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Economic and environmental feasibility analysis with the exchange of lighting technology for a residence in a rural area

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ABSTRACT
Since the invention of the light bulb, many technologies have been perfected or invented in order to produce electric light. Currently, seeking sustainability, new sources of light have been developed within a scale that takes into account energy expenses, useful life, sustainability and cost-benefit. Therefore, LED (Light Emitting Diode) lamps have been dominating the market for their cost-effective ratio. In this context, this article aims to make an analysis of the current market situation and show the turnaround time of the replacement of LED lamps in a residence in the rural area of the city of Campo Grande MS, since the rural area is still the place where incandescent lamps can be installed. The results obtained, as expected, showed an excellent cost-benefit ratio for the replacement, which concludes the feasibility of such a substitution. Finally, a study based on the literature review of the work shows that in addition to having an economically viable return, such lamps are beneficial to the environment, and can be almost completely recycled.

Keywords: Lamp, Technology, Electrical, Luminosity, Efficient.

INTRODUCTION

The search for sustainability makes it necessary to debate the notion of balance between the socio-environmental, economic and political dimensions, since the consumption of certain products ends up minimizing environmental impacts.

On the other hand, this dynamic can affect the generation of waste that ends up degrading the environment, as is the case with the replacement of incandescent lamps by fluorescent lamps.

This is because when these lamps lose their usefulness, their trace metals such as Mercury, Antimony and Lead go into the environment, especially when they are disposed of inappropriately. Thus, they end up affecting the fauna and flora and harming the environment in a very dangerous way (DURÃO; WINDÔLLER, 2008; ZANICHELI et al, 2004).

A new lighting concept has been established in the last decade, which is the use of LED lamps. This technology is described as the third stage of the electric light bulb, the first being Thomas Edison's

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incandescent filament bulbs, which are still in use, and the second being fluorescent bulbs, which generate light from a mixture of gases in a phosphor-coated tube.

In Brazil, in the past, the main types of lamps used were incandescent, with a cost up to five times lower than those of new technology. However, it had an 80% higher energy expenditure and its durability was ten times lower than that of fluorescent lamps, consequently contributing to the negative environmental impacts caused in the energy generation processes.

Thus, the replacement of incandescent lamps by fluorescent lamps was observed on a large scale, since fluorescents were arguably more economical (SEBALOS & MELO 2019).

It should be noted that hazardous or toxic waste, also called "toxic waste" are those that, when disposed of incorrectly, will cause damage to the environment and living beings in the long term, as their toxins can be released into the air, land and water. Such waste usually comes from industries or commerce, but can be residential, agricultural, military, radioactive sources from hospitals, dry cleaners, laundries, among others.

It should be noted that since the Industrial Revolution, hazardous waste began to have significance, when there was an increase in urbanization, due to the population that previously lived in rural areas migrating to cities in search of job opportunities, intensifying the generation of more waste (BALBIM, KRAUSE & LINKE, 2016).

Among the hazardous wastes, mercury appears as a major polluter of the environment, especially if it comes from fluorescent lamps, which represented significant domestic, commercial and industrial savings, being widely used, without correct disposal.

The fluorescent lamp, when ruptured, releases the mercury contained inside it in the form of vapor, which can be inhaled and absorbed in the body, triggering health problems for those who handle it or can accumulate in the environment, causing contamination (MORAIS, 2013).

The management of this waste is essential for the correct disposal and protection of the environment and the health of living beings. Thus, the process of decontamination of fluorescent lamps is important, because when mercury is removed from these lamps, the other components present become recyclable and can be transformed into new materials (MORAES, 2015).

The use of LED in the form of a light bulb, in addition to being a technological advance, is very interesting from the point of view of environmental benefits, as its energy consumption is considerably lower than conventional lamps, such as incandescent and compact fluorescent lamps.

Other environmental benefits of LED lamps are the characteristics and possibilities of final waste disposal, in addition to their durability. The LED is produced with materials that are non-toxic to the environment, which means that it can be disposed of without the need for a special destination and final disposal. Its durability is another interesting aspect, as it requires fewer changes, which consequently generates fewer discards in the environment (SANTOS, BATISTA, POZZA & ROSSI, 2015).

Despite the advantages of durability and energy savings, LED lamps still represent the "green promise" among technologies that demand low pollution and high energy efficiency. Its advantages of lower consumption and greater durability, compared to other technologies, represent a lower environmental impact in its use, reducing the demand for electricity and consequently the need to expand the electric energy production systems, most of which, in their majority, cause some type of environmental damage in their construction and/or operation (FERNANDES & RASOTO, 2017).

Therefore, this work is a comparative study, aiming at the conscious implementation of a more energy-efficient lighting system, from which the economic and environmental feasibility of the exchange of technologies will be analyzed.

OBJECTIVE

GENERAL OBJECTIVE

The general objective of this study is to analyze the economic and environmental feasibility through a case study for the exchange of LED technology in a residence, in the rural area of Campo Grande/MS.

SPECIFIC OBJECTIVES

- Carry out an economic and environmental feasibility study from the point of view of sustainability, by replacing conventional lamps with LED lamps in the residence of the rural area in Campo Grande/MS;
- Verify the economic feasibility of three different types of lamps;
- Analyze the environmental impact of disposal by changing different types of light bulbs.

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

LIGHTING TECHNOLOGY

Incandescent bulbs are bulbs that produce light by heating the tungsten filament. The efficiency of these lamps is around 10 to 20 lm/W, depending on their construction and operating temperature (DOE, 2012a). The lifespan of an incandescent bulb is around 1,000 hours (OSRAM, 2009; SIMPSON, 2008). Therefore, they are considered inefficient sources of light, as 90% of the input energy is lost as output (BRUNNER et al., 2010), that is, they are lamps that convert only 5% of the electricity consumed into light, and the rest is eliminated in the form of heat (FERRARI, 2012).

Fluorescent lamps are those in which light is generated by electrical discharge in an internal gas or vapor. For the purpose of illumination, a small amount of Mercury is introduced into the tube and a special Phosphor material is used to convert the ultraviolet light into visible light. These bulbs have higher efficiency and lifespan than incandescent bulbs. The conversion factor from one to the other is 4 to 1, i.e., a 60 W incandescent bulb corresponds to a 15 W fluorescent bulb (VITO, 2007).

The Light Emitter Diode (LED) lamp is a prominent technological evolution in the lamp market. LED lamps are semiconductor devices that are filled with gases and coated with different phosphor materials. LED is practical because it is small and can be applied to various materials, such as plastics, wood, and in various places, such as showcases, lamps, offices, homes, among others. The generation of light does not emit heat and, therefore, there is no heating of the places where it is installed, which expands the range of materials that can receive the installation of this lamp.

According to Gianelli et al. (2009), LED technology began in the 1960s with its first use for emitting visible light in 1962. From 1970 onwards, this technology became commercially viable and the first high-luminosity LEDs appeared in 1980 to be widely used in the most diverse applications. The basic components of the LED lamp, according to Gianelli et al. (2009), are: the protective plastic lens, the electrode with the gold wire and the connection, together with the heat sink, the protective silicone and the LED chip itself.

LED technology, according to Sousa et al. (2012), represents the newest trend in the lighting sector for environmentally friendly buildings in order to reduce electricity costs and preserve the environment.

Figure 01: Lamps (incandescent, fluorescent and LED)

Font: (SANTOS, 2015)

ENVIRONMENTAL ASPECTS

Incandescent bulbs have been proven to be less efficient when compared to other types of bulbs out there. The average efficiency of fluorescent lamps and LED lamps is almost the same. However, it is estimated that LED tubes have higher efficiency compared to LED bulbs.

The use of mercury in fluorescent lamps is essential for them to work properly, but their concentration should not exceed 5 mg per lamp (Reyraap & Gallardo, 2012). Incandescent and LED lamps, on the other hand, do not have this characteristic, although a certain amount of mercury is used, which can represent a risk of contamination to the environment, even if the release of the toxic element does not occur while the glass of the lamp is intact.

Generally, the mercury content varies between 4 to 5 mg, an amount that does not cause direct harm to human health. However, the fact that mercury is cumulative in the food chain makes these residues problematic, especially in situations where the accumulation of broken fluorescent lamps occurs. In these cases, the released element can destroy the protective ozone layer in the atmosphere, contaminate surface water bodies or groundwater, and accumulate in biomes, biota, among others (ENERGY STAR, 2010).

Mercury can affect all groups of organisms and ecosystems, including water and soil microorganisms and fauna in general (WANG et al., 2012). The presence of this substance in the environment is an imminent risk to human health, and there are reports in the literature on cases of Alzheimer's, Parkinson's and infant mortality related to exposure to environmental mercury contamination (WANG et al., 2012; BOSEO´REILLY et al., 2010). Currently, only 20% of fluorescent lamps can be recycled, a process that is considered very costly (AMAN et al., 2013).

Another environmental issue to be highlighted is directly related to the consumption and use of energy from the LED lamp. According to DOE (2012b), the incandescent lamp has a higher environmental impact compared to fluorescent and LED lamps due to the low efficiency and the high amount of energy required to produce light, which increases the chances of wasting matter in the environment, in the form of energy.

FINAL WASTE DISPOSAL

Waste can be found in solid and semi-solid states, and results from industrial, domestic, hospital, commercial, agricultural, service and sweeping activities. Included in this definition are sludge from water treatment systems, and those generated in pollution control equipment and installations. Also certain liquids whose particularities make it unfeasible to discharge them into the public sewer network or bodies of water, or require solutions that are technically and economically unfeasible in the face of the best available technology.

For all this solid waste, a classification must be made where hazardous waste, which requires specific disposal, is separated from non-hazardous waste, which can be deposited in conventional landfills (NBR 10.004 - ABNT, 2004).

Conventional incandescent bulbs are produced from glass and metal and therefore do not contain materials that are harmful to the environment. In fact, it's okay to dispose of incandescent light bulbs in landfills. However, they should not be thrown in the trash for glass recycling, as the type of glass used in the production of lamps is different from conventional glass. One problem is that the useful life of incandescent lamps is shorter compared to LED or fluorescent lamps, which generates a large amount of waste to be disposed of in landfills (SANTOS, BATISTA, POZZA & ROSSI, 2015).

Fluorescent lamps are composed of chemical components that are highly polluting and toxic to the environment and, therefore, these lamps cannot be disposed of in public landfills directly, as shown in Figure 02, requiring a prior recovery of these compounds to avoid environmental damage (SANTOS, BATISTA, POZZA & ROSSI, 2015).

According to Sebben (2012), Brazil is the fourth country that consumes the most fluorescent lamps in the world. Disposal is carried out by companies that receive these lamps and send them for recycling to specific companies. The National Solid Waste Policy (BRASIL, 2010) established the mandatory implementation of reverse logistics systems for fluorescent lamps, making manufacturers and distributors responsible for final disposal (SILVA, 2013).

In the case of LED lamps, 98% of the materials in their composition are recyclable and do not contain heavy metals, such as mercury, in their production, being less aggressive to humans. In addition, when they are switched off, their relighting time is shorter (ECYCLE, 2012).

Figures 02: Disposal of lamps (waste)

Source: Author

METHODOLOGY

In this research, we worked simultaneously with quantitative data, with the collection of the loads of a residential unit, and qualitative data with the elements that make up the various lamps, for the analysis of the discards and the environmental consequences of this disposal. In this way, it involves both numerical information and information from narrative or analytical texts, characterizing it as a research with a mixed method in terms of its nature.

As for the purpose, it is an applied research because it presents a systematic study that aims to solve practical, concrete and operational problems, in this case, a study on lamp waste.

The objective of the research is descriptive, as it will describe what happens in the environment if a light bulb that consumes more energy is not used and which one is more harmful to the environment.

The data are from a primary source, obtaining the lighting characteristics of the house under study and with the data obtained in the city's commerce, where the research was carried out. As a secondary source with bibliographic study on the subject. Therefore, it is characterized as a mixed source in terms of the origin of the data collected.

And, finally, regarding the data collection procedures, the research is a case study. In this research, a study of a rural single-family unit was made, investigating a phenomenon within a real, clearly defined context. Comparing the technical data, the electricity savings involving the three technologies of incandescent, fluorescent and LED lamps and their residual characteristics were surveyed.

In this subsection, the methods used for the experiment will be presented, along with the results obtained.

ECONOMIC FEASIBILITY STUDY

The study was carried out in a single-family home composed of four people in the rural area of the city of Campo Grande/MS and based on literature reviews on the different types of lamps that could be used.

Residence details (house area: 60m²):

- 1 room
- 1 kitchen
- 2 bedrooms
- 2 bathrooms
- 1 runner
- 1 service area
- 1 balcony

- 1 garage

  Total: 10 bulbs

In this implementation, samples of three lamp technologies were selected, which are equivalent for this experiment:

- Incandescent bulb - 60 w
- Compact fluorescent lamp - 15 w
- LED Bulb - 8 W

For the economic analysis, the calculation was carried out for the lamp considering a period of 8 hours, during 30 working days, with an electricity tariff of R$ 0.924810 (base of the distributor ENERGISA in the state of Mato Grosso do Sul in the year 2022). A comparison was made between the lamp technologies that are presented:

- Power consumed (kW);
- Number of lamps (unit);
- Monthly electricity consumed (kWh/month);
- Annual electricity consumed (kWh/year);
- Energy fee (R$);
- Total cost per year (R$/year).

ENVIRONMENTAL FEASIBILITY STUDY – SUSTAINABILITY

In addition to the economic aspect, the sustainability of the project can be observed under some interrelated aspects: environmental impacts of manufacturing and post-use.

Environmental Impacts of Manufacturing and Post-Use

Because they have a long duration of use, the use of LED bulbs reduces the disposal of bulbs, which without proper recycling are dumped in nature. It is estimated that only 6% of the 100 million fluorescent lamps sold are recycled, and the rest are discarded in landfills without any specific treatment, contaminating soil and water with heavy metals.

Conventional light bulbs have high energy consumption. Incandescent ones stand out: 90% of the energy consumed is not transformed into light, but into heat.

Fluorescent lamps have glass, which, due to incorrect disposal, breaks during transport and can injure and contaminate individuals who use this means of survival. In addition, contaminating groundwater, lakes and rivers.

The LED bulb consumes an average of 70 to 90% less energy than conventional bulbs, as it does not require much heating to generate light. By consuming less energy, it does not waste energy with unnecessary heating, i.e., measures related to avoided energy demand, indirectly producing less carbon dioxide in the atmosphere. The greenest energy is energy that is not used.

An LED bulb can be up to 98% recycled, and even if disposed of irresponsibly, it causes much less environmental damage than those with previous technology.

RESULTS

To compare electricity consumption, the use of 10 lamps for 8 hours a day, 30 days a month, for one year (365 days) and at a cost of R$0.924810/kWh was considered (Table 01).

Table 01: Comparison between annual and monthly lamp technologies

TECHNOLOGY	WATTAGE WATTS(W)	Kw	QUANTITY OF LAMPS (UNIT)	ELECTRICITY (kWh/month)	ELECTRICITY consumed/YEAR (kWh/year)	ENERGY FEE (R$)	TOTAL COST/YEAR (R$/YEAR)
INCANDESCENT BULB	60	0,06	10	144,00	1.752,00	R$ 0,924810	R$ 1,620.27
FLUORESCENT LAMP	15	0,015	10	36,00	438,00		R$ 405,07
LED BULB	8	0,008	10	19,20	233,60		R$ 216,04

Source: Author Himself

Thus, it can be observed that if compared to the LED lamp and the fluorescent lamp, the incandescent lamp appears with a higher consumption value, for the same luminosity. Fluorescent and LED lamps, on the other hand, are in a more efficient range of consumption, with LED consuming almost half of the fluorescent lamp.

Table 1 shows the difference between monthly consumption is 124.80 kWh/month from incandescent to LED, so the LED bulb becomes interesting in the first month. The difference in consumption from incandescent to fluorescent is R$ 108 kWh/month.

As an analysis, the value of the lamps in the local commerce of Campo Grande/MS was also surveyed, for comparison with a possible replacement between the lamps, as shown in Table 02.

Table 02: Comparison between the values of lamps in the local market of Campo Grande MS

TECHNOLOGY	LAMP POWER (W)	VALUE (R$)	Average lamp life (hours)	Spent on lamps for the same time of use (20,000 hours) (R$)
INCANDESCENT BULB	60	59,90	1.000	898,50
FLUORESCENT LAMP	15	15,90	5.000	47,70
LED BULB	8	18,90	15.000	18,90

Source: Author Himself

Another interesting result is that if we add up the values of each lamp and each monthly consumption, we can observe a value compared to the LED bulb of 36% more for the fluorescent bulb and 435% for the incandescent bulb.

In recent years, there has been a relative increase in the value of incandescent bulbs, not because they are more efficient, but because of the type of use. These have become widely used for decorative lighting, and since this is a specialized niche, their market value has been added. In this way, they became obsolete, with their manufacture prevented by legislation and economically unfeasible to be used. Currently, the consumer buys incandescent bulbs only if there is no other possibility.

It should be noted that there was an intense migration from incandescent lamps to fluorescent lamps, especially after the manufacture of compact PL or fluorescent lamps that could replace incandescent lamps (E27 nozzle socket). However, it was publicized that the disposal of the lamps should be separated from the common garbage, but did not inform the harmful that these lamps caused to the environment and even to human health. Thus, there was not and is no commitment from society to its proper disposal.

It is also possible to see that the lamps have a different average lifespan and for the same time the value of the LED lamp becomes much more attractive than the fluorescent and incandescent ones. The usage time of the LED on is 3 times longer than fluorescent and 15 times longer than incandescent. This information is recommended by most manufacturers, however, what is observed is that LED bulbs are not lasting the life they report.

The problem is that the LED has an intense duration, but your driver if it has electronic components of poor quality burns out in a short time. The driver is a device that converts the alternating current coming from the electrical network into direct current of adequate voltage for the luminaires to function properly. To put lower-priced LED bulbs on the market, usually the driver components are of very poor quality.

One last result that can be obtained would be about disposal, since according to the literature reviews, in addition to being better than other technologies, the LED lamp can be almost completely recycled and does not present health risks like the fluorescent lamp, where mercury is present.

FINAL THOUGHTS

In the work carried out, it can be seen that the LED lamp proved to be more economical when compared to the lamps commonly used in the home. In addition, as its energy consumption is lower than the others, the return on investment in changing the lamps is high.

The LED lamp is a technology that has been improving more and more, which makes us believe that its efficiency will still increase with the course of new discoveries, and the price of its components will possibly decrease even more. It was possible to evaluate the benefits of the LED bulb for the consumer and the environment, since the bulb has a long useful life, which ensures less bulb replacement over the years, in addition to savings in the consumer's energy bill.

Lower consumption is extremely important in isolated rural properties, which often use off-grid photovoltaic energy (not connected to the electricity grid), with the use of batteries or a generator set in the non-solar period.

For the environment, it is an alternative to mitigate pollution, as the composition of the LED lamp is not harmful and has greater durability, minimizing the number of lamps to be discarded.

The incandescent lamp, on the other hand, has a lower durability, increasing the number of changes and discards, and the glass is composed of small metal particles, and must be treated separately from recyclable glass.

The fluorescent lamp is composed of Mercury and its decontamination is an expensive and time-consuming process. This decontamination is necessary because mercury disposed of incorrectly compromises the quality of soil and water bodies.

REFERENCES

Associação Brasileira de Normas Técnicas (ABNT). (2004). NBR 10004: Resíduos sólidos–Classificação. Rio de Janeiro: ABNT. 71 p.

Aman, M. M., Jasmon, G. B., Mokhlis, H., & Bakar, A. H. A. (2013). Analysis of the performance of domestic lighting lamps. Energy Policy, 52, 482–500. https://doi.org/10.1016/j.enpol.2012.10.060

Balbim, R., Krause, C., & Linke, C. C. (2016). Cidade e movimento: Mobilidades e interações no desenvolvimento urbano. Brasília: Ipea: ITDP. ISBN: 978-85-7811-284-4.

Brasil. (2010). Lei nº 12.305/10 – Política Nacional de Resíduos Sólidos (PNRS). Retrieved from http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm (accessed January 29, 2015).

Bose O'Reilly, S., McCarty, K. M., Stecklinh, N., & Lettmeier, B. (2010). Mercury exposure and children's health. Current Problems in Pediatric and Adolescent Health Care, 40, 186–215. https://doi.org/10.1016/j.cppeds.2009.12.004

Brunner, E. J., Ford, P. S., McNulty, M. A., & Thayer, M. A. (2010). Compact fluorescent lighting and residential natural gas consumption: Testing for interactive effects. Energy Policy, 38, 1288–1296. https://doi.org/10.1016/j.enpol.2009.12.024

Durão, W. A. J., & Windmöller, C. C. (2008). A questão do mercúrio em lâmpadas fluorescentes. Química Nova na Escola, 28, 15–19. Retrieved from http://qnesc.sbq.org.br/online/qnesc28/04-QS-4006.pdf (accessed April 4, 2017).

Ecycle. (2012). Lâmpadas LED podem ser recicladas? Retrieved from http://www.ecycle.com.br/component/content/article/49-lampadas/685-lampadas-led-podem-ser-recicladas.html (accessed June 7, 2012).

Energy Star. (2010). Information on compact fluorescent light bulbs (CFLs) and mercury. Energy Star Program: U.S. Department of Energy. Retrieved from http://www.energystar.gov/ia/partners/promotions/change_light/downloads/Fact_Sheet_Mercury.pdf (accessed August 1, 2012).

Fernandes, A. L., & Rasoto, V. I. (2017). Estudo sobre a viabilidade econômica e impactos urbanos no uso de lâmpadas LED (diodo emissor de luz) na iluminação pública da cidade de Curitiba. Revista FAE, 20(2), 21–34.

Ferrari, B. (2012). Uma luz no debate ambiental: A era das lâmpadas incandescentes está chegando ao fim, e as novas tecnologias que estão despontando prometem reduzir a conta de luz e o impacto no meio ambiente. Revista Exame, 46(21), 120.

Gianelli, B. F., et al. (2009). O emprego de tecnologia LED na iluminação pública: Seus impactos na qualidade de energia e no meio ambiente. In Latin American Congress on Electricity Generation and Transmission – CLAGTEE (Vol. 8, pp. 1–12). Ubatuba.

Moraes, V. M. (2015). Resíduos de lâmpadas fluorescentes: Seu contexto na PNRS e a importância da destinação adequada (Undergraduate monograph). Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ.

Morais, A. S. C. (2013). Incorporação de resíduo de vidro de lâmpada fluorescente em cerâmica vermelha (Doctoral thesis). Centro de Ciência e Tecnologia da Universidade Estadual do Norte Fluminense.

Osram. (2009). Life cycle assessment of illuminants: A comparison of light bulbs, compact fluorescent lamps and LED lamps. Germany. 26 p.

Rey Raap, N., & Gallardo, A. (2012). Determination of mercury distribution inside spent compact fluorescent lamps by atomic absorption spectrometry. Waste Management, 32, 944–948. https://doi.org/10.1016/j.wasman.2011.12.003

Santos, T. S., Batista, M. C., Pozza, S. A., & Rossi, L. S. (2013). Análise da eficiência energética, ambiental e econômica entre lâmpadas de LED e convencionais. Limeira – SP.

Seballos, R., & Melo, F. X. (2019). Reciclagem e descarte de lâmpadas fluorescentes. Revista Diálogos Interdisciplinares, 8(2). ISSN 2317-3793.

Sebben, E. (2012). Alto custo dificulta o descarte de lâmpadas. Retrieved from http://www.ecodesenvolvimento.org/posts/2012/outubro/alto-custo-dificulta-o-descarte-de-lampadas-afirma?tag=rr (accessed January 29, 2015).

Silva, F. R. (2013). Impactos ambientais associados à logística reversa de lâmpadas fluorescentes. InterfacEHS – Revista de Saúde, Meio Ambiente e Sustentabilidade, 8(1), 42–69. https://doi.org/10.5935/2317-4875.20130005

Simpson, R. S. (2008). Lighting control: Technology and applications. Focal Press. 575 p.

Sousa, T. C., & Ferrari, L. de C. de B. (2012). Análise econômica da substituição de lâmpadas fluorescentes por tecnologia LED em uma empresa de manutenção de máquinas. In Encontro Nacional de Engenharia de Produção (Vol. 32, pp. 1–12). Bento Gonçalves.

Vito. (2007). Eco design study Lot 19 domestic lighting. Preparatory Studies for Eco design Requirements of EuPs. Retrieved from http://www.eup4light.net/assets/pdffiles/Final_part1_2/EuP_Domestic_Part1en2_V11.pdf (accessed September 13, 2012).

Wang, J., Feng, X., Anderson, C. W. N., Xing, Y., & Shang, L. (2012). Remediation of mercury contaminated sites – A review. Journal of Hazardous Materials, 221-222, 1–8. https://doi.org/10.1016/j.jhazmat.2012.03.036

Zanicheli, C., et al. (2004). Reciclagem de lâmpadas: Aspectos ambientais e tecnológicos. p.22. Retrieved from http://www.iar.unicamp.br/lab/luz/ld/L%E2mpadas/reciclagem_de_lampadas_aspectos_ambientais_e_tecnologicos.pdf (accessed May 6, 2017).