

Article – Smart Energy

Evaluation of Global Heating Reduction Potential with the Replacement of Electricity Supplied by the Local Concessionaire Via Solar Renewable Source.

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HIGHLIGHTS

- The objective of this paper is to evaluate, through the 100-year Life Cycle Analysis, Global Warming Potential (GWP) and Global Temperature Increasing Potential (GTP) impact categories.

Abstract: The objective of this paper is to evaluate, through the 100-year Life Cycle Analysis, Global Warming Potential (GWP) and Global Temperature Increasing Potential (GTP) impact categories. It is proposed scenario of replacement of the energy matrix for the supply of electricity by Solar Photovoltaic, adopting as consumption base the facilities of Supermarkets, as they contribute to environmental impacts for greenhouse gas emissions such as: intensive use of electricity, occupation large areas such as the main building or parking lot sealing the ground, the movement of customers' vehicles with air and noise pollution and the use of plastic bags. Modifying the energy matrix using electricity from renewable sources enables the reduction of greenhouse gas emissions. According to proposed scenarios for the composition of the energy matrix, based on the emission values of the Concessionaire's matrix, the result of the analysis confirms the

premise that the use of renewable sources contributes to the reduction of environmental impacts, and that the substitution of Concessionaire's energy matrix for Photovoltaic Solar Energy represents a reduction in terms of kgCO₂-eq, over the 100-year horizon, of 85% for GTP and 86% for GWP.

Keywords: renewable energy, life cycle assessment, environmental impact.

INTRODUCTION

Identifying the causes of greenhouse gas emissions and their implications for climate change has aroused the interest of all societies regarding the assessment and management of their magnitude for the planet. Electricity generation is a major contributor to greenhouse gas emissions into the atmosphere.

According to the Greenhouse Gas Emissions Inventory (GHG) from Thermoelectric Plants (fixed sources), in the years 2003 and 2010, the energy sector industries should promote, monitor and participate in the development of studies and research on alternative sources of electricity and energy efficiency as a means of reducing GHG emissions [1].

From the point of view of the product Life Cycle Analysis applicable to this work, the main objectives for Sustainable Development are highlighted, as [2]:

- One in five people still do not have access to electricity.
- Three billion people use wood, coal and animal waste for cooking and heating.
- Energy is the main contributor to climate change, representing on average 60.0% of global greenhouse gas (GHG) emissions.
- Reducing carbon intensity in power generation is a key long-term goal.

Renewable sources are viable for power generation with potential to minimize environmental impacts. According to [3], the use of renewable sources of energy is intensifying, with the reduction of the costs of the energy systems, as well as in relation to the benefits provided to the environment. Among these sources, stand out the low potential hydroelectric, wind, solar and biomass as solar, wind and biomass,

To evaluate and identify how the substitution of non-renewable and greenhouse gas emitting sources used in the generation and supply of Electric Energy, compared to the use of non-polluting renewable sources, has been the target of studies to reduce emissions. An example is presented by [4], who evaluate the air quality in the region by changing the energy matrix in a thermoelectric plant (from oil to oil-natural gas mixture). It is identified that with the substitution of oil with a mixture of 10% oil and 90% natural gas, there is a behavior consistent with the expected use of natural gas, resulting only in NO₂ with intermediate values, possibly influenced by the percentage of used oil.

Other studies show that the use of alternative and renewable energy sources implies lower indices of environmental impacts, such as the emission of greenhouse gases, to be highlighted [5] and [6].

The Supermarket Sector and its significance in the scenario of electricity use

Supermarkets stand out for the multiple services provided. Like other commercial establishments, they imply impacts on the environment, whether by the generation of waste, dissemination of plastic bags, high consumption of electricity, among others. In these establishments, demand and consumption of electricity are high, which encourages studies to evaluate how the use of alternative sources of electricity, as well as the application of sustainable practices, can reduce environmental impacts such as global warming.

According to [7] through data from the Brazilian Association of Supermarkets (Abrás), in 2014, the segment consumed 8.6 GWh, equivalent to 2.5% of energy consumption throughout the country. The average consumption per store was 103 MWh, which resulted

in an expense of about R \$ 3.5 billion with the energy bill alone. Supermarkets are the largest energy consumers in the retail sector.

The author [7] also highlights two situations: (i) since 2012, stores have intensified their actions to make the sector “greener”. According to a survey by Abras, in the period 2012-2014 there was a 5.4% reduction in energy consumption by Brazilian supermarkets. In this segment, the main demand is to make the refrigeration sector more efficient.

The Table 1 shows the classification by characteristics of the main store types.

Table 1 – The classification of stores types.

Storetype	Numberofstore	Shop area (m ²)	Numberofcheck-outs	Numberof itens
Convenience	2,187	58	2	3,348
Limitedassortment	614	428	3	8,742
Supermarket–grocerystores	2,843	1,464	10	18,137
Hiper/super centers	230	5,336	12	28,745
Warehouseclubs	311	3,173	10	8,585

Source:DEPEC- [8].

To reduce consumption, greenhouse gas emissions and operating costs with electricity, in addition to Energy Efficiency practices in production systems, it is possible to propose and apply changes in the composition of the energy matrix including renewable energy sources.

Energy Matrix for Electric Power generation and supply by the Concessionaires

The Table 2 presents the main sources of the electric power generation matrix in Brazil.

Table 2: Composition of the Brazilian Electric Power Generation Matrix.

Composition of Electric Power Generation Matrix	
Type	(%)
Hydraulic	65.2
Natural gas	10.5
Biomass	8.2
Solar and Wind	6.9
Coal	4.1
Nuclear	2.6
Petroleumandderivatives	2.5

Source: BEN 2018 – Empresa de PesquisaEnergética – EPE [9].

When electricity generation occurs from the burning of petroleum products such as turbines, boilers and combustion engines, it favors air pollution through the emission of pollutants such as carbon dioxide, methane, nitrous oxide, sulfur dioxide and others. These gases end up causing climate change, rising average temperatures on the planet, changes in biodiversity, and damage to human health.

According to the authors [10], they indicate the predominance of hydroelectric dams in the future, although renewable sources of energy such as wind and solar have a high possibility of growth.

All sources of energy contribute to greenhouse gas generation. This study considers the emission factor, which takes into account the mass of CO₂ equivalent (CO₂ + CH₄ and N₂O emissions) released for each unit of energy produced. The Table 3 gives some examples of this equivalence.

Table 3: Greenhouse gas emission factor by source of electricity generation.

Source	EmissionFactor (gCO _{2e} /kWh)	Source	EmissionFactor (gCO _{2e} /kWh)
Hydraulic	86	Coal	1.144
Solar	85	Natural gas	518
Wind	16	fueloil	781
Nuclear	14	Diesel oil	829
Geothermal	13 a 380	Biomass	0

Source: Adapted from [9].

The use of alternative energy sources in commercial establishments and supermarkets arouses interest in view of the significance of this sector and [11] proposes an environmental management model directed to medium and large supermarkets, through the installation of diesel generators in order to supply the energy used at rush hour. And the subsequent replacement of diesel by biodiesel, obtained through the used frying oil, aiming at reducing environmental impacts for society as a whole and seeking competitive advantages for the participating companies.

The research of [11, 12] aims to reduce the electricity consumption of a Commercial Building, located in Recife - PE, through a thermoelectric unit (generator set) that operates with natural gas, serving as an alternative source of energy in the energy matrix of the project. The results showed a reduction in monthly savings of approximately 20% in electricity, but it did not evaluate the environmental impacts.

One of the objectives of this article is to arouse interest in the study of the environmental impact arising from the use of alternative sources of electricity generation.

Life Cycle Assessment Methodology – LCA

Preliminary studies of environmental impacts of products began in the 1960s and were acquiring new scopes and more complex and detailed approaches. The theme had greater evolution since the 1980s, when the first conception of [13] emerged.

From the LCA, varieties of resources, operations and processes are reevaluated, with the purpose of reducing greenhouse gas emission rates in the atmosphere, soil pollution, among other impact categories. In the LCA of a product, specific software is employed, which includes data sets and assists in the application of the methodology. Some of the available software are GABi, openLCA, SimaPro and Umberto.

This paper evaluates the use of inputs and energy (mass and energy) to identify inputs and outputs to assess the impacts on the system life cycle, and identify the possible improvements in these impacts that the substitution of electric power sources may provide.

OBJECTIVE

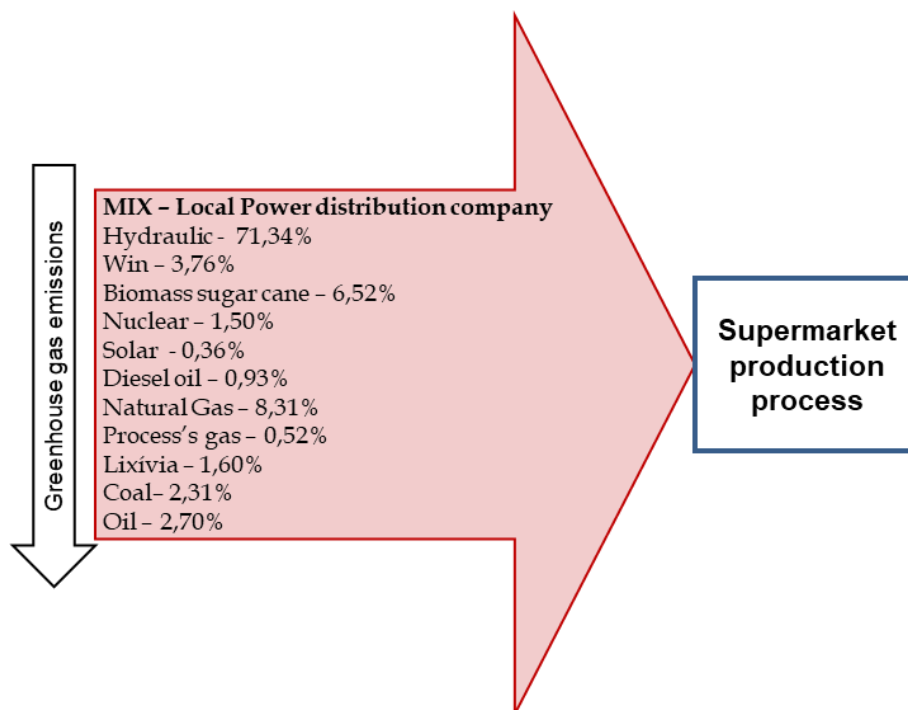
This paper aims to identify the possibilities of improving greenhouse gas emission rates through Life Cycle Analysis, using as an example the energy consumption in Supermarkets, considering that it combines production and trade with the effects of its operation in the generation of these emissions, as well as the large number of establishments in Brazil and in the World. It is also possible to extend the method of

analysis to similar sectors such as Bakery, Confectionery and Shopping Malls. This study aims to assess environmental impact through two main approaches to determine carbon equivalent: The Global Warming Potential (GWP) and the GTP (Global Temperature Change Potential). The first considers the influence of gases on the Earth's energy balance change and the second considers the influence on temperature increase. Both are measured over a 100-year period, the most commonly used being GWP. Emissions analyzes consider uses of alternative sources in place of the Electricity provided by the Concessionaire. To achieve the goal, Life Cycle Assessment (LCA) concepts and modeling are used and, to support the study, a systematic literature review was developed in the Science Direct, Web of Science and Scopus databases.

METHODS

This work includes the following steps:

- Structure the proposed problem to identify the necessary elements as indicators and dimensions of sustainability to carry out life cycle analysis, according to ISO 14000/14400: 2009, which encompasses the LCA Structure: Definition of objective and scope. , Life Cycle Inventory Analysis, Impact Assessment, and Interpretation of Results.
- Evaluate how Electricity supply by a Concessionaire collaborates with its energy sources for environmental impact. The inputs of the energy matrix consider contribution percentages of energy inputs obtained from the [14] database as shown in Figure 01.



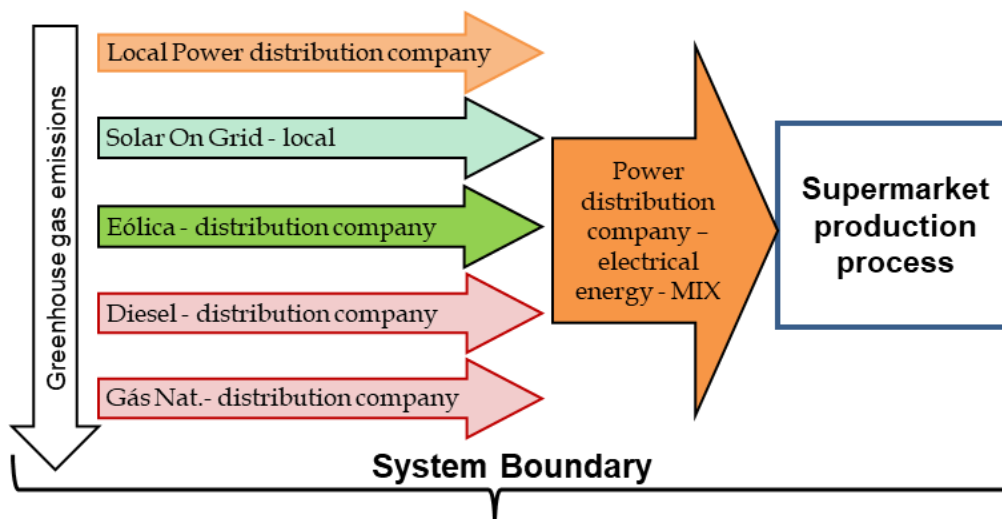
Source: Balanço Energético Nacional – BEN (2017) [14].

Figure 01- Electric Power Generation Matrix.

Losses in the electrical system of Generation, Transmission, Equalization Substations, Transformation and Distribution of Electricity are not considered. Note that these percentages vary constantly over time with the insertion of new sources.

- From scenarios of changes in the energy matrix to supply electricity especially Solar Photovoltaic, verify the reduction of greenhouse gas emissions in terms of GTP and GWP.

Possible (alternative) scenarios of insertion of electric power generation sources are exemplified in Figure 02.



Source: The authors.

Figure 02- Alternative Mix of Electric Power Generation Matrix.

The tool used to assess the contribution to greenhouse gas generation is the universal Umberto NXT software, version 7.1. The structure of the energy matrix is modeled, as shown in Figure 02, and it is evaluated how changes in the matrix modify such emissions.

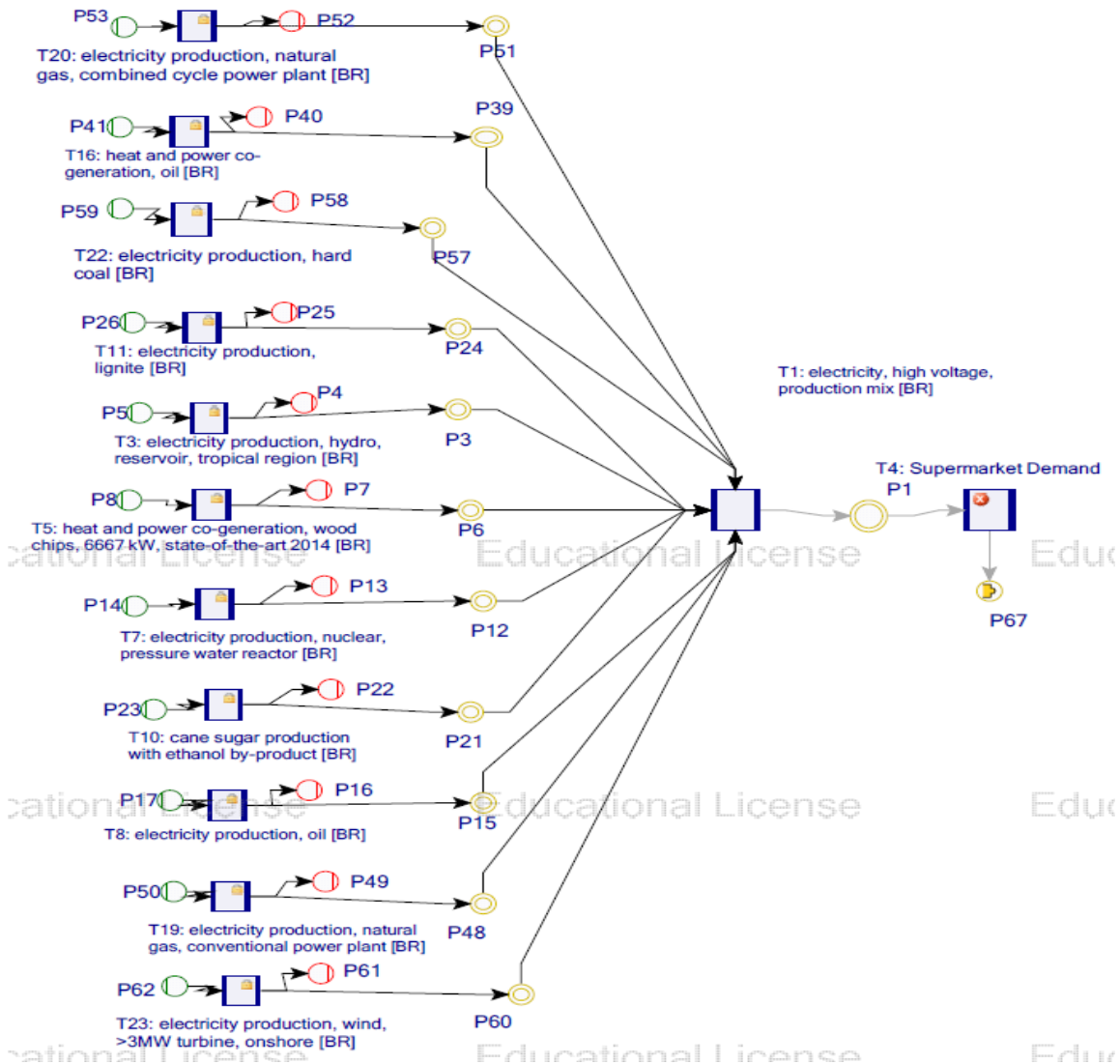
The amount of Global Electricity used in the Supermarket for production and sale is analyzed. The boundary considered is between the energy production until the supermarket entrance, that is, all the loads of the productive systems are part of the global analysis of the Supermarket operation. Emissions occur during the generation of electricity and loads from the supermarket's productive sectors consume this energy. The higher the consumption in the supermarket, the greater the energy demand of the supply system and the greater the emissions and contribution to global warming.

The consumptions of each productive sector are disregarded, as this action demands knowledge of each activity, being necessary to include its specificities, technical aspects and production equipments. For example, in the bakery sector it is necessary to analyze the individual recipes of the bread types and your energy consumptions. An example of this can be seen in [15] which analyzes the process of bread making.

As a reference flow is adopted the value equal to 1MWh, which expresses the amount of energy needed to perform work, in terms of use of inputs and energy (mass and energy) to identify inputs and outputs, primary and secondary data, evaluation methods and tools to study potential environmental impacts and observe local emissions and quantify environmental impacts.

The cut-off criterion used considers the percentage contribution in the energy matrix that makes up the utility's power supply network provided by the National Interconnected System (NIS) operated by the National System Operator (NSO). The energy matrix is mixed with percentage contributions as shown in Figure 03.

The definition of electricity consumption of the supermarket considers the average in MWh of the values recorded during twelve months from the electricity bills of the local electricity concessionaire - COPEL. The average monthly value adopted is 86.62 MWh. The average daily consumption value is estimated at 2.9 MWh. Daily operation starts at 7am and extends until 11pm. Proportionally separating the consumptions throughout the day according to the activities, it is estimated that approximately from 7am to 6pm there is 60% and from 6pm to 7am the equivalent of 40% of the total consumption value. Thus, a daytime consumption of 1.7 MWh / day and a nighttime consumption of 1.2 MWh / day are considered.



Source: Umberto NXT Software, version 7.1 [16].

Figura 03- Modeling of the mix of the electricity supply system.

For analysis purposes, to estimate the average daily generation of a Solar Photovoltaic system connected to the Distribution Grid, a defined power system of 75 kWp (maximum capacity without the need for special protection projects), location 25.42611° S - 49.2522° W, 19° inclined plane, (PR = 0.78; $H_{tot} = 4.153 \text{ Wh / m}^2$, $E = 243 \text{ kWh / day}$) and, as a result, power generation of approximately 7,300 kWh per month corresponding to 243 kWh per day.

The Characterization Factor is the Global Warming Potential for each greenhouse gas ($\text{kg CO}_{2e} / \text{kg gas}$) whose category indicator is kg CO_{2e} per functional unit. For example, 1 ton of methane (CH_4) corresponds to 21 tons of carbon equivalent (CO_{2e}) GWP-100 (IPCC AR2) or 5 tons of CO_{2e} GTP.

In proposing scenarios, it must be considered that for the operation of the Supermarket it is necessary to supply constant energy and with quantity and quality (kWh and KW - Consumption and Demand) necessary for production. The use of alternative sources must provide for adequate inputs for the generation operation. Due to this fact, some scenarios are foreseen: (i) 100% of concessionaire energy, (ii) 100% through the contracting of solar energy supply during the day (12h); (iii) 100% energy via natural gas.

RESULTS

As shown in the Graph in Figure 04, the largest portion of the contribution to temperature rise is the source of natural gas (eg index = $3.5 \cdot 10^{-7}$), followed by hydraulics, coal, charcoal, sugar cane, oil,petroleum, process gas, nuclear and wind. The main elements that compose the indices are carbon dioxide, carbon monoxide, methane, among others.

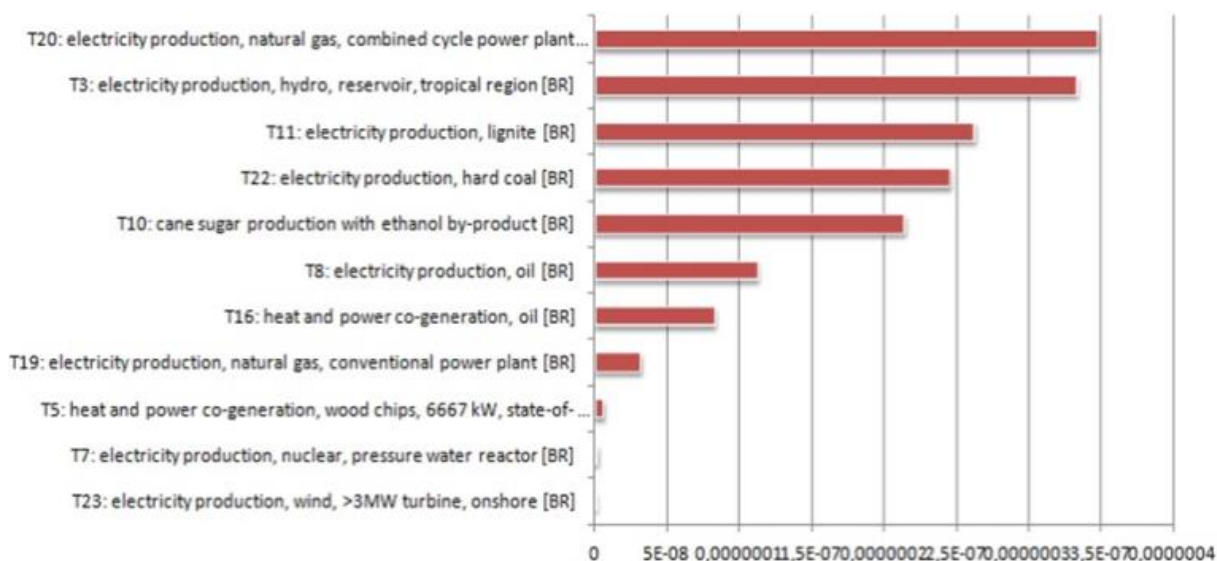
GTP - 100 (Global Temperature Potential over a 100-year horizon) and GWP - 100 (Global Warming Potential over a 100 year horizon) results were obtained for the proposed scenarios, as shown in Table 4.

Table 4 - GTP e GWP for proposed scenarios.

Electric Power Matrix (%)	GTP 100 years (kgCO _{2-e})	GWP 100 years (kgCO _{2-e})
Local Power Distribution	$1.64 \cdot 10^{-6}$	$2.04 \cdot 10^{-6}$
Solar	$2.54 \cdot 10^{-7}$	$2.78 \cdot 10^{-7}$
Natural Gas	$6.11 \cdot 10^{-6}$	$6.41 \cdot 10^{-6}$

Source: The authors.

The construction of the graphs of Figures 04 and 05 consider 100% supply of electricity supplied by the concessionaire. Both show the plots that contribute to generate the characterization factor kg CO_{2-eq} per functional unit for GTP and GWP.



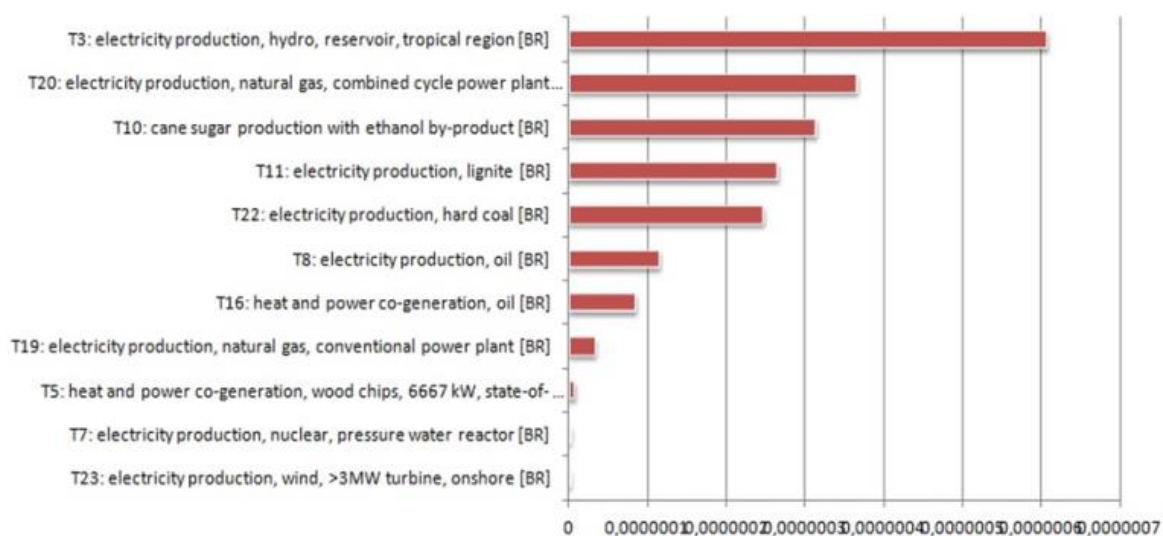
Source: Umberto NXT Software, version 7.1 [16].

Figure 04 - Global Temperature Change Potential with 100% Local Power Distribution. (kg CO_{2e}/MWh.)

Following the methodological procedures already described, we obtained results of GTP - 100 (Global Temperature Potential on 100 years horizon) and GWP - 100 (Global Warming Potential on a 100 years horizon), for the proposed scenarios, as presented by Table 4.

From this reduction perspective, in the simulation based on the 100-year baseline characterization model of the Intergovernmental Panel on Climate Change - IPCC 2013 (GTP and GWP - database available in Umberto software), comparing the supply of electricity for the emission values of the Concessionaire's 100% energy matrix and the MIX

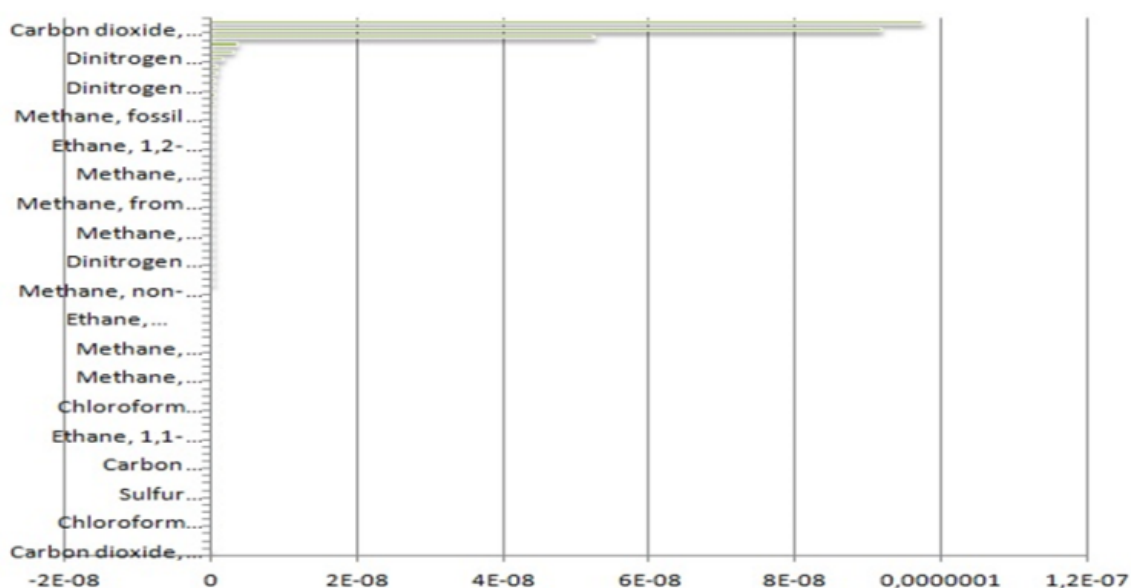
of the proportion indicated in item 3 (60% and 40% respectively), it is estimated that its replacement represents a reduction in terms of kgCO₂-eq over the 100-year horizon of 85% for GTP and 86% for GWP.



Source: Umberto NXT Software, version 7.1 [16].

Figure 05 - Global Warming Potential GWP with 100% Local Power Distribution. (kg CO_{2e}/MWh.)

The graph of Figure 06 presents the GTP with 100% of supply through solar source.



Source: Umberto NXT Software, version 7.1 [16].

Figure 06. Global Warming Potential GWP with 100% de Solar Energy. (kg CO_{2e}/MWh em 100anos)

CONCLUSION

Considering that the supermarket segment consumed 8.6 GWh of energy throughout the country, with average consumption per store of 103 MWh, it is assumed that investments and facilities in obtaining credit lines to increase the installation of photovoltaic generation

system will contribute significantly to reduction of greenhouse gases, with values proportional to the base established in this work to 86.62 MWh with reduction of kgCO₂-eq, in the 100-year horizon, of 85% for GTP and 86% for GWP. Other encouraged energy sources should be assessed to verify the impact on emissions.

In this sense, global and individualized energy efficiency actions should be developed by productive sector, evaluating the substitution of internal inputs responsible for greenhouse gas emissions, such as in refrigeration systems. The replacement of the power generation and supply inputs should be associated.

Some suggestions for reducing consumption are:

- i) Replace energy efficient and low light efficiency lamps (fluorescent by LED).
- ii) Replace furnaces with models with higher productivity and better thermal insulation.
- iii) Use equipment and systems for the production of food cold and thermal comfort with cold production control systems at various points of use that enable automation (use of inverters in compressors).
- iv) Install control systems in cold room doors, that besides reducing the opening time of the door can avoid them being left open.
- v) Remanufacture lighting circuits to take advantage of natural lighting.
- vi) Seek to eliminate losses in cold storage and exhibition chambers.

It is evident that the use of alternative and clean sources such as solar and wind generate considerable impact in reducing greenhouse gas emissions. This action multiplied by the number of stores in Brazil and worldwide creates a ripple effect for this reduction. It is necessary to evaluate the contributions by type of activity and productive sector of supermarkets to know the volume of energy consumption by productive sector. Actions and practices to reduce consumption can be better evaluated and in which sector will generate the best economic and environmental results.

Still this type of analysis can provide more consistent subsidies to suggest public policies directed to this and other productive sectors by encouraging energy efficiency practices and actions for entrepreneurs wishing to invest in improving environmental conditions. In addition, encourage the practice of applying carbon credits commercially, as well as actions such as Social Carbon Methodology (SCM) - used to analyze reality and guide sustainable development initiatives associated with climate change.

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REFERENCES

1. Departamento de meio ambiente. Divisão de Estudos e Planejamento Inventário de Emissões de Gases de Efeito Estufa provenientes de Usinas Termelétricas (fontes fixas) do período 2003 a 2010. Brasília – DF. ELETROBRAS 2010. Accessed in december 2018. Available from: <http://cgtee.gov.br/Files/Inventario-de-Emissoes-de-Gases-de-Efeito-Estufa-das-Empresas-Eletronbras-2010.pdf>
2. Sustainable Development Goals (SDG). ONU Accessed inset/2018 Available from: <http://www.un.org>.
3. AKELLA, A.; SAINI, R.; SHARMA, M. Social, Economical and environmental impacts of renewable energy systems. In: Renewable energy for sustainable development in the Asia Pacific Region Conference, Fremantle, Western Australia, 4-8 February 2007. Renewable Energy, v. 34, n. 2, p. 390-396, 2009.

4. SILVA, F.P.; LIMA, A.M.M. Avaliação da qualidade do ar pela mudança da matriz Energética em usina termoeleétrica: óleo para mistura Óleo-gás natural. *Rev. Geog. Acadêmica*. XIII.2016. v.10, n.1.
5. VARUN; PRAKASH, R.; BHAT, I. K. Energy, economics and environmental impacts of renewable energy systems. *Renewable and Sustainable Energy Reviews*, 2009. v. 13, n. 9, p. 2716-2721.
6. BERRILL, P.; ARVESEN, A.; SCHOLZ, Y.; GILS, H.; HERTWICH, E. Environmental impacts of high penetration renewable energy scenarios for Europe. *Environmental Research Letters*, v. 11, n. 1, 2016.
7. Reis, Tiago. Supermercados buscam soluções para reduzir consumo de energia. In: Procel Info – Centro Brasileiro de Informação de Eficiência Energética, 2016. Available from <https://goo.gl/ikojq3> - access in set/2018.
8. DEPEC – Departamento de Pesquisas e Estudos Econômicos. Available from <https://goo.gl/AHwQFg>. Access in set/2018.
9. Relatório Final do Balanço Energético Nacional BEN 2017 – Empresa de Pesquisa Energética – EPE, Available from https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2017.pdf - Access in set/2018.
10. DALE, Alexander T. et al. Modeling future life-cycle greenhouse gas emissions and environmental impacts of electricity supplies in Brazil. *Energies*, 2013, v. 6, n. 7, p. 3182-3208.
11. ZANCAN, MARCOS DANIEL. CASTELLANELLI, CARLO. RUPPENTHAL, JANIS ELISA. HOFFMANN, RONALDO. Utilização de fontes alternativas de energia em supermercados de médio e grande porte visando a autossuficiência energética no horário de ponta e a redução de impactos ambientais. In: XIII SIMPEP - 6 a 8 de Novembro de 2006. Bauru, SP, Brasil.
12. OCHOA, A. A., DINIZ, H, SANTANA, W., SILVA, P. e OCHOA, L. Aplicação de uma fonte alternativa de energia termelétrica a gás natural visando reduzir o custo com energia elétrica em um edifício comercial. *HOLOS - Revista Científica do Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Norte*, 2015, Ano 31, Vol. 1
13. Guinée J. B., (final editor), Gorreé M., Heijungs R., Huppes G., Kleijn R., de Koning A., van Oers L., Wegener Sleeswijk A., Suh S., Udo de Haes H. A., de Bruijn H., van Duin R., Huijbregts M. A. J., Lindeijer E., Roorda A. A. H. and Weidema B. P. (2001b) Life cycle assessment; An operational guide to the ISO standards; Parts 1 and 2. Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, The Netherlands, Available from www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html. Access in set/2018.
14. Balanço Energético Nacional 2017: Ano base 2016, Empresa de Pesquisa Energética. –EPE, Rio de Janeiro: 2017 Available from <https://goo.gl/tyV53R> Access in setembro/2018
15. RIBEIRO, MARCOS AURÉLIO JUSTINO; Aplicação da Avaliação do Ciclo de Vida na Busca de Eco eficiência na Fabricação de Pães de Forma. Dissertação de Mestrado Programa de Pós-Graduação em Tecnologia do Centro Federal de educação Tecnológica do Rio de Janeiro, 2011.
16. Umberto® - Hamburg GmbH. Umberto LCA+ Life Cycle Assessments or Environmental Product Declarations - Umberto NXT LCA (V 7.1) – License available at UTFPR-PG – PPGEP-PG.



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