is more efficient than other energy sources, with a higher calorific value. The diesel, consumed only to generate electricity (Figure 2), is the second most used fuel. As none of the micro-enterprises have energy generators, this fuel is not used among them.

The presence of electricity generators occurs in larger dairies, which may be associated with the investment in this type of resource as it tends to become more feasible when increasing its production scale.

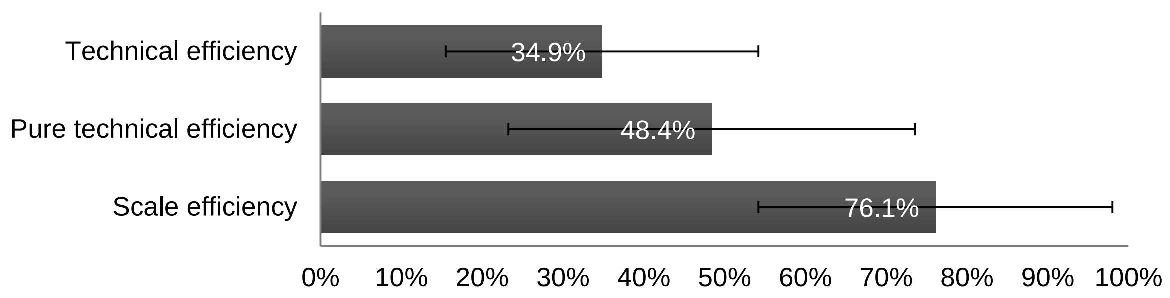
These results not only illustrate that the dairy units have a low utilization of natural gas and fuel oil but suggests that the inclusion of alternative fuels in the energy mix of the sector is still incipient (Figure 2). Micro-enterprises that use more than one source of fuel were not identified, and there are an increased proportion of dairy units, which use electric generators by increasing their size. These results are related both to the low utilization of the boilers by these companies, 78.4% of micro or small establishments (Figure 1), as well as to the low availability of alternative energy sources (Figure 2). The second source of fuel usually occurs, due to the harnessing of some waste (biomass) derived from its dairy process.

Considering that firewood and others (Figure 2) are used as the renewable fuels in 66.7% of cases, it is apparent the Brazilian dairy industry has maintained the representativeness of renewable sources existing in the Brazilian food industry. From the 2014 energy consumption of the food industry, firewood accounted for only 10.1% of all energy consumed (MME, 2015). This difference probably refers to the large representation of bagasse burning and sugarcane straw in the Brazilian food industry energy mix.

Efficiency analysis

The DEA model with input orientation was used and has identified that the Brazilian dairy industries have a medium-to-high efficiency scale (Figure 3). Their pure technical efficiency and global efficiency scores are, respectively, low-to-moderate and low-to-medium. Only two establishments are global efficient, which have obtained pure technical and scale efficiencies equal to 100%. Two others dairies are pure technical efficient.

Figure 3. Means and standard deviations of technical, pure technical and scale efficiency scores of Brazilian dairy establishments.

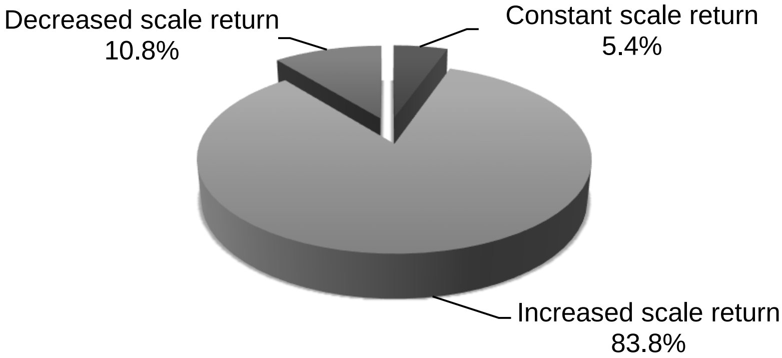


A paired *t*-test was performed to confirm the difference between pure technical and scale efficiencies of Brazilian dairies. Significant differences were identified between scale and pure technical efficiencies at a 5% probability level ($p = 0.023$). This result confirms the differences between the levels of scale and pure technical efficiencies. Brazilian dairies have higher scale efficiency scores than pure technical ones. It means that there are higher gaps associated with the adequate utilization of the resources available (pure technical efficiency) than the use of an adequate production scale (scale efficiency).

The association between scale and pure technical efficiency scores were investigated by Pearson's correlation test. A low Pearson's correlation coefficient was obtained (r = -0.373) that was significant at a 5% probability level (p = 0.023). This finding implies that those companies who have a high level of pure technical efficiency tend to present a low level of scale efficiency and vice versa. From a practical perspective, it highlights the difficulty in conciliating acts to attempt both scale and technical efficiencies, as regards strategic decisions.

Two dairy establishments have been working with its most productive scale size (constant returns to scale). For the four establishments operating with a decreased scale return, any increase in their production will increase average costs—a diseconomies scale regime. On the contrary, most of them have been functioning with an increased scale return and, thus, any increase in their production will decrease average costs, i.e., an economy scale regime (Figure 4).

Figure 4. Distribution of dairy establishments according to the returns to scale.



Among the technical efficient dairies, establishments 5, 9, 21 and 37 are noticeable as inefficient benchmarks (Figure 5). These establishments make an efficient use of their inputs and, therefore, they are located in the efficient frontier, regarding the dataset analyzed. If a dairy is considered one of the main benchmarks, this means that its input-output relationships are similar to those that many of the inefficient dairy products would have if they were able to eliminate their gaps and thus achieve the efficient frontier.

The main benchmark is establishment 21. It represents one of the 28 out 33 (75.7%) inefficient dairies. Establishment 21, which is both, technical and scale efficient, is a 37-year-old medium company, which processes a mean value of 745 kL milk/d, produces many types of cheeses, including fresh and long maturation cheeses, besides butter and other concentrated products. The establishments were classified in terms of number of employees, according to the Brazilian Service to Support Micro and Small Enterprises (in Portuguese) classification (SEBRAE/SP, 1998).

The most economic relation between electricity spends and volume of milk processed was obtained by establishment 21 (R$0.1417/L), while that between thermal energy spends and volume of milk processed was attained by establishment 9, which is the benchmark (R$0.0120/L).

Figure 5. Main benchmarks for inefficient dairy establishments. The frequency indicates the number of establishment for which each benchmark is a reference.

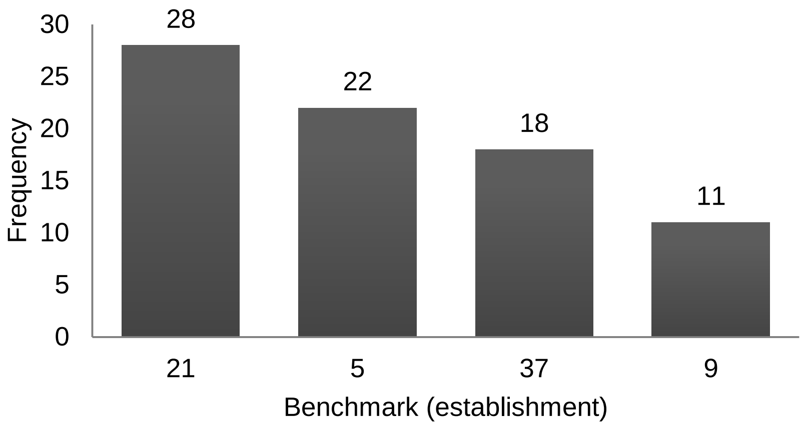
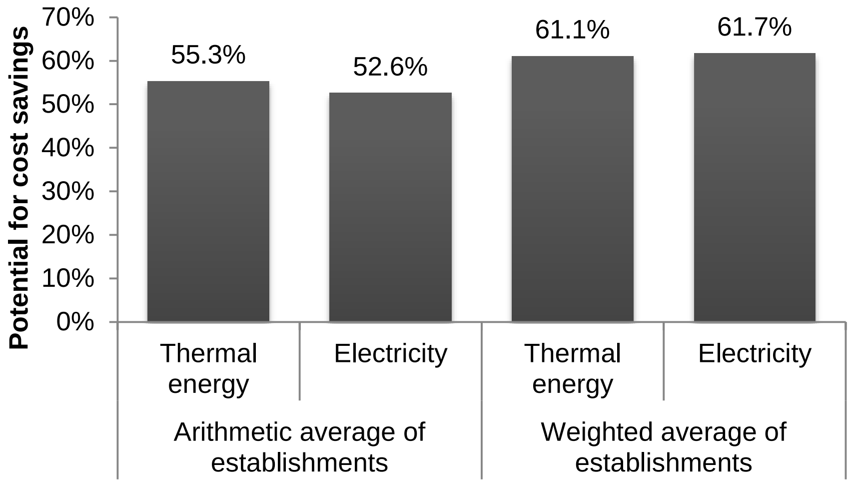


Figure 6 illustrates the potential of saving costs per input, based on the target to acquired when each inefficient dairy was projected radially in the DEA efficient frontier. In the context of the arithmetic average of the potential to reduce each company’s costs, an equilibrium was identified in the gaps associated with electricity and thermal energy spends. It also persists when the weighted average of the potential spending reduction, according to production volume (milk processed) was considered. This observation reveals that the energetic inefficiencies are similarly distributed between micro, small, medium and large dairies. In contrast, Ramírez et al. (2006) studied energy consumption in European dairy industries and identified signs that small dairies are less efficient than larger ones.

Figure 6. Average total potential of costs reduction per input. The total potential cost saving are presented to thermal energy and electricity by arithmetic and weighted average.



Discussion

Boilers are heat exchangers commonly used in heat systems to produce either or both hot water and steam (Saidur et al., 2010). As noted by Bylund (1995), water-tube boilers (the most common type in dairies), in which the flue gasses pass inside the tubes, are used for low or medium pressure systems, whereas, for high pressure and large steam power outputs, the water is circulated inside the tubes. Boilers fueled with oil, coal or gas; operate with a pressure between 900–1,100 kPa, and efficiency that varies from 80 to 92% (Bylund, 1995).

The analysis of the Brazilian dairy industry energy mix displays a distinct scenario where firewood is the most utilized fuel, especially in boilers, followed by diesel, even been utilized only by generators (Figure 2). The former situation is associated with the availability of planted forests (Pottmaier et al., 2013) and that many dairy units are located near agroforestry bases, where the biomass use is facilitated due to logistic reasons (CNI, 2012). In the latter instance, diesel-powered generators are the most commercialized in the country (Bylund, 1995). Tsai et al. (2014) and Yang et al. (2015) mentioned the advantages of diesel engines in generators are due to its output power and fuel efficiency, as regards calorific value.

Regarding the firewood use, in 2015, Brazil had 7.8 M ha of planted trees and this wood was mainly intended to supply the needs of the pulp, paper, steelworks and wood panel industries (IBÁ, 2016). Simultaneously, in the same year, around 46.8 M t of wood residues from the processing and forest harvesting industry were generated, with 33.0 M t through forestry activities and 13.8 M t via forest industrial activities (IBÁ, 2016). A considerable portion of these residues is left in the field to fertilize the soil and the other part, composed of woodchips, small firewood, sawdust and paper scraps, is used to generate energy by burning in boilers for steam and electricity for their industries but also other consumers, such as the dairy, agriculture, feed and textile industries.

As of April 2017, Brazil has 535 biomass thermal units under operation, which represents 9% of all energy generated in the country. These units mainly use agroindustrial residues (76.7%, 417 thermoelectric units) and forest biomass (22.5%, 88 thermoelectric units), which correspond to 14.7 GW of thermoelectric energy produced (ANEEL, 2017). Most of these forest biomass thermal units are derived from industries and small energy producers that use woodchip, black liquor and firewood as a renewable source to generate steam and electricity for their businesses. Some of them also generate surplus power for sale, depending on the scale. The majority are located in the south, southeast and central-west regions of the country, considered the most potential areas, due to the high concentration of forest plantations, particularly of *Eucalyptus* spp.

As a comparison, woodchips are one of the most valuable biomass fuels in Europe, with almost 4,000 woodchip plants bigger than 1 MW around the territory (Albani et al., 2014). Woodfuel is considered a local energy source in Europe, representing only 4% of European Union imports. Based on the current European energy policy, biomass is a core element, with a general target of 20% renewable resources in the energy supply to be meet by 2020 (Bentsen and Felby, 2012). The European Union have experienced a substantial increase of more than 22 M ha of wooded land over the past 20 years, and the wood industries residues are expected to increase some 30% by 2030 (Pelkonen et al., 2014).

On the contrary, with a vast territory and excellent soil and climate conditions for biomass production, such as *Eucalyptus* sp. plantations and sugarcane, Brazil is a potentially great source of biomass for dairy units and other industries. There is a gap between this recognized potential and the biomass insertion. Even considering that firewood is the most consumed fuel, the process efficiency should be improved with replacement by woodchips, for example, which are considered more efficient than firewood due to logistic and material homogeneity. Some of these industries are unaware of the benefits to be gained from using woodchips or even continue to use firewood because their boiler models are obsolete (Nascimento and Biaggioni, 2010).

In part, the low insertion of other biomass types reflects the lack of integration between dairy units and responsibility for generating activities implementing these fuels. It is necessary to register the agents that provide these relatively less conventional sources of biomass that could be utilized by the dairy units to purchase, where practicable and, hence, contribute to a gradual substitution of petroleum derivatives. The existence of more than 1,000 dairy establishments located throughout the country (MAPA, 2017) can be a major facilitator for the development of this type of integration. As stated by Saidur et al. (2011), companies are continually looking for new fuels that are less expensive than the traditional ones. They also look for a renewable source, which may be interesting from a marketing perspective. The lower price commonly associated with natural sources and the possibility to use the waste generated by the establishment consequently reduce its treatment costs (Fernández et al., 2012; Saidur et al., 2011). The low insertion of petroleum derivatives, such as fuel oil and natural gas, emphasizes the outcome of increases in petroleum prices in recent decades. Even if the recent depression of oil prices in the international market is considered, diesel and fuel oil continue to be expensive in Brazil, which is not an attractive incentive for dairy units.

Another observation concerning the low use of other types of fuels is that none of the dairies surveyed declared itself a biogas producer. There are many papers that highlight the potential of waste in dairy industrial process for the production of biogas (Coskun et al., 2012; Sage et al., 2008) that can be used to generate heat or steam, and electricity through cogeneration, for example (Holm-Nielsen et al., 2009; SENAI/PR, 2016). Besides aiding in waste management (Dobos and Floriska, 2007; Nogueira et al., 2015), this operation can be nested together with conventional treatment processes (Coskun et al., 2012), facilitating its integration with existing systems. It also enables energy generation in a decentralized way (SENAI/PR, 2016). The recent electricity price increases have encouraged the search for alternative sources for their generation (CNI, 2007; Lamas and Giacaglia, 2013).

The use of solar panels, which had already been extensively used in Brazil for domestic thermal energy production, may also be considered a feasible alternative to electricity production. Akwa et al. (2014) remarked on Brazil’s significant solar energy potential, currently one of the fastest rising solar markets in the world, with a great part of its land located between latitudes 5° N and 33° S, in the tropical zone. In 2014, this kind of energy debuted in Brazilian government auctions (BRASIL, 2016). In 2017, Banco do Brasil (BB; a major and government-controlled Brazilian bank) launched a program of financing lines aimed at the use of renewable energy (BB, 2017). It is predicted that the country will reach the mark of 1 GW in installed capacity on photovoltaic plants, in 2017 (ABSOLAR, 2017).

In the case of diesel-fueled generators, this paper suggests a change in the current market, by offering biomass or biogas competitive power generators. Among such actions, a recommendation is that government agencies should motivate the sector via tax reductions or subsidies for the purchase of solar panels or biomass/biogas generators, for instance. Such a policy can encourage the medium- and long-term reduction of diesel representation in the energy mix of the dairy industry, as exemplified in Brazil in the 1970s with ethanol, and in the mid-2000s with biodiesel (MME, 2016). As Nogueira et al. (2015) mentioned, obtaining finance in Brazil is difficult, which hinders the implementation of these systems. The government agencies should provide financial resources direct to micro and small dairies at low rates.

From the benchmark perspective, establishment 21 is a large dairy (more than 1,000 employees), manufacturing about 750 kL milk/d and producing fresh cheeses, medium- (< 3 months) and long- (> 3 months) maturing cheeses, as well as butter and curd cheese. It is 37 years old and is located in Minas Gerais State. In comparison, establishment 9, also located in Minas Gerais State, is young (7 years old) and a small dairy (only 35 employees) that manufactures about 20 kL milk/d and produces fresh cheeses, medium-maturing cheeses (< 3 months) and curd cheese. The Minas Gerais State is the largest producer of raw milk (9,145 M L of raw milk produced in 2015) (IBGE, 2017a) and has the greatest number of establishments registered in the database from the Federal Inspection Service (SIF) (in Portuguese), which indicates that there are 1,174 SIF-registered dairies in Brazil (MAPA, 2017). The state has also many educational and research institutions focused on dairy and food engineering (Antonialli et al., 2013).

As observed in Figure 6, the results also imply that the company’s size is not decisive regarding energy efficiency. The company’s portfolio appears not to be important. Hence, the differences in efficiency scores should be related to other variables, such as location.

According to the author's knowledge about the sector and data available in the literature, this study suggests the leading causes of energetic inefficiencies in dairies are: i) the use of obsolete equipment; ii) utilization of inadequate parameters in the equipment; iii) the low insertion of good practices to minimize the energy waste; iv) the use of raw milk of low quality; and v) the losses of products during manufacture.

i) In the processing line, the use of obsolete equipment can result in excessive consumption of steam and electric energy, further to low yields and high loss rates. In addition, old boilers can considerably reduce the transformation of fuels for steam production, while outdated generators should have similar effects on electricity production.

ii) In some cases, the processing parameters may be oversized, contributing to a higher consumption of energy resources, such as cases where the equipment is used for an extended period than is necessary, or the consumed steam intended to reach higher temperatures than necessary, for example.

iii) As good practices to minimize the electricity consumption, the identification and correction of failures in the isolation systems of the refrigeration chambers may be mentioned, as well as the behavior of the employees themselves, e.g., when disconnecting equipment not under operation, or programming the production for a low energy consumption at peak times. In the context of thermal energy consumption, the use of condensed steam from heat exchangers, efficient boiler operation (e.g., the periodicity of the purges), identification and correction of leaks and lack of insulation of the pipes carrying the steam, can be highlighted. Alves et al. (2014) stated that the refrigeration systems used to conserve dairy products could account for up to 60% of the total energy used.

iv) The use of low-quality milk (high bacterial counts, for example) can impact the energy consumption, by using a more drastic binomial time-temperature than would be applied to process milk with a low bacterial count. The use of low-quality milk is also capable of affecting the yield of the produced products, consequently, causing increased consumption of energy resources for the production of the same quantity of products. This analysis does not include the product dimension (revenue, produced volume), which limits the inference of this type of impact.

v) The same criteria were adopted for the losses of products along the production process. However, the resources have been inefficiently or incompletely used (Molina-Azorín et al., 2009), i.e., a kind of inefficiency.

Despite the suggestions found in the literature, citing that small- and medium-sized enterprises face less pressure to adopt environmental performance practices (Holt and Ghobadian, 2009) than their larger-sized counterparts, the results here indicate that there is no influence of dairies' size on the efficient use of energy resources. Although they are less targeted by environmental agencies, small- and medium-sized dairies are induced to capitalize on their energy resources to remain competitive against large dairies and minimize costs.

These results indicate that the energy mix of Brazilian dairies cannot be considered as sustainable as it should be and resources are used inefficiently. Regarding the composition of the energy mix, the large share of firewood (the most used fuel for boilers), as well as the diesel, which is the most used fuel for generators, can be highlighted. In relation to the low energy efficiency observed (in terms of energy inputs of the DMU), both electricity and thermal energy consumption can be considered hotspots.

A cleaner energy mix should be a medium- and long-term goal for the sustainable development of the Brazilian dairy industry. To contribute to this aim, this work proposes the following suggestions based on the research results:

1. Conduct and make available biomass suppliers register to the dairy units. A simple list of all biomass suppliers to energy use could be the missing link between them and the dairy industries.
2. Discourage the petroleum products use by exempting or reducing taxes on renewable fuels and its technologies. It could directly affect the industrial thermal energy production from boilers, and the industrial electricity production from generators.
3. Offer low-cost credit to the micro and small dairies so that they can finance the purchase of the following:
    i. Thermal energy and electricity generation equipment powered by biomass or biogas.
    ii. Solar panel for electricity generation.

iii. Installation of generation plants producing biogas from by-products of industrial processes.

4. Offer training programs aimed at identifying good practices in the use of electricity and thermal energy. Increase access to information and enhance awareness, by the publication of booklets, books and courses through institutions of education, research and extension.

In summary, it is observed that the proposals exposed in this document about the energy mix are of a structural nature and, therefore, a state's responsibility. Goldemberg et al. (2002) and Silveira et al. (2013) emphasize the importance of government interference in the form of laws and subsidies to change the profile of any energy mix; which is illustrated in Saidur et al. (2011) and Lin and Lei (2015). According to Lipp (2007), besides the involvement of citizens, the political commitment is one of the critical factors for successful renewable energy policy objectives. In regards to energy efficiency, this study believes that an increase in the dairy market competitiveness can induce the dairies to aim for high energy efficiency scores. It can occur with higher competition in international markets, as well as with the entrance of international companies in the Brazilian market.

Given the importance of environmental sustainability in modern industries, attention to the energy consumption and energy mix of the dairy sector is expected from both environmental organizations, as well as public agencies. Studies, recommendations and public policies, incentives aimed at sustainable economic development should be created. Any shift to either or both reduce the energy consumption and expand the use of clean and renewable energy sources, will help to make the Brazilian dairy industry more sustainable.

Conclusions

Brazil's dairy industry has an energy mix that is relatively poorly diversified. The thermal energy is mainly generated by firewood (86.5%), while power relies on diesel (84.2%). This study also identified high inefficiencies regarding the use of electricity and thermal energy in these industries. The global technical efficiency is low (34.9%). The dairies are more scale efficient (76.1%) than pure technical (48.4%), and there is no evidence that inefficiencies are differently distributed according to the size of the establishment.

This analysis of the Brazilian dairy's energy mix profile will be able to develop further studies and public policies for the sector, intending to be continuously conducted for a cleaner and renewable energy use. The homogeneity found in regards to thermal and electricity generation is positive, given it should facilitate the development of generic policies and influence the Brazilian dairy industry as a whole.

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Supplemental Material

Table A.1. Establishment size's classification criteria according to the employee numbers.

Size	Number of employees
Micro	Maximum of 19
Small	20–99
Medium	100–499
Large	More than 500

Source: SEBRAE/SP (1998), adapted.

As commented in Methodology, this article used data from the Master's thesis of the senior author (LIMA, 2015). However, in this article were measured a new type of efficiency (energetic) for a specific group of dairies establishments (only cheese-making). Then, this article considered only a part of the establishments and variables contained in the original database.

The five categories of dairy establishments from (MAPA, 1952) are: dairy warehouse, plant warehouse, dairy plant, dairy farm and processing plant. The original database was built from the contact with 377 establishments, the sent of 292 questionnaires to the dairy industrial units (69% of the establishments interviewed), and the obtained 68 responses (23% of the questionnaires sent) (LIMA, 2015).

Despite the representativeness of the profile of the cheese-makers described in Results, it should be noted that the 37 products analyzed represent a low percentage of the probable number of existing cheese-makers. Therefore, the results must be taken with caution.

4 CHAPTER 2: BULK WATER CHARGES IN THE DAIRY INDUSTRY: A CASE STUDY OF INTERSTATE BASINS IN MINAS GERAIS, BRAZIL

BULK WATER CHARGES IN THE DAIRY INDUSTRY: A CASE STUDY OF INTERSTATE BASINS IN MINAS GERAIS, BRAZIL

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Luiz Paulo de Lima, Aline Gonçalves Spletozer, Laércio Antônio Gonçalves Jacovine, Antônio Fernandes de Carvalho

Abstract

Water is an essential input for any agribusiness, used for various purposes such as hygiene procedures, heat exchangers and beverage formulation. Water charging, regulated in Brazil by the National Water Resources Policy (Federal Law 9.433/97), is an important issue for the food industry, since it may change the profile of food production costs. Thus, this article aimed to estimate the price increases in the dairy industry from the use of water charging and evaluate the potential benefit of this collection, comparing it to some planned investments in basins plans. We used a case study of a dairy that produced 1 t/d of mozzarella cheese in the state of Minas Gerais. Results indicated that water charging among the basins with current collection models may vary up to 131%. The increase in price related to water charging was low (0.04–0.09% of production costs), indicating that it can be absorbed by the industry. Conversely, values collected by the basins may be decisive for implementation of several actions aiming an average quantity and quality of water, which is good for the industry, itself. In the current charging collection models in the state of Minas Gerais, it is possible to recognize that collection is a promising initiative for the economical valuation of water. However, charging still seems to lack sufficiency in safety and a rationalization for its use.

Keywords: Dairy. National water resources policy. Production costs. Water pricing. Water resources management.

Introduction

Water is an essential input for industries. In the dairy industry, water is used for purposes such as cleaning procedures, heat exchangers and brine preparation. Studies indicated that for each liter of milk processed, a dairy consumes from 1 to 7 liters of water (SILVA, 2006; SARAIVA et al., 2009; MAGANHA, 2006). However, due to the risk of scarcity, which plagues various areas of the country, this natural resource is transformed into an economic commodity (CORREA, 2016). An example of this was the creation of the National Water Resources Law (PNRH, in Portuguese), implemented by Federal Law No. 9,433/97 (BRASIL, 1997). Among other measures, the PNRH regulates a survey for raw water use.

The amount to be charged for the use of raw water is calculated based on a public price and aimed to: (i) indicate the actual value of water to its user; (ii) encourage its rational use; and (iii) obtain resources for basin recovery (BRASIL, 1997). Collection mechanisms and amounts are negotiated based on public debate within the Managing Committees of each basin (ANA, 2014); with the funds collected primarily applied in the basin in which they were generated (BRASIL, 1997). Currently, charging for water use follows the dominance of water between states and union, being present in both. The union has the domain of interstate basins, i.e., those that cover more than one state (Paraíba do Sul, Rio Doce, São Francisco, etc.), while the states have the domain of groundwater and rivers that are born and flow in the state itself (Médio Paraíba do Sul/Rio de Janeiro, Mogi/São Paulo, Piranga/Minas Gerais, etc.). Although, charging is present in both union and states-dominated basins, the charging practices are restricted to those basins that have implemented charging through the integrated action of their committee; thus, potential impacts are restricted to some basins in Brazil (ANA, 2018a; 2018b).

In general, the amount to be charged for the use of raw water is a function of the volume (m^3) of surface and/or groundwater extraction, water consumption (difference between the volume captured and released), and the discharge of effluents (with charge according to organic load, measured in kg of biochemical oxygen demand (BOD)). However, not all basins adopt this charge. Furthermore, among the basins that charge for raw water use, there are variations between charging mechanisms (e.g., unit values for each type of use). Therefore, depending on the geographical location of the dairy, and despite the fact that it may have the same production profile as other dairies, it may pay different amounts for raw water use, or even it may not have any charge.

This scenario is complex because one of the main consequences of charging this public price is the increase in production costs. This, in turn, will lead to lower profit margins and/or higher prices for consumers. Consequently, the location of the dairy can be a determining factor for its competitiveness, contributing to its permanence (or not) in the market.

Small number of studies related to industrial water use (FÉRES et al., 2005) and the impact of charging for its use (OCDE, 2017), makes it difficult to deepen these discussions, especially for a specific sector such as the dairy industry. Therefore, it is necessary to document the impacts of this charge on competitiveness among industries and, at the same time, to consider the economic benefit of charging for the use of water resources for their management (OCDE, 2017). Thus, this article aimed to estimate the price increases resulting from raw-water use charges through a case study of a dairy producing mozzarella cheese, and to evaluate the potential benefit of this collection, comparing it with some planned investments in basins plans.

Materials and methods

This research was conducted from a case study of a small dairy located in Minas Gerais, producing 1 t/d of mozzarella cheese (360 d/year). Mozzarella cheese is the most consumed cheese in Brazil (SEBRAE, 2014). In 2011, Brazil produced about 8.67×10^5 t of cheese, of which 28.1% (equivalent to 2.44×10^5 t) was mozzarella cheese (SEBRAE, 2014). The state of Minas Gerais has the largest concentration of dairies (LIMA et al., 2017) and is the largest dairy producer in the country (IBGE, 2018).

Impact of raw water charges on the dairy industry was assessed by: (i) identifying the current raw water charge models in Minas Gerais; (ii) calculating the respective amounts to be charged/collected by the basin water agencies for the use of raw water by the dairy industry; (iii) estimating possible increases in the cost of cheese production associated with the charge for the use of raw water; and (iv) measuring the representativeness of the annual amount collected by the water agencies for the dairy's raw water use as compared to the amount required for the execution of some investments in the basin.

Current evaluation models

Data referring to models for charging for the use of raw water in basins were collected from the information available on the website of the National Water Agency (ANA, in Portuguese). Models for charging for the use of raw water for each installment (capture, consumption, release and transposition) follow the calculation structure:

$$Amount\ charged = (Basis\ of\ calculation).(Unit\ price).(Coefficients)$$

where *Amount charged* is the financial value of each installment (capture, consumption, release or transposition) corresponding to the charge for the use of water resources; *Basis of calculation* refers to the volume of water used for extraction, consumption, release (and/or dilution), or transposition; *Unit price* defines the unit financial value per m^3 of water use, based on the objectives of the collection instrument; and, the *Coefficients* aimed to adapt the defined mechanisms to objectives, specificities of the basin or specific uses. Coefficients may vary, depending on the objectives, the classes of water body use at the capture and release points (or generally, interference points in the water body).

Total amount to be charged is the result of the sum of the amounts charged in each of the parcels, referring to the different types of water use. It should be noted that, depending on the type of water use or the basin, the calculation structure described may have different unit public prices and coefficients.

Amounts charged

The amounts to be charged were calculated from the *unit prices* and the current collection *coefficients* in the interstate basins, with collection implemented in Minas Gerais (Table 1). For the calculations, we considered: (i) water consumption (1.51 L of water per L of processed milk), effluent generation (58.86 kg of chemical oxygen demand ratio—COD per m^3 of processed milk), and BOD/COD ratio (0.29), available from SILVA (2006); (ii) yield (9.9 L of milk for each kg of cheese produced with acidified dough after 24h in refrigeration), available from MENDES et al. (2015); (iii) effluent uptake/discharge in Class 2 waterbody, with water reuse rate between 0–20%; and (iv) discharge of effluents with a 70% BOD removal rate.

Table 1. Unit public prices (PPU) charged for raw-water use in interstate basins covering Minas Gerais

Use	Unit	Doce	Paraíba do Sul	Paranaíba	Piracicaba/Jaguari	São Francisco
Catchment	R$/m³	0.0308	0.0112	0.0152	0.0130	0.0103
Consumption	R$/m³	*	0.0224	*	0.0262	0.0205
Wastewater release	R$/kg**	0.1643	0.0784	0.0709	0.1308	0.0719
Transposition	R$/m³	0.0411	*	*	0.0196	*

* unreported charge amounts; ** measured in kg BOD.

Source: ANA (2018b).

Price increment

The estimate of the price increase for mozzarella cheese associated with the charge for the use of raw water was made through the relationship between the amount charged for the use of raw water and the sale price of cheese in the industry for each basin. The selling price of cheese in the industry was estimated from the price average of mozzarella cheese in retail in the state of São Paulo in 2017 (CEPEA, 2017; 2018), and data on the distribution of profit margin to the production chain dairy products (MILKPOINT, 2016). We used data for São Paulo as a function of the availability of a monthly database. The state is also a major consumer center. Throughout 2017, the sale price of 1 kg of mozzarella cheese in the state ranged from R$ 14.11 to R$ 15.82, with an average of R$ 14.88 (CEPPEA, 2017; 2018).

Charging representativity

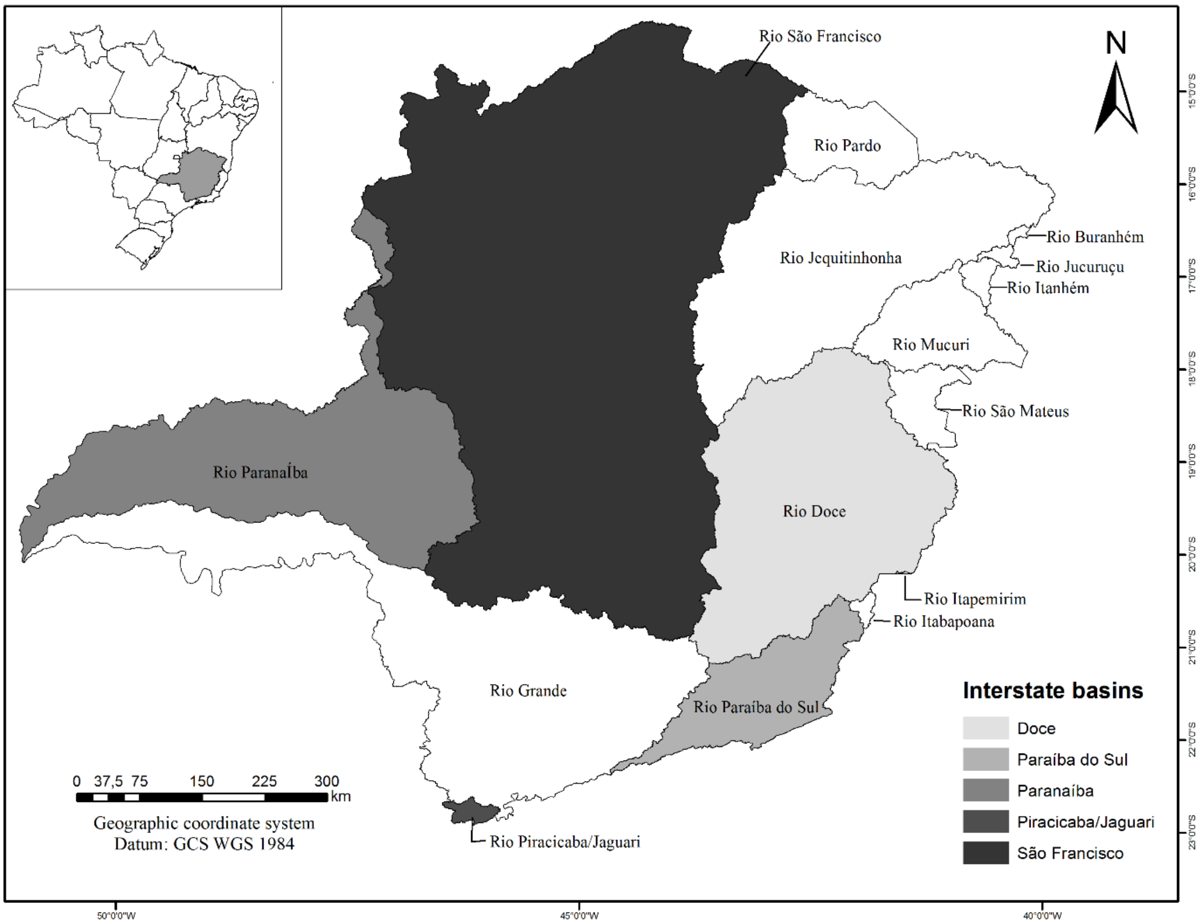
Finally, we analyzed the percentage ratio between the annual estimates of the amount collected through charging for raw water at the dairy in question, and the amount needed to make some investments to improve quantity and quality of water from a basin.

Results and discussion

Current evaluation models

In addition to the São Francisco basin, in which most of the mining territory is located, charging for the use of raw water is implemented in the following interstate basins: Paraíba do Sul, Piracicaba/Jaguari, Doce and Paranaíba. States basins with implemented charges are: Araguari, Caratinga, Manhuaçu, Pará, Piracicaba, Piracicaba and Jaguari, Piranga, Pomba and Muriaé, Preto/Paraibuna, Santo Antonio, Suaçuí and Velhas (ANA, 2018b). Due to the diversity of charging models in use in the state basins of Minas Gerais (ANA, 2018b), for calculation purposes, only the interstate basins under the domain of the union were considered. The choice is due to their greater territorial coverage of the state when compared to state basins. Figure 1 illustrates the spatial organization of interstate basins of Minas Gerais.

Figure 1. Interstate basins with charges for water use in Minas Gerais, according to current charging models.



Amounts charged

Unitary public prices presented for models of raw-water use charges from interstate basins covering Minas Gerais are detailed in table 1. These values refer to the 2018 fiscal year, specified in Resolution No. 20 (ANA, 2018b). According to the data presented, it can be verified that all basins are charged for raw water extraction and effluent discharge (organic load, measured in kg BOD). The same is not true for the consumption and transposition of water. The amounts charged for discharging effluents are 366–906% higher than those charged for raw water extraction. The Rio Doce basin registers the highest collection amounts for raw water extraction (R$ 0.0308/m³) and for the discharge of effluents (R$ 0.1643/kg).

Price increment

Results obtained in relation to the raw-water use charge for the dairy evaluated are presented in table 2. The Rio Doce basin presented the highest currency amount collected for raw water use (R$ 3,164.33/year), equivalent to R$ 0.01 per kg of mozzarella cheese—0.09% of the average selling price of the product in the industry. For the other basins, the annual amount charged for the use of raw water ranges from R$ 1,367.65 to R$ 2,457.14, representing 0.04–0.07% of the cheese sales price in the industry.

Table 2. Annual charge for the use of raw water (R$), corresponding to the production of mozzarella cheese, for surface catchment and wastewater discharge in the assessed dairy industry, by basin*

Use	Doce	Paraíba do Sul	Paranaíba	Piracicaba/Jaguari	São Francisco
Surface catchment	165.75	60.27	81.80	69.96	55.43
Wastewater release	2,998.57	1,430.85	1,293.97	2,387.18	1,312.22
Total annual value	3,164.33	1,491.12	1,375.77	2,457.14	1,367.65
Value per kg of mozzarella cheese	0.00879	0.00414	0.00382	0.00683	0.00380

* considering the capture and discharge of wastewater for industrial use in Class 2 water bodies, with a water reuse rate between 0–20%. For calculation purposes, we considered the annual volume of water captured, in m³/year, according to grant values, equal to the annual volume of water captured, in m³/year, according to measurement data.

Results showed that the increase in the production cost of the mozzarella cheese, and consequent price increase caused by the raw water charge, is low. That is, these costs can be absorbed by the dairies. These costs of water input in the production of mozzarella cheese are below those obtained by other authors. FÉRES et al. (2005) reported a water input cost in relation to the sale price of 0.28% in the food and beverage industries located in the Paraíba do Sul basin.

Charging representativity

The amounts charged for raw water use appear to be unrepresentative for the dairies. However, the amounts collected by the basin committees can be decisive for the implementation of various actions aimed at improving the quantity and quality of water. Table 3 illustrates the relationship between the annual amount paid by the dairy industry and the amount needed to make some investments to improve water quantity and quality. In this case, the representativeness of the amounts paid was estimated, considering the charging models in force in each of the interstate basins, and an interval was presented, referring to the percentage of what was collected from the evaluated dairy, compared to the values required for the implementation of investments.

Table 3. Relationship between the total amount paid for raw water use in the Alto Rio Grande Basin and the average value of some investments aimed to improve water quantity and quality

Investment	Average value* (R$)	Ratio (%)**
Landfill (unit)	411,688.13	0.33–0.77
Selective collection (unit)	50,000.00	2.74–6.33
Recovery of springs and riparian forests (ha)	5,025.48	27.21–62.97
Recovery of eroded land (ha)	3,683.45	37.13–85.91
Flood prediction and warning system (unit)	157,500.00	0.87–2.01
Sanitary sewage treatment (unit)	2,530,187.70	0.05–0.13
Sorting ecomposting (unit)	250,000.00	0.55–1.27

* in accordance with the investments foreseen in the Alto Rio Grande Basin Water Resources Master Plan between 2015 and 2034 (IGAM, 2014); ** refers to the estimates of the total collected by the studied basins, regarding the charge for.

Even analyzing the charge for raw water use at a small dairy, as in the present study, the total amount paid over a year is relevant for a basin. By itself, charging for the use of raw water needed for the annual production of this dairy corresponds, for example, to the price of recovering 0.27–0.63 ha of springs and riparian forests, or recovering 0.37–0.86 ha of eroded land, according to the values specified in the

Executive Summary of the Alto Rio Grande Basin Water Resources Master Plan (IGAM, 2014). Thus, when considering a larger dairy or a set of enterprises that pay for the use of raw water, it is expected that a larger volume of resources will be raised, enabling greater investments, such as the implementation of landfill units, selective collection and wastewater treatment.

Investing the resources raised in the basin itself is beneficial for industries, as it can contribute to maintaining, improving and increasing the quality and volume of the water supply. These resources allow more sustainable management of local water resources, avoiding, for example, water scarcity scenarios. It should be noted that, in times of water crisis, a reduction or prohibition of some uses of water (e.g., industrial), to the detriment of human consumption, is foreseeable. In addition, water resources management must always provide for multiple water uses (BRASIL, 1997), which reinforces the commitment that industries must make to reducing the risk of scarcity.

Charging for the use of raw water is in accordance with the National Environmental Policy (BRASIL, 1981), which imposes on users a requirement to contribute to the use of environmental resources for economic purposes, and imposes on the polluter, from the viewpoint of dilution of wastewater in water bodies, the obligation to recover and/or indemnify the damage caused. Thus, this mechanism aimed to recognize the economic value of water by charging for its use, and finances programs for the environmental recovery of water resources, since the resources received are used to improve the quantity and quality of water in the basin itself. However, the effectiveness of charging for the use of raw water in relation to the incentive to rationalize its use has yet to be proven. This involves the collection of values that allows reduction of pollution to a value that respects the framing of water bodies, which defines the quality required for water and its preponderant uses. FÉRES et al. (2005) and FLORES et al. (2010), for example, demonstrated that the cost of wastewater treatment is much higher than charging for its dilution. In FLORES et al. (2011), for example, charging for the use of raw water represented 2.14% of the cost for its wastewater treatment in concentrated milk production.

Implementing charges for the use of raw water with relatively low values may be a strategy to achieve greater acceptance in a production environment and thus facilitate the implementation of this type of policy. However, 15 years after the application of charges for the use of raw water in federal basins in Brazil (ANA, 2018a), it is necessary to update the amounts charged to bring them closer to the real value of this natural resource. Thus, industries would be encouraged to use it rationally, just as they do with other resources (e.g., energy and raw materials). Admittedly, further studies are needed to understand the broader impact of raw water charges on all facets of the dairy industry. Depending on the added value of the product and the production profile (wastewater treatment, extraction and water consumption) this impact may be more (or less) significant than those obtained in this research. Moreover, Brazil's dairy industry is quite diverse, producing similar products through different technologies.

The choice of Minas Gerais was due to its representativeness for the dairy sector (LIMA et al., 2017; IBGE, 2018), while the choice of interstate basins was due to its coverage (Figure 1). However, the extrapolation of the results of this research to other states and/or basins should be carefully analyzed, since not all models of raw-water charges in Brazil were reviewed. Similarly, it should be noted that, depending on the technological level (production methods) and the market strategy (selling price) adopted, there may be considerable differences in the impact of charging for the use of raw water, compared to that identified for the dairy industry in question.

Conclusions

The amount to be paid for the use of raw water in the production of mozzarella cheese in federal basins in Minas Gerais varies depending on the current charging models, and the highest amount charged is slightly more than double the lowest value. Relationship between the amount charged for raw water use in the assessed dairy and the selling price of the product in the industry ranged from 0.04–0.09%, indicating that the value charged for the use of raw water used in the production of mozzarella cheese is too low.

From current charging models, it is possible to recognize that charging is a promising initiative to economically value water. And, through the collected amounts, it is possible to finance actions for environmental recovery of water resources. Due to the low impact of the raw water charge on the final price of mozzarella, the amounts charged do not yet induce rationalization, since there are reports in the literature that the raw water charge is still much lower than the costs involved with wastewater treatment and/or its reuse in other production processes (FÉRES et al., 2005; FLORES et al., 2010).

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Supplemental Material

It is important to highlight that, in the Methodology, the volume of processed milk and cheese produced, the sale prices of the cheese and the quantity of bulk water were considered constant during the year.

Despite the low impact of the bulk water charge observed in relation to the final price of mozzarella cheese, this impact could be measured with higher precision through the profit margin.

Finally, the tables A.1, A.2 and A.3 show the same data illustrated in tables 1, 2 and 3, respectively. However, in these cases, the tables show monetary values converted to United States Dollar – US$ (considering the conversion rate of R$4.1476/US$, based on January 2020).

Table A.1. Unit public prices (PPU) charged for raw-water use in interstate basins covering Minas Gerais

Use	Unit	Doce	Paraíba do Sul	Paranaíba	Piracicaba/Jaguari	São Francisco
Catchment	US$/m³	0.0074	0.0027	0.0037	0.0031	0.0025
Consumption	US$/m³	*	0.0054	*	0.0063	0.0049
Wastewater release	US$/kg**	0.0396	0.0189	0.0171	0.0315	0.0173
Transposition	US$/m³	0.0099	*	*	0.0047	*

* unreported charge amounts; ** measured in kg BOD.

Source: ANA (2018b).

Table A.2. Annual charge for the use of raw water (US$), corresponding to the production of mozzarella cheese, for surface catchment and wastewater discharge in the assessed dairy industry, by basin*

Use	Doce	Paraíba do Sul	Paranaíba	Piracicaba/Jaguari	São Francisco
Surface catchment	39.96	14.53	19.72	16.87	13.36
Wastewater release	722.97	344.98	311.98	575.56	316.38
Total annual value	762.93	359.51	331.70	592.42	329.74
Value per kg of mozzarella cheese	0.00212	0.00100	0.00092	0.00165	0.00092

* considering the capture and discharge of wastewater for industrial use in Class 2 water bodies, with a water reuse rate between 0–20%. For calculation purposes, we considered the annual volume of water captured, in m³/year, according to grant values, equal to the annual volume of water captured, in m³/year, according to measurement data.

Table A.3. Relationship between the total amount paid for raw water use in the Alto Rio Grande Basin and the average value of some investments aimed to improve water quantity and quality

Investment	Average value* (US$)	Ratio (%)**
Landfill (unit)	99,259.36	0.33–0.77
Selective collection (unit)	12,055.16	2.74–6.33
Recovery of springs and riparian forests (ha)	1,211.66	27.21–62.97
Recovery of eroded land (ha)	888.09	37.13–85.91
Flood prediction and warning system (unit)	37,973.77	0.87–2.01
Sanitary sewage treatment (unit)	610,036.58	0.05–0.13
Sorting ecomposting (unit)	60,275.82	0.55–1.27

* in accordance with the investments foreseen in the Alto Rio Grande Basin Water Resources Master Plan between 2015 and 2034 (IGAM, 2014); ** refers to the estimates of the total collected by the studied basins, regarding the charge for.

5 GENERAL CONCLUSION AND PERSPECTIVES

This work proposes analyze the sustainability in the Brazilian dairy industry. For this, initially, it analyses the energy mix and energy efficiency and, in sequence, the charge for the bulk water use in the Brazilian dairy industry. By the results obtained: (i) the dairies make use of a large quantity of natural resources, (ii) there is a large margin to improve the efficiency in relation to the energy use, and (iii) the public polices, such as National Water Resources Policy, can contribute effectively to improve natural resources rational use and to finance sustainable actions for them.

The Brazilian dairy industries do not make an efficient use of their energy resources. In addition, they have an energy mix poorly diversified. In relation to energy generation, its energy mix is also poorly sustainable. Therefore, it should be adopted a set of actions to improve the efficient use of the energy in Brazilian dairy industries, as well as the use of clean and renewable energy resources.

The payment for bulk water use allowed impact positively the quality and quantity of water available in local water basins. It can contribute to rationalize the water use and to mitigate some of the environmental impacts caused by water use in industrial activities. Therefore, an expansion of charging to other water basins, as well as the improved of the charging models, should be considered as an effective alternative to imposes to the polluter the compensation of the damages caused, to indicate to the users the water real value, and to finance the water resources preservation.

Finally, there is a future perspective of a more rational use of the natural resources in the Brazilian dairy industry. However, it should occur gradually from the entry of new more competitive dairy establishments, and from the development of policies associated with the internalization of environmental impacts caused by users/polluters.

In future researches, it should be investigated: (i) the impact of this charge in another dairy products, (ii) clean and renewable energy resources that could be adopted by the Brazilian dairy industry, as well as (iii) the potential energy saves through each one of the suggestions proposed in Chapter 2.