Urban Studies and Public Administration
Vol. 1, No. 1, 2018
www.scholink.org/ojs/index.php/uspa
ISSN 2576-1986 (Print) ISSN 2576-1994 (Online)

Original Paper

Consumption of Electrical Energy in Water Supply and Wastewater Systems in Brazil

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Received: April 28, 2018 Accepted: May 10, 2018 Online Published: May 17, 2018

doi:10.22158/uspa.v1n1p51 URL: http://dx.doi.org/10.22158/uspa.v1n1p51

Abstract

Traditional processes adopted in water supply and wastewater systems consume large amounts of energy and generate relevant environmental impacts, since energy use is considered one of the largest anthropogenic sources of greenhouse gases. The industry consumes 7% of all energy produced in the world, increasing the costs of operations that cannot be fully passed on to users, especially in developing countries such as Brazil. The worldwide projection of rising electricity prices further aggravates the situation, motivating a mapping of the energy efficiency of the sector in order to identify points of improvement. Several articles on the topic have already been published, but information for Brazil is scarce. This paper presents a review on the energy consumption in each stage of the water and wastewater sector, including the Brazilian scenario. Searches on the site www.sciencedirect.com, using as keywords wastewater, water, energy, consumption and Brazil and government websites resulted in 20 documents that compose this work. The objective of this work was to review the energy consumption in collective water supply and wastewater systems, from raw water abstraction to the final disposal of the treated sewage, by compiling information and adding data on the Brazilian scenario. In general, the current system is inefficient and require political integration in water and energy in order to overcome the challenges.

Keywords

energy, consumption, water, wastewater

1. Introduction

The water industry is a major consumer of energy. From the construction phase of the plant to the demobilization of the equipment, at the end of the plant's life, it is necessary to use energy. Most, however, is consumed during the operation of the water and wastewater treatment plants. In the United States, about 4% of the country's electricity is required to potable and distribute water, as well as to collect and treat the sewage produced (Longo et al., 2016). It is estimated that this consumption represents 7% of the total energy produced in the world, with a tendency to grow, due to the population increase, which is expected to grow 70% by 2050 (Wakeel et al., 2016). Typically, energy consumption represents 5 to 30% of the operating costs of a water and wastewater treatment plant in the world (Kang & Chae, 2013). Most of this energy is electrical and is used to power pumps, valves, compressors, and other equipment (Wang et al., 2016). In Brazil, companies of water and sewage services spent 847 million dollars on energy in 2010, or 10.8TWh. Expenditures on energy are among the largest expenses in the water sector in Brazil and the world (Vieira & Ghisi, 2016). According to the latest information pointed out by the National Sanitation Information System in Brazil (SNIS), the rate of consumption of electricity in water and sewage systems is U$ 0.075/kWh.

On the other hand, the energy sector is the second largest consumer of water in the world, behind only irrigation (Li et al., 2016a). Water is consumed by the energy sector in different processes, such as the extraction of fossil fuels, refining, cooling of thermoelectric plants, etc. (Wakeel et al., 2016). In the United States, for example, the use of water in thermoelectric plants for energy generation corresponds to approximately 49% of the total water abstracted in their territory (Li et al., 2016a). It is estimated that in 2010, 583 billion cubic meters, or 15% of the total water abstraction in the world, was used in the energy sector (Wakeel et al., 2016).

In this way, water is needed to produce energy and energy is used in the water cycle, to collect, distribute and treat water, as well as collect and treat sewage. As two basic resources for the socioeconomic development of cities, water and energy interrelate, representing the nexus-water-energy. The scarcity of one can limit the development, industrialization, and urbanization of cities, as well as change the climate of the region (Li et al., 2016b). This interconnection between two fundamental resources for life and world production has become a fascinating topic. The water-energy nexus has permeated the modern economy and become prominent in political discourses in various countries (Li et al., 2016a). It is necessary to understand and quantify the use of electricity in the water sector to develop integrated public policies that guarantee the sustainable use of resources through efficient models, technology, better management and appropriate choices for the future expansion of the sector.

2. Method

This paper presents a systematic literature review that consists of an overview of existing evidence pertinent to a clearly understanding of the subject. For this, a selected literature was analyzed and the data found were compiled in tables and illustrated in figures, making more evident the stages of the cycle of greater consumption of energy, that can be better managed.

The methodology used was to review the literature, through searches on the site www.sciencedirect.com, using as keywords wastewater, water, energy, consumption and Brazil. Due to the scarcity of articles found in Brazil, government websites, such as the Ministry of Cities, were analyzed, extracting information from relevant technical reports.

This study applied the method developed by Ensslin et al. (2010), known as Proknow-C method—Knowledge Development Process and Constructivist. It is a systematic approach to organize the information collected in the literature and covers the construction of knowledge in stages. First, the selection of articles is done using keywords in defined databases. Then the articles are filtered based on specific criteria, such as alignment with the topic of interest and scientific relevance. Finally, redundant and unavailable ones are eliminated. Once the bibliographic portfolio is established, the material is analyzed in a systematic way, elucidating points of interest and pointing out gaps to be filled. This study resulted in 20 documents that compose this work and are discussed.

3. Result

Figure 1 shows the consumption of electricity in the urban water cycle, as it is found in most countries, with an average of 1kWh/m^3 of water entering the city in the form of drinking water and leaving as treated sewage. Figure 2 presents the usual consumption in stages, with higher values being observed in Wastewater Treatment Plants (WWTP). The analysis here does not consider the energy consumption in the construction phase of the systems. Few researchers have studied this type of consumption, due to the lack of available data and their reduced magnitude compared to the system operation phase, which represents 70% of total consumption (Singh & Kansal, 2016) or even 94% (Wakeel et al., 2016).

The energy expended in gross groundwater abstraction can be estimated at 0.0027kWh/m^3 of high water in one meter. In surface collection, consumption can be neglected if the Water Treatment Plant (WTP) is close to the source. In general, the surface uptake varies from 0.0002 to 1.74kWh/m^3 and the underground from 0.37 to 1.44kWh/m^3 (Wakeel et al., 2016). In Brazil, 47% of the water catchment is on the surface, 39% is underground and 14% is mixed, with energy consumption between 0.25 and 4.5kWh/m^3 (Vilanova & Balestieri, 2015).

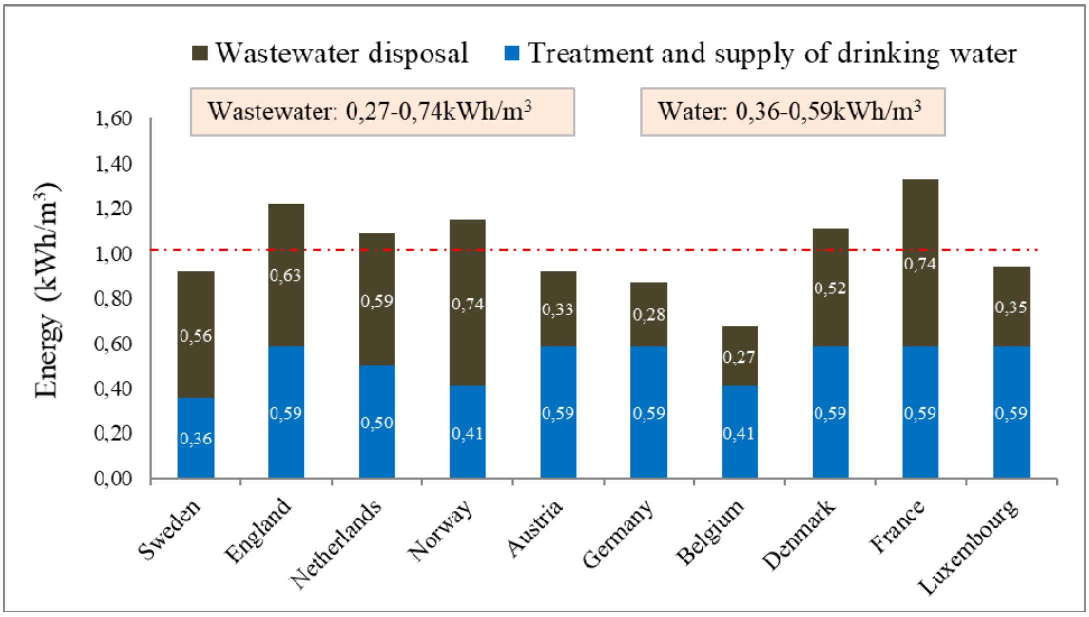

Figure 1. Electricity Consumption in the Urban Water Cycle

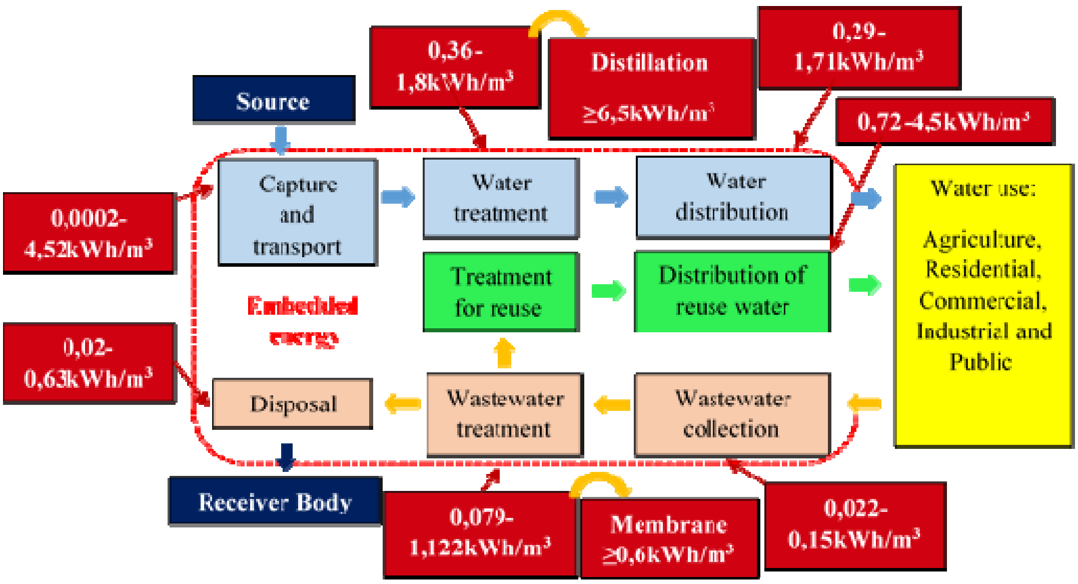

Figure 2. Electricity Consumption in the Stages in the Urban Water Cycle

The use of electricity in WTP is mainly affected by the quality of raw water and the technology used, with distillation being the largest consumer, with a demand between 6.5 and 25.5kWh/m^3 (Wakeel et al., 2016). In Brazil, 10 billion cubic meters of water per year are treated, consuming 8.59 billion kWh (SNIS, 2016).

In the distribution of treated water, the greater the distance, the volume lost in the path and the demand, the greater the energy consumption (Wakeel et al., 2016). In England, because pipes of the nineteenth century are still in use, up to 70% of the water can be lost. In Brazil, the percentage is 28.2%, which corresponds to the per capt of 61.6 L/day. In terms of energy, this means a loss of 0.25kWh/m^3 or 0.27% of the total energy consumed in the country. The reduction in water loss in distribution is one of the most efficient ways to save energy, with economies of 25 to 50% (Vilanova & Balestieri, 2015). The average loss in many countries is between 17 and 20% (Wakeel et al., 2016). Vilanova and Balestieri (2015) investigated the use of energy in water supply (capture, treatment and distribution) in Brazil. Electricity cost accounted for 16.8% of operating costs and consumption in WTP accounted for 1.9% of total consumption in the country. The average usage was 0.862kWh/m^3, about twice the world average. The latest data from the SNIS, in 2014, shows a worsening in the rate of loss, rising to 37%. While Australia and New Zealand are practically zeroing this percentage. In Brazil, 80% of the population is served with water distribution (SNIS, 2016).

Energy consumption in the final use of water is much higher than in the supply, due to the great heating of the water. This spending depends on behavioral factors and the change in habits could reduce consumption by at least 50% (Wakeel et al., 2016). In Brazil, per caput consumption was 139L/day in 2012, which represented 23.5% of the water used in the country. The remainder was used in irrigation (53.5%), industry (16.6%) and animal consumption (6.4%) (Vilanova & Balestieri, 2015). In the SNIS data for 2014, per caput consumption rose to 154 L/day (SNIS, 2016).

The energy consumption, in the collection and the pumping of sewage to the WWTP, depends on the topography of the region, population density, distance to the WWTP and structure of the city's sewage system. Singh and Kansal (2016) estimated the average consumption in India in 45.3% of the total consumed in the WWTP. Consumptions between 0.022 and 0.042kWh/m^3 are typical in the world, accounting for 5 to 18% of the total used in the WWTP (Longo et al., 2016). Brazil has a collecting network 157,000 kilometers long, serving only 49% of the population (SNIS, 2016).

The energy demand in the treatment of sewage will depend on the flow, effluent quality and types of processes adopted (Metcalf & Eddy, 2016). In Brazil, the annual volume of treated sewage is 2.6 billion cubic meters (81% of sewage collected), consuming 802 million kWh in the year, or 0.24 kWh/m^3 (SNIS, 2016). This value is low, due to the many WWTP in the country based on stabilization ponds or Upflow Anaerobic Sludge Blanket (UASB) reactors, which consume very little electricity. In Germany and Italy, about 1% of the country's energy consumption is in the WWTP and is a good estimate for the European countries (Longo et al., 2016). Wang et al. (2016) cited 0.6% for the United States and Li et al. (2016a) reported from 0.21 to 0.49% for China. In general, treatment requires between 0.3 and 0.6kWh/m^3 (Shen et al., 2015), representing 15 to 40% of the cost of operating the WWTP, behind only the workforce (Gikas, 2016).

LONGO et al. (2016) presented a review of the literature on energy consumption in WWTP in North America, Asia and Europe. The aeration process in the secondary treatment consumes most of the energy, between 45 and 75% of the total consumption. Wakeel et al. (2016) reported the energy consumption in WWTP of different countries with average consumption of 0.38 to 1.122kWh/m^3, dominated by aeration. Li et al. (2016a) studied nine WWTP in China and observed that 60% of energy expenditure is in the secondary treatment and that consumption is much lower than in developed countries, justified by the lower quality of the treated effluent and the modernity of WWTP in China, built on last 10 years. Singh and Kansal (2016) analyzed the energy consumption in WWTP in India, being 65.5% electric and 27.8% associated with the materials used in the process. Catarino and Henriques (2016) evaluated 14 WWTP in Portugal and noted that aeration consumes 53% of energy, with an increase of 30 to 50% in plants with an additional stage of nutrient removal. Energy consumption is lower as the required level of treatment is less stringent. In Brazil, for example, the removal of phosphorus is not mandatory in WWTP, which means that electricity consumption will be lower than in countries where tertiary treatment with phosphorus removal is required by legislation. Countries with more stringent quality standards and/or area boundaries may use more efficient, smaller-area systems such as membranes, even if they pay the price of the highest energy consumption. According to Gikas (2016), 20% of the energy in the WWTP is consumed in auxiliary processes, such as pumping and lighting stations, with 0.52kWh/m^3 being the only energy used in treatment (55% due to aeration). The author created a pilot WWTP, with maximum removal of COD in physical processes and minimal use of aerobic processes. According to the author, only optimizing traditional processes is not sufficient to reduce the high energy consumption in the WWTP, since an organized effort in Switzerland only managed to save 12%. Automated aeration control systems have reduced energy consumption in WWTP, and several other economics suggestions are cited by Catarino and Henriques (2016), even though they represent small contributions.

Disposal of the final effluent consumes little energy. With water scarcity, several countries are reusing this effluent. On average, water reuse consumes between 0.18 and 0.63kWh/m^3 (treatment without distribution) (Wakeel et al., 2016). To produce reuse water there are different technologies with different energy consumptions.

The management of the sludge produced in the WWTP can consume 0.074 and 0.15kWh/m^3 (Longo et al., 2016). In Brazil, it is estimated that between 150 and 220 thousand tons of dry mud were produced in 2010 (Pedroza et al., 2010). On average, 30% of the costs in the WWTP are attributed to the treatment of sludge produced (Shen et al., 2015). However, some authors affirm that the sludge has the potential to make the WWTP self-sufficient in energy, since the calorific value of dry sludge is 12 to 20MJ/kg, close to coal (14.6-26.7MJ/kg) (Zabaniotou & Samolada, 2014). Regardless of the scale, each WWTP can improve its energy efficiency, saving 20 to 40% and, in some cases, up to 75% (Catarino & Henriques, 2016).

4. Discussion

Table 1 shows the consumption of electric energy in the water and sewage systems, with the sewage treatment being presented in Table 2. It can be seen the great variety in the energy demand, mainly due to the different quality standards for the effluent treated and the technology used. At different levels of treatment, different consumptions are observed, with a typical behavior: the more rigorous the level of treatment, the greater the energy consumption. The largest expense in water supply in Brazil is related to the enormous loss rates. Due to the heating of the water during its use, the energy consumption is much higher than in the other stages of the cycle. Reducing losses and stimulating the conscious use of water can significantly reduce the demand for energy, in addition to reducing the volume of sewage generated, however, per capita consumption and loss rates are increasing in the country. Most of the studies are in the WWTP, due to the greater consumption of energy, mainly in the aerobic processes. In Brazil, the tropical climate allows the use of anaerobic systems, which consume less energy and still produce biogas. UASB reactors are the predominant technology nowadays in the country (PROBIOGAS, 2016a), but most of the produced biogas is burned, without energetic use. To reverse this scenario, the PROBIOGAS project is underway, with the objective of increasing the use of biogas in Brazil. The main barriers to invest in biogas are: uncertainty about the cost/benefit of the project; few reference projects in the country; difficulty in accessing technical, commercial and legal information; lack of specific policies. All these difficulties can be overcome with political support (PROBIOGAS, 2016b), which could transform WWTP into energy generating units, attracting investments that would improve sanitation rates in the country. In addition, energy use contributes 57% of the gaseous emissions responsible for global warming and only 0.3% of the water on the planet can be used for consumption (FUNASA, 2006), leading to improvements in the management of these resources.

Table 1. Energy Consumption in the Stages of the Water and Wastewater Sector

Process step	Contry	Consumption (kWh/m^3)	Description	Reference
Capture and transport	World average	0,0002-1,74	Surface	Wakeel et al. (2016)
		0,36-0,47	Underground	
	Spain	4,07	Surface	
	Australia	3,3	Surface	
	Brazil	0,25-4,5	Mixed	Vilanova and Balestieri (2015)
Desalination water treatment	World average	0,36-0,47	Reverse osmosis	Wakeel et al. (2016)
		0,92	Nano filtration	
		0,5-1,7	Electrodialysis	
		1,1-1,8	Solar photolysis	
		6,5-25,5	Distillation	
		2,4-8,5	Overall average	
Distribuição	Germany	1,71	-	Wakeel et al. (2016)
	China	0,29	-	
	India	0,3	-	
	Canada	0,68	-	
Supply (abstraction,	Brazil	0,862	Mixed	Vilanova and

conventional treatment and distribution)	World average	0,37	Surface water	Balestieri (2015)
	World average	0,48	Subterranean water	
	Brazil	0,73	-	SNIS (2016)
End use	Australia	50	Heating	Wakeel et al. (2016)
Sewage collection	India	0,07-0,11	-	Singh and Kansal (2016)
	World average	0,022-0,042	-	Longo et al. (2016)
Sludge management	World average	0,074-0,15	-	
Effluent final disposal and reuse	Australia	0,02	Final disposal	Wakeel et al. (2016)
	World average	0,18-0,63	Reuse	
	Israel	0,72		
	Singapore	0,93		
	Australia	2,5-4,5	Reuse in scattered area	

Table 2. Energy Consumption in Wastewater Treatment

Area	Capacity	Process	Consumption (kWh/m^3)	Reference
World average			0,38-1,122	Wakeel et al. (2016)
World average		Conventional Activated Sludge	0,3-0,65	Gikas (2016)
South Africa		Stabilization ponds	0,079-0,28	Wang et al. (2016)
South Africa		Thickening filter	0,19-0,41	Wang et al. (2016)
South Africa		Conventional Activated Sludge	0,33-0,61	Wang et al. (2016)
South Africa		Aeration Ditch	0,48-1,03	Wang et al. (2016)
India		Conventional Activated Sludge	0,26	Singh and Kansal (2016)
South Korea			0,243	Kang and Chae (2013)
Germany			0,4-0,43	Wang et al. (2016)
China			0,12-0,38kWh/t	Li et al. (2016b)

China		Anoxic-anaerobic-oxide	0,254-0,31	Wang et al. (2016)
China	2 million m^3/day	Anoxic-anaerobic-oxide	0,13	Wang et al. (2016)
China		Membrane	0,6	Li et al. (2016a)
China		Anoxic-anaerobic-oxide	0,45	Li et al. (2016a)
China		Humic filter	0,25	Li et al. (2016a)
China		Aeration Ditch	0,4-0,5	Li et al. (2016a)
China	45m^3/day	Humic filter	0,15	Wang et al. (2016)
Greece	380m^3/day	WWTP described by Gikas (2016)	0,087	Gikas, (2016)
Brazil			0,24	SNIS (2016)
Brazil		Conventional Activated Sludge	0,57	Vieira and Ghisi (2016)
United States	104-106m^3/day		0,52-0,55	Wang et al. (2016)
United States		Conventional Activated Sludge with chlorine disinfection	0,287	Wang et al. (2016)
United States		Conventional Activated Sludge with UV disinfection	1,12	Wang et al. (2016)

5. Conclusion and Recommendation

This work presented a review in the literature on the consumption of electric energy in water supply and sanitary sewage. The typical global consumption is around 1kWh/m^3 and needs to be reduced, considering the environmental impacts and associated costs. In developing countries, where much of the population is still lacking and cannot afford high water and sewage tariffs, the current model becomes a deficit. Adopting efficient energy management, however, could make it economically attractive. In Brazil, UASB reactors can generate energy through the biogas produced, if there is an integration in water and energy policies, in order to overcome the current barriers. Policies to stimulate the rational use of water and its reuse, as the Chinese government has implemented and some Brazilian cities that face water shortages are doing now, for example, help to reduce the energy consumption, since much of the water used becomes wastewater. Incentives and investments in the sector, to recover the energy potential of the wastewater, besides fostering the energy self-sufficiency of the WWTPs, which collaborate for the production of a clean and renewable energy in the country, will lead to economic gains; these gains could boost the growth of the basic sanitation in the country and help to unlock the national health system.

References

CATARINO, J., & HENRIQUES, J. (2016). Sustainable value e an energy efficiency indicator in wastewater treatment plants. *Journal of Cleaner Production*, *2016*.

ENSSLIN, L., ENSSLIN, S. R., LACERDA, R. T. O., & TASCA, J. E. (2010). *ProKnow-C, Knowledge Development Process-Constructivist* [Technical process with pending patent in the National Institute of Industrial Property (NIIP) of Brazil].

FUNASA. (2006). Fundação Nacional de Saúde. Manual de Saneamento. In *Editora Assessoria de Comunicação e Educação em Saúde* (4ª edição revisada).

GIKAS, P. (2016). Towards energy positive wastewater treatment plants. *Journal of Environmental Management* (in press).

KANG, J., & CHAE, K. J. (2013). Estimating the energy independence of a municipal wastewater treatment plant incorporating green energy resources. *Energy Conversion and Management*, *75*, 664-672. https://doi.org/10.1016/j.enconman.2013.08.028

LI, F., CHIRAMBA, T., XU, J., KELLER, A., WANG, H., DONG, Y., & GU, Y. (2016a). Quantification of the water, energy and carbon footprints of wastewater treatment plants in China considering a water-energy nexus perspective. *Ecological Indicators*, *60*, 402-409. https://doi.org/10.1016/j.ecolind.2015.07.012

LI, W., LI, L., & QIU, G. (2016b). Energy consumption and economic cost of typical wastewater treatment systems in Shenzhen, China. *Journal of Cleaner Production* (in press).

LONGO, S., D'ANTONI, B. M., BONGARDS, M., CHAPARRO, A., CRONRATH, A., FATONE, F., … HOSPIDO, A. (2016). Monitoring and diagnosis of energy consumption in wastewater treatment plants. A state of the art and proposals for improvement. *Applied Energy*, *179*, 1251-1268.

METCALF & EDDY. (2016). *Tratamento de efluentes e recuperação de recursos*. Tradução Ivanildo Hespanhol e Jose Calos Mierzwa.

PEDROZA, M. M., VIEIRA, G. E. G., SOUSA, J. F., PICKLER, A. C., LEAL, E. R. M., & MILHOMEN, C. C. (2010). Produção e tratamento de lodo de esgoto-uma revisão. *Revista Liberato*, *11*, 89-118.

PROBIOGAS. (2016a). *Viabilidade técnico-econômica de produção de energia elétrica em ETEs a partir do biogás, Brasília*.

PROBIOGAS. (2016b). *Barreiras e propostas de soluções para o mercado de biogás no Brazil, Brasília*.

SHEN, Y., LINVILLE, J. L., DEMIRTAS, M. U., MINTZ, M. M., & SNYDER, S. W. (2015). An overview of biogas production and utilization at full-scale wastewater treatment plants (WWTPs) in the United States: Challenges and opportunities towards energy-neutral WWTPs. *Renewable and Sustainable Energy Reviews*, *50*, 346-362. https://doi.org/10.1016/j.rser.2015.04.129

SINGH, P., & KANSAL, A. (2016). Energy and GHG accounting for wastewater infrastructure. *Resources, Conservation and Recycling* (in press).

SNIS. Sistema Nacional de Informações sobre Saneamento. (2016). *Diagnóstico dos Serviços de Água e Esgotos-2014*.

VIEIRA, A. S., & GHISI, E. (2016). Water-energy nexus in low-income houses in Brazil: The influence of integrated on-site water and sewage management strategies on the energy consumption of water and sewerage services. *Journal of Cleaner Production*, *133*, 145-162. https://doi.org/10.1016/j.jclepro.2016.05.104

VILANOVA, M. R. N., & BALESTIERI, J. A. P. (2015). Exploring the water-energy nexus in Brazil: The electricity use for water supply. *Energy*, *85*, 415-432. https://doi.org/10.1016/j.energy.2015.03.083

WAKEEL, M., CHEN, B., HAYAT, T., ALSAEDI, A., & AHMAD, B. (2016). Energy consumption for water use cycles in different countries: A review. *Applied Energy*, *178*, 868-885. https://doi.org/10.1016/j.apenergy.2016.06.114

WANG, H., YANG, Y., KELLER, A. A., LI, X., FENG, S., DONG, Y., & LI, F. (2016). Comparative analysis of energy intensity and carbon emissions in wastewater treatment in USA, Germany, China and South Africa. *Applied Energy*, *184*, 873-881. https://doi.org/10.1016/j.apenergy.2016.07.061

ZABANIOTOU, A. A., & SAMOLADA, M. C. (2014). Comparative assessment of municipal sewage sludge incineration, gasification and pyrolysis for a sustainable sludge-to-energy management in Greece. *Waste Management*, *34*, 411-420. https://doi.org/10.1016/j.wasman.2013.11.003