Industrial solar collector vs alternative solar collector: Environmental impact comparison by LCA perspective

Colector solar industrial versus colector solar alternativo: Comparação do impacto ambiental por perspectiva LCA

DOI:10.34117/bjdv7n7-353

Recebimento dos originais: 07/06/2021
Aceitação para publicação: 14/07/2021

Adrison Carvalho de Loreto
Engenheiro Ambiental, UNISC,
Endereço: Av. Independência, 2293 - Universitário, Santa Cruz do Sul - RS, 96816-501
E-mail adrison2010@hotmail.com

Adriane de Assis Lawisch Rodriguez
Doutora, UNISC,
E-mail adriane@unisc.br

Allan Ramone de Araujo Scharnberg
Mestre, UNISC
E-mail allan.ambiental@outlook.com

Rafael Martins da Silva
Doutor, UNISC
E-mail rafaelmartins26@yahoo.com.br

Diosnel Antonio Rodriguez Lopez
Doutor, UNISC
E-mail diosnelrl@gmail.com

Adilson Moacir Becker Junior
Mestre, UNISC
E-mail adilsonj@unisc.br

ABSTRACT
Adequacy to sustainable development standards requires the use of methods and tools that enable the quantification and monitoring of environmental impacts related to production processes. As a subsidy to the potential reduction of impacts by solar collectors, this paper proposes an environmental evaluation, considering an alternative solar collector scenario to be compared with a commercial one, from the life cycle perspective. Using the Life Cycle Assessment (LCA) tool, the scenarios were evaluated using the SimaPro 8.5 software. The functional unit definition was defined with real system verification through the system preparation and operation in the laboratory, which is characterized as heating 26 L of water utilizing a thermosyphon system at a temperature greater than or equal to 38 ºC. Analyzing the LCA results, it was observed that the alternative system use offers environmental impacts reduction in all impact categories selected when compared to the commercial system. In addition, a sensitivity analysis was proposed considering a variation in polyester resin mass used in the alternative system.

The simulation of changes in the resin resulted in even more decreases in the environmental impacts. Regarding thermal efficiency, the industrial system excelled in terms of absorption capacity and thermal reserve. Thus, the present paper using the analyzes proposed within the defined scope, allowed the comparison between the systems in such a way that it was possible to know whether the use of the alternative solar collector results in environmental advantages without losing thermal efficiency.

Key-words: Solar energy**,** Solar collector, Environmental Impacts, Life Cycle Assessment, Renewable energy.

RESUMO
A adequação às normas de desenvolvimento sustentável requer a utilização de métodos e ferramentas que permitam a quantificação e monitorização dos impactos ambientais relacionados com os processos de produção. Como subsídio à potencial redução dos impactos dos colectores solares, este documento propõe uma avaliação ambiental, considerando um cenário alternativo de colectores solares a ser comparado com um cenário comercial, do ponto de vista do ciclo de vida. Utilizando a ferramenta de Avaliação do Ciclo de Vida (ACV), os cenários foram avaliados utilizando o software SimaPro 8.5. A definição da unidade funcional foi definida com verificação real do sistema através da preparação e funcionamento do sistema em laboratório, que se caracteriza por aquecer 26 L de água utilizando um sistema de termossifão a uma temperatura igual ou superior a 38 ºC. Analisando os resultados da ACV, observou-se que o uso do sistema alternativo oferece uma redução do impacto ambiental em todas as categorias de impacto seleccionadas quando comparado com o sistema comercial. Além disso, foi proposta uma análise de sensibilidade considerando uma variação na massa de resina de poliéster utilizada no sistema alternativo. A simulação de alterações na resina resultou em ainda mais diminuições dos impactos ambientais. Em relação à eficiência térmica, o sistema industrial destacou-se em termos de capacidade de absorção e reserva térmica. Assim, o presente trabalho, utilizando as análises propostas no âmbito definido, permitiu a comparação entre os sistemas de tal forma que foi possível saber se a utilização do colector solar alternativo resulta em vantagens ambientais sem perder a eficiência térmica.

Palavras-chave: Energia solar, Colector solar, Impactos ambientais, Avaliação do ciclo de vida, Energia renovável.

1 INTRODUCTION

The increase in energy demand and the fossil fuels potential shortage has been motivating the search for alternative energies that can supply the required demand (BENLI *et al.*, 2016; JUNIOR *et al.*, 2020). According to Ge et al., (2018), the global energy demand is still dependent on 75% to 80% of fossil fuels, which represent finite resources used for electricity or thermal energy production. In addition, fossil fuel burning results in severe environmental consequences to human health, atmospheric pollution, and soil quality (ERDENEDAVVA, *et al*., 2017). Concomitantly, the energy price from conventional sources is also volatile and grows as resources become accessible, opening opportunities for renewable sources (GAUTAM *et al*., 2017). In this context, solar energy stands out as clean energy and high energy potential, as well as due to its geographic distribution especially in countries with high solar incidence (COMODI, 2015; GE *et al.*, 2018). Among renewable sources, solar collectors have been standing out, which uses heat and reserve water a solar plate, a water storage tank, and piping (UCTUG *et al*., 2018). Photothermal energy has been seen with notoriety due to the ability of a body to absorb solar radiation by heat form (DA SILVA, 2017). In Brazil, the most used systems are called solar collectors. These systems have as a fundamental principle the water density exchange as a function of temperature (OLIVEIRA, 2014). The conversion of solar radiation into heating represents the most direct way of applying solar energy, with growth potential, but still directly dependent on solar radiation incident (GE *et al*., 2018). In this context, Brazil has favorable conditions for such technologies because it is in the tropical region where there is solar radiation incidence throughout the entire year. However, the use of this potential is still latent, requiring a consolidated development (SILVA RMD, 2015). When compared to countries already consolidated in terms of use of solar energy, such as Germany, the sunniest region of the European country has a solar radiation index 40% lower than the index of the least sunny region in Brazil (DE SOUZA CABRAL *et al*, 2013).

Solar collectors have aimed at the possibility of emitting zero greenhouse gases during such an operation phase (KYLILI *et al*., 2018). Even so, the efficiency of the system is dependent on climatic conditions and can vary from region to region, affecting not only the thermal energy production but also the environmental impacts (UCTUG *et al*., 2018). In addition, According to Uctug *et al*., (2018), several scientific studies identified environmental impacts resulting from the manufacturing stages of solar panels and boilers, presenting in many cases, steel, and copper as responsible for the main environmental hotspots. In this sense, it is necessary to assess the environmental impacts, through the quantification of the relevant environmental aspects to solar collectors (ARDENTE F. *et al*., 2005). Among the alternatives, we highlight the Life Cycle Assessment (LCA), which is a methodological tool for the assessment and quantification of environmental impacts throughout the system life cycle, from resource extraction, energy use, manufacture, distribution, use, and final disposal or recycling (ARNAOUTAKIS *et al*., 2017). LCA has been used to support the research in solar energy produced by solar collectors and to discover where the environmental impacts come from. In a study carried out in Turkey, H. Benli (2016) demonstrated that the use of solar collectors would provide savings of US $ 162.5 million for the gas installation for electrical energy production. In addition, the use of these systems would make it possible to reduce the emission of 720 kt of CO2 eq. emitted in the gas transportation used until then. (H. Benli, (2016); Kylili *et al*., (2018)) highlights the solar collector use on an industrial scale would achieve energy savings ranging from 35 to 75 GJ used for water heating on large scales. In addition, the emission of 2 to 5 tons of CO2 in the thermoelectric plants would also be avoided, intended for the energy production for heating water (KYLILI *et al*., 2018). Erdenedavaa *et al*., (2018), in a study carried out in Mongolia, evaluated the solar collector performance and the thermal gain evaluation provided by its use in a detached house. The system was used to supply the demand for a coal stove and an electric heater for heating water. Based on the total thermal energy required for the house through the system, CO2 savings of 32% and 18% are obtained when using a coal stove and electric heater, respectively (ERDENEDAVAA *et al*., 2018). Studies related to photothermal systems in some countries in Europe and Asia, such as France (De laborderie, 2011), Turkey (H. Benli, 2016), Mongolia (Erdenedavaa *et al*., 2018), Thailand (Eskew, John *et al*., 2018), Greece (Koroneos, C., Nanaki, E., 2012; Tripanagnostopoulos, Y. *et al*., 2005), bring in their scope the comparison of the use of solar energy and electricity for heating water, bringing the environmental gain when using photothermal systems. On the other hand, it is observed that, in most studies, mitigating measures or alternative materials that may reduce the environmental footprint resulting from the production of solar collectors are not proposed. Taking this factor as a reference, the present work aims at the environmental assessment by ACV and thermal efficiency of a solar thermal system produced with alternative materials, both for the solar plate and for the boiler, and later comparison of this with industrial systems. The data used in the inventory were collected directly from the primary source, when available, for the alternative system as technical catalogs were used for the industrial system.

2 MATERIALS AND METHOD

This paper aimed to propose a solar collector environmental assessment, using LCA. It is noteworthy that the pilot project was developed on a laboratory scale and will be detailed as to its main design parameters that are relevant to LCA, mainly related to the Life-Cycle Inventory.

2.1. GOAL AND SCOPE DEFINITION

The LCA goal was defined as identifying the manufactured solar collector hotspots, and later comparing it with a commercial system. The system boundaries selected was gate-to-gate LCA, considering the following productive and logistical stages under analysis:

- Materials transport to the consumer
- Solar collector production
- Lifetime
- Final disposal.

According to the National Institute of Metrology, Quality, and Technology (Inmetro), the solar collector uses for activities that consume high energy demands, such as shower, can result in significant savings due to the electric shower inactivation, which is responsible for raising the shower water temperature to 38 to 40 ºC. Based on this principle, the functional unit (FU) was characterized by heating 26L of water, at a temperature greater than or equal to 38 ºC, for 20 years. The reference flow (RF) to fulfill the selected FU was defined as a solar collector manufactured from alternative materials.

To verify the system compliance with the functional unit adopted, thermocouples were installed at the entrance and exit of the solar plate, as well as in the boiler, aiming to collect data temperature (**Figure 1**) every 30 minutes. The measured updates were collected using an AGILIENT 34970A data acquisition system. Through the developed database, it was possible to build a daily meal ramp for the system, aiming to confirm the achievement of the objective outlined in the functional unit choice and thus prove the system viability for further environmental assessment.

Figure 1: Alternative Solar Collector

The alternative system was measured for 4 months, from March to June of 2018. In general, at the water consumption output, average temperatures above 38 ºC were measured, except on rainy days. Temperatures below 38ºC were identified only at the early morning hours, which does not affect the established functional unit.

2.2. INVENTORY

In the system production stage, the base materials used to develop the boiler, as well as the collecting plate, were quantified. Once all the materials used to assemble the system are manufactured in different cities as shown in **Table 1**, it was considered the materials transportation by lorries from them to Santa Cruz do Sul.

Table 1**:** Materials suppliers to the alternative solar collector production

Material	City	Distance from Santa Cruz do Sul
Glass fiber	São Paulo	1250 km
Copper pipes	São Paulo	1265 km
Aluminum box	São Paulo	1285 km
Galvanized steel sheet	Porto Alegre	149 km
PVC pipes	Joinville	750 km
Resin	Goiás	1800 km

In the system production, the boiler was developed using orthophthalic polyester resin impregnated with 10% w/w sunflower residue, materials that aim to replace steel and polyurethane as raw materials. The chosen resin is a thermoset material produced through a plastics recycling process. The sunflower residue impregnation in the resin promotes greater thermal reserve capacity due to the orthophthalic resin pores filling, thus increasing the boiler thermal insulation capacity.

Regarding the manufactured solar plate, the conductive matrix used was made by galvanized steel, a material that replaced copper. In addition, the solar plate was painted with ink incorporated with nanostructured titanium dioxide, which was synthesized in the laboratory, using the Sol-Gel method (BATISTA, P. S, 2010). Once TiO_2 can present a high surface area, its use aims to improve the solar plate thermal absorption capacity. Previous analysis in TiO2 surface area has shown a surface area of 82 m²/g. This area quantified was close to the results obtained by SANTOS et al. (2017), which presented a TiO2 surface area of 74 and 85 m²/g. The materials quantification is presented in **Table 2**.

Table 2: Alternative solar collector inventory

Specification	Material	Mass
Boiler	PVC	0,48 kg
	Sunflower	2,33 kg
	Orthophthalic resin	35,31 kg
	Butanox	0,35 kg
	Total weight	**38,47 kg**
Solar plate	Copper pipe 22	17,97 kg
	Copper pipe 9,53	1,165 kg
	Aluminum plate	5,4 kg
	Glass fiber	7,5 kg
	TiO2	2,5 g
	Total weight	**32,035 kg**

2.3 LIFE CYCLE IMPACT ASSESSMENT

Impact 2002 was chosen as the evaluation method, represented by Climate Change, Natural Resources, Human Health, and Ecosystem Quality categories. The results were obtained through modeling in SimaPro 8.5 software. The evaluation method was chosen due to its clarity in demonstrating the main environmental impacts of each system, thus achieving the quantification and qualification of each system's potential impact.

2.4. INTERPRETATION

Taking as a reference the most impactful materials, a sensitivity analysis was suggested. In this stage, it was proposed the mass variation of the most impactful materials according to the characterization phase. Thus, sensitivity analysis provided the environmental impacts behavior verification, resulting from these materials, depending on the variation of their mass in the system.

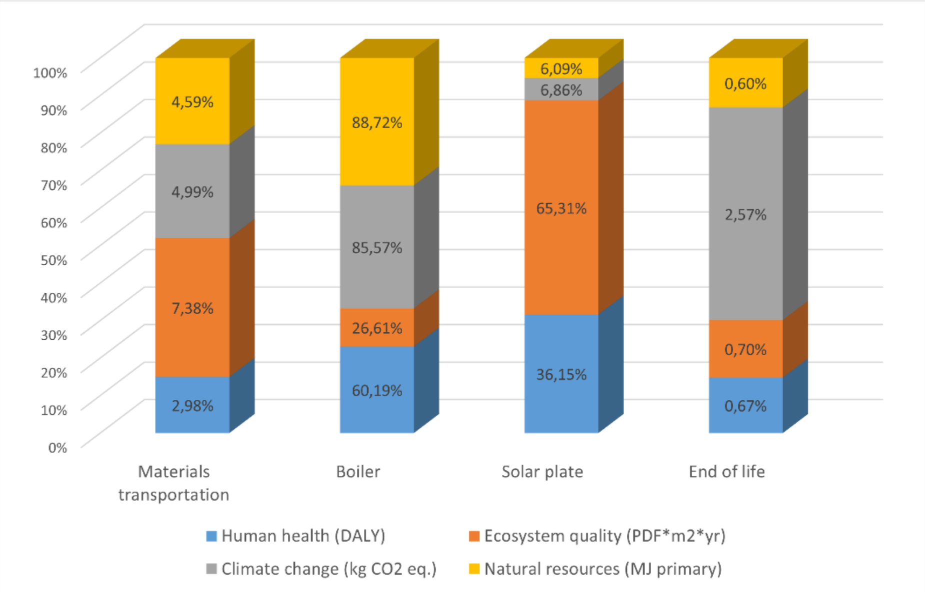
3 RESULTS AND DISCUSSION

3.1 ALTERNATIVE SOLAR COLLECTOR IMPACTS CHARACTERIZATION

As shown in **Figure 2**, the selected impact potentials categories from the production phase were calculated. Observing the results, boiler production contributed more than 85% in total climate change and natural resources categories. This condition is justified by the high amount of energy consumed in employed materials manufacturing. A similar result was also presented by Laborderie *et al*. (2011), who explain that the electrical energy used in water heating system components production can be responsible for 80 - 90% of total impacts caused in the climate change category.

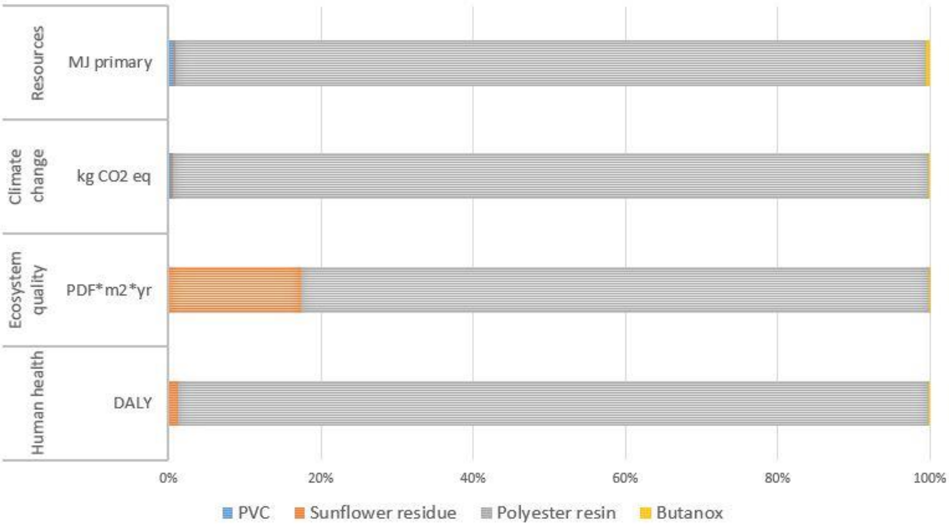
In ecosystem quality and human health categories, the solar plate makes a greater contribution to impacts caused by the system. Since the solar plate is basically composed of metals, the impacts related to mining stand out as preponderant to obtained results (LUZ, A. B. *et al*., 2018).

Figure 2: Alternative solar collector environmental impacts



When we analyze the boiler contributions, it can be noticed that the environmental impact potential (**Figure 3**) is concentrated in saturated polyester resin usage. This happens due to the greater representativeness in mass when compared to the other boiler components. The polyester resin available in the Ecoinvent database is produced from organic compounds derived from oil extraction, with no option to select a resin from plastics recycling. According to the company responsible for the manufacture of recycled polyester resin, 30% w/w of recycled PET bottles are used in the composition and the remainder is used as commercial polyester resin. Therefore, the original data set was adapted, considering 30% from recycled PET and the rest from commercial resin. In **Figure 3**, it can also be seen that, for the ecosystem quality category, approximately 18% of the impact is due to a partial contribution of sunflower usage. The result is related to the sunflower cultivation stage, considering all necessary inputs from planting to harvest. The presence of materials used for soil fertilization, as well as in the change in land use during the production of sunflower, reflects the representativeness of 18% in the ecosystem quality category. This result coincides with the analysis made by Figueiredo *et al*. (2012), who state that fertilizers and diesel used in the sunflower cultivation stage are the major contributors to the impacts on the sunflower life cycle.

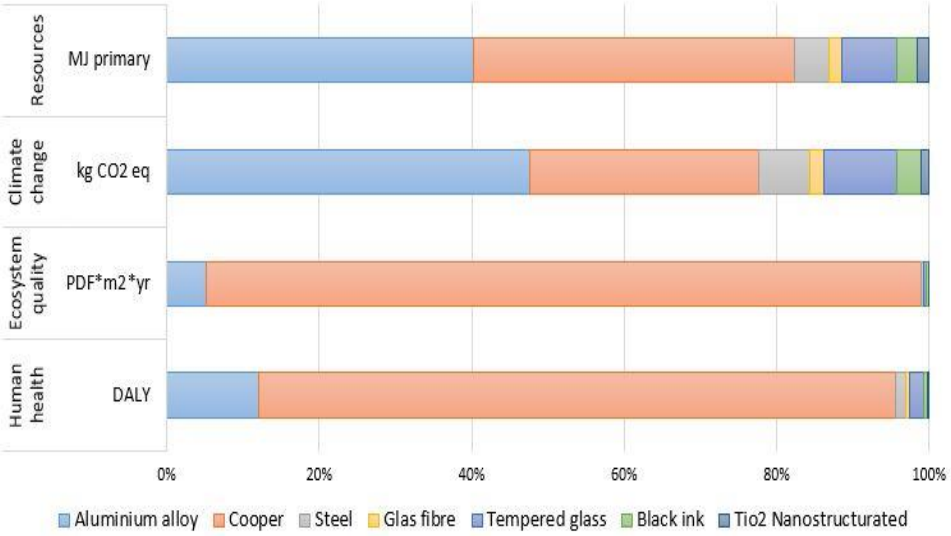
Figure 3: Alternative boiler production environmental impacts



Regarding the solar plate impact, the contributions of copper and aluminum are highlighted, as shown in **Figure 4**. Among the impacts inherent to copper mining, the main ones occur on the soil and on the surface and underground waters. Once the copper is discarded in the soil, the organic matter present at the site is affected, which interrupts the growth of vegetation and provides ecosystem turbulence (HERTWICH, Edgar G. *et al.*, 2015). When mining wastewater is emitted, there is also the potential for contamination of water resources due to the copper presence.

In Climate Change and Natural Resources categories, a greater share of the aluminum contribution could be noticed. As mentioned by Macedo *et al*. (2016), aluminum production has environmental impacts linked to mineral extraction stages, high energy consumption, and harmfulness to human health offered by exposure to materials present in mines.

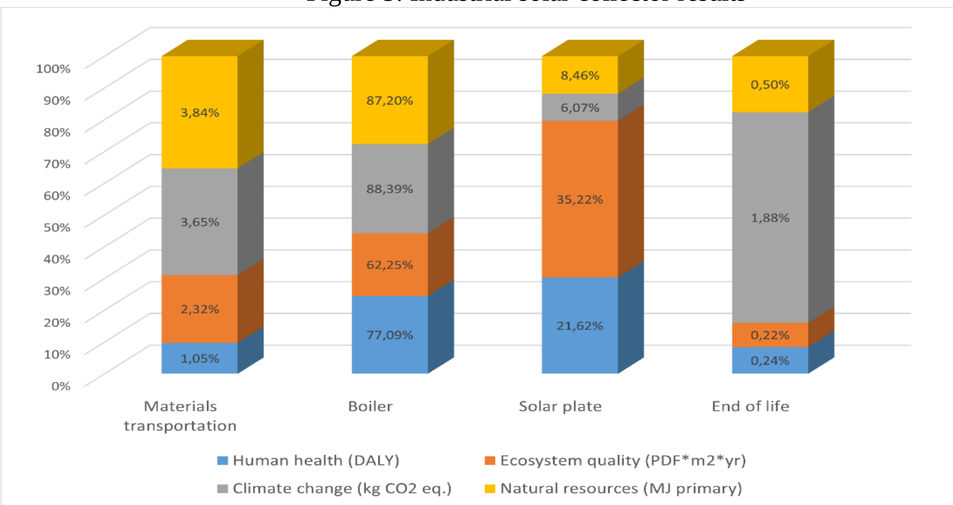
Figure 4: Alternative solar plate environmental impacts



3.2. INDUSTRIAL SOLAR COLLECTOR IMPACTS CHARACTERIZATION

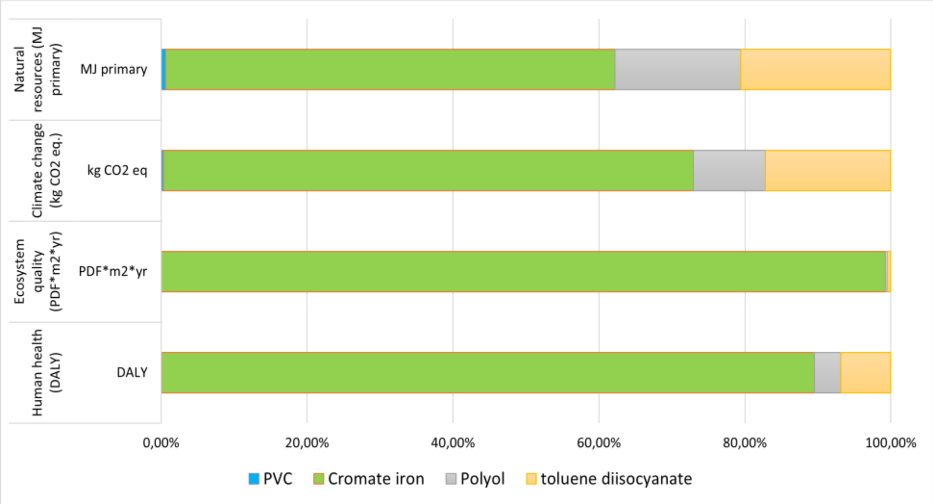
The industrial scenario impacts characterization is shown in **Figure 5**. As we can see, industrial boiler production proved to be the biggest contributor in all the environmental categories analyzed due to the components used in the industrial thermal reservoir manufacture.

Figure 5: Industrial solar collector results



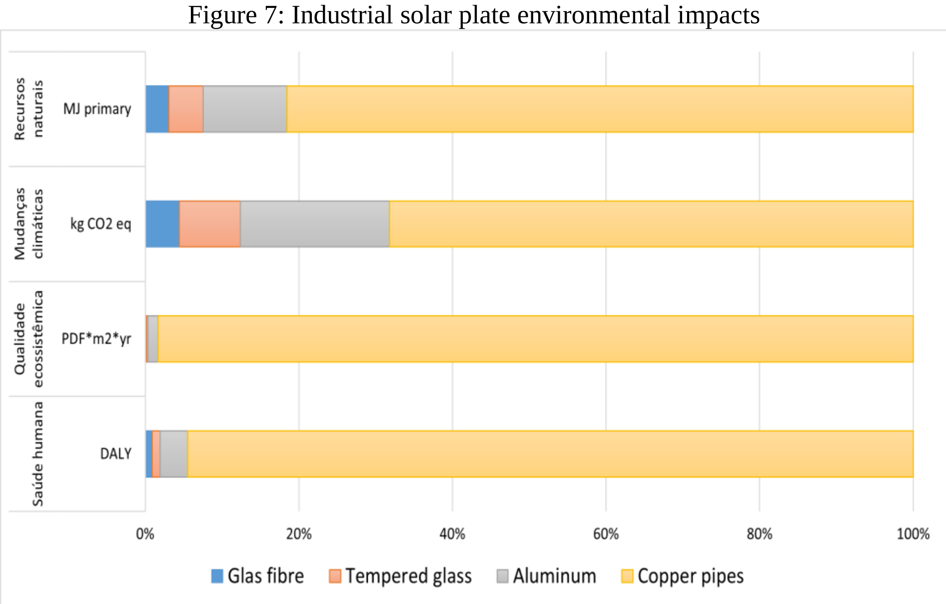
In **Figure 6**, it is observed the impact resulting from the use of steel in boiler constitution, since the steel industry requires great demand of energy and materials. More than 50% of the number of materials and energy that enters its production process results in gaseous effluents and solid waste. In addition, the processes used at high temperatures for steel production are generally conducted by wood-fired ovens. (GERVÁSIO H., 2008). In the category of natural resources, it was possible to notice the importance of the reagents necessary for polyurethane (PU), polyol, and diisocyanate production. PU is a polymer formed by non-biodegradable chains, so when they are discarded incorrectly in the environment they will not degrade naturally (RIZZO, Marcos *et al*., 2015).

Figure 6: Industrial boiler environmental impacts



The industrial solar plate environmental impacts characterization (**Figure 7**) demonstrates a major contribution regarding copper, also due to a greater amount of material used (4.5x than alternative plate). In addition, in the climate change category, there was also a contribution from aluminum, as previously mentioned.

Figure 7: Industrial solar plate environmental impacts



3.3. ENVIRONMENTAL SCENARIOS EVALUATION

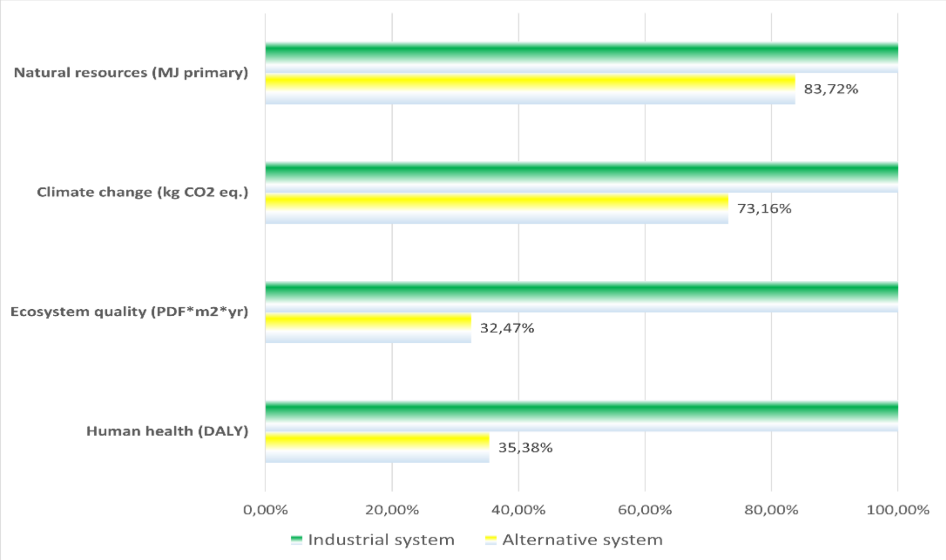
Analyzing the environmental impacts of both systems, the boiler contributed considerably: The alternative boiler due to the resin and the industrial boiler due to the steel. On the other hand, when comparing the systems through the impacts provided in all the boundaries defined in this scope (**Figure 8**), all selected categories presented reductions in the environmental impacts, when comparing the alternative system to the industrial one.

In the human health category, there was a 64.62% reduction in impacts. The polyester resin, despite being the largest contributor in this category, had less participation in the impacts when compared to the chrome steel present in the industrial scenario. As previously mentioned, the steel industry offers a great danger to human health due to the processes required in the production stage (GERVÁSIO H., 2008).

As shown in **Figure 8,** in the Ecosystem Quality category, the alternative scenario presented a reduction of 67.53% in impacts when compared to the industrial scenario. In addition, by replacing copper with galvanized steel in the alternative plate, the environmental impacts in this category were reduced by 50%. This result is justified by the contribution of copper discussed in the characterization stage. However, in this category, a small increase in environmental impacts was observed in the transport stage of the alternative system. This increase is potentially related to the density of the polyester resin. As it is a dense material, it will demand more fuel for vehicles when transporting it.

In the climate change and natural resources categories, fewer impact reductions were observed, which were reduced by 26.84% and 16.28% respectively, when compared to the industrial scenario. In these categories, it is important to emphasize that the resin available in the database used to perform the LCA understudy comes from the manufacture of petroleum. From an environmental point of view, the oil industry is characterized as a great pollution source. The oil refining processes are based on high consumption of water and energy and the production of many gases harmful to human health, liquid effluents, and solid waste without treatment.

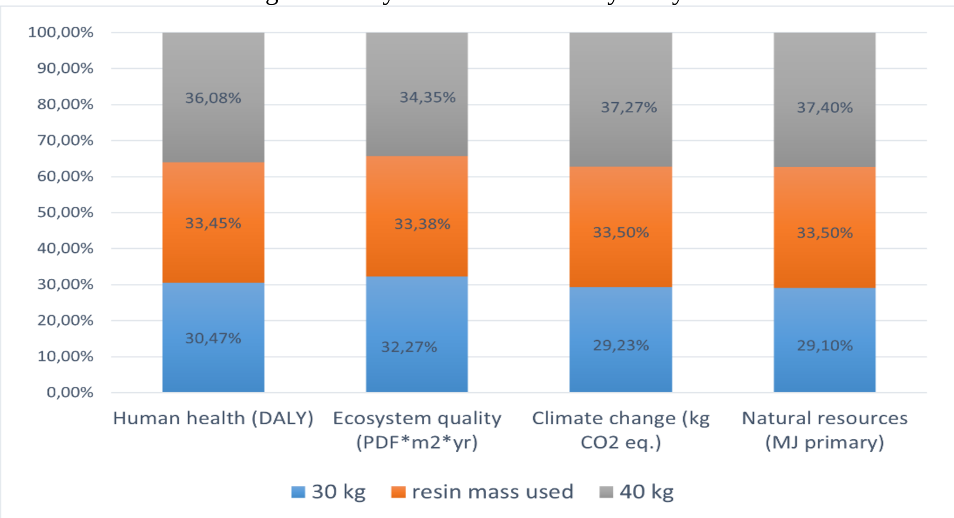
Figure 8: Environmental impacts comparison between the systems



3.4 SENSITIVITY ANALYSIS

Considering that the polyester resin gained notoriety among the most influential materials in the environmental impacts produced by the alternative system, a parameter of 7% variation in mass was adopted. By using this coefficient of variation, it was possible to know the resin environmental impacts behavior as a function of mass variation (**Figure 9**).

Figure 9: Polyester resin sensitivity analysis



Observing a sensitivity analysis results, we could see the main impact variation was in the Climate Change and Natural Resources categories, represented by a variation of about 4%. This difference is justified by the resin manufacturing method, which is carried out in the oil industries, where oil is the principal resource used. Therefore, there is a direct relationship between the resin used and natural resources extraction. How much more resin is used in the thermal reservoir, bigger will be the natural resources extraction. Therefore, the scenario with 30 kg of resin had lower environmental impacts when compared to the others.

On the other hand, the alternative thermal reservoir was built with a thickness of 2 cm. By decreasing the mass of resin used, the thickness is consequently reduced. This fact can lead to a decrease in the reservoir's heat resistance, impairing the system's thermal storage capacity.

During this project, it was found a recycled polyester resin available in the market. According to the company responsible for manufacturing the recycled polyester resin, its composition is 30% recycled PET bottles and the rest equal to commercial polyester resin. Therefore, it was proposed a comparison (**Figure 10**) between the alternative boiler already made and a second scenario with the recycled resin. Looking the results, it was possible to see a reduction in most categories, highlighting the category of Ecosystem Quality where the use of polypropylene reduced the impacts in 23.59% in relation to the alternative system.

As steel and copper are characterized as the main materials for the thermal absorption efficiency of solar plates, they cannot be changed, as they directly contribute to the efficiency of the system and, consequently, to the established functional unit. Regarding to the material transport, it was also not necessary to assume the change of suppliers, since the impacts produced by transport were not significant when compared to the other stages.

4 CONCLUSIONS

When carrying out the system environmental analysis, the LCA performed demonstrated the alternative system made has less potential for environmental impacts in all selected categories when compared to industrial system.

Since the manufactured system fulfilled the functional unit adopted for this project, the possibility of creating alternative solar water heating systems is emphasized, with less potential to impact the environment without significant loss in the heating and thermal reservation capacity of water for human use.

ACKNOWLEDGEMENTS

Authors would like to thanks to all those who contributed to this work and especially for funding agencies CNPq (Process n° 427402/2016-6), CAPES and FAPERGS.

REFERENCES

ARNAOUTAKIS, Nektarios, et al. Comparative experimental Life Cycle Assessment of two commercial solar thermal devices for domestic applications. Renewable Energy, v 111, p 187-200, 2017.

Batista, P. S.; Propriedades morfológicas e estruturais e rendimento quântico de geração de radicais hidroxilas em amostras sintetizadas de dióxido de titânio. Tese de Doutorado, Universidade Federal de Uberlândia, 2010.

BENLI, Hüseyin. Potential application of solar water heaters for hot water production in Turkey. **Renewable and Sustainable Energy Reviews**, v. 54, p. 99-109, 2016.

BHAT, I. K. et al. LCA of renewable energy for electricity generation systems—a review. **Renewable and Sustainable Energy Reviews**, v. 13, n. 5, p. 1067-1073, 2009.

BLISS, Raymond W. The derivations of several "plate-efficiency factors" useful in the design of flat-plate solar heat collectors. **Solar Energy**, v. 3, n. 4, p. 55-64, 1959.

BOUÇAS, Lucas Netto. Condução térmica em metais: parte 1: experimento prático. 2011.

SILVA, Cristiano Alves da; RODRIGUES, Luciano Brito; WILLERS, Camila Daniele. Avaliação do ciclo de vida no Brasil: uma investigação nas principais bases científicas nacionais. Prod. [online]. 2013, vol.23, n.2, p. 436-447.

CIAMBRONE, David F. **Environmental life cycle analysis**. CRC Press, 2018.
COMODI, Gabriele et al. Multi-apartment residential microgrid with electrical and thermal storage devices: Experimental analysis and simulation of energy management strategies. **Applied Energy**, v. 137, p. 854-866, 2015.

DA SILVA, Adriana Hoenisch; MORAES, Carlos Alberto Mendes; MODOLO, Regina Célia Espinosa. Avaliação ambiental do setor calçadista e a aplicação da análise de ciclo de vida: uma abordagem geral. In: **Forum Internacional de Resíduos Sólidos-Anais**. 2017.

DE LABORDERIE, Alexis et al. Environmental impacts of solar thermal systems with life cycle assessment. In: **World Renewable Energy Congress-Sweden**. Linköping University Electronic Press, Linköpings universitet, 2011. p. 3678-3685-ISBN 978-91-7393-070-3.

DE SOUZA CABRAL, Isabelle; TORRES, Adriana Cazelgrandi; SENNA, Pedro Rocha. Energia Solar–Análise comparativa entre Brasil e Alemanha. 2013.

DE OLIVEIRA, Anderson Geraldo Alves. Modelagem e simulação de um sistema solar de aquecimento e distribuição de água quente. 2014.
DOS SANTOS, Luciano Miguel Moreira. **Avaliação ambiental de processos industriais**. Oficina de Textos, 2017.

ERDENEDAVAA, Purevdalai et al. Performance analysis of solar thermal system for heating of a detached house in harsh cold region of Mongolia. Renewable Energy, v. 117, p. 217-226, 2018.

ESKEW, John et al. An environmental Life Cycle Assessment of rooftop solar in Bangkok, Thailand. **Renewable Energy**, v. 123, p. 781-792, 2018.

FAIZAL, M. et al. Energy, economic and environmental analysis of metal oxides nanofluid for flat-plate solar collector. **Energy Conversion and Management**, v. 76, p. 162-168, 2013.

FIGUEIREDO, Filipa; GERALDES CASTANHEIRA, E.; FREIRE, Fausto. LCA of sunflower oil addressing alternative land use change scenarios and practices. In: **Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2012)**. 2012. p. 1-4.

JUNIOR, Jayron Alves Ribeiro et al. Energia fotovoltaica: estudo de viabilidade econômica para implantação em edificações residenciais no Tocantins. **Brazilian Journal of Development**, v. 6, n. 2, p. 6702-6715, 2020.

GAUTAM, Abhishek et al., 2017. A review of technical improvements, economic feasibility and world scenario of solar water heating system. Renewable and Sustainable Energy Reviews, v. 68, p. 541-562, 2017.

GE, T. S., et al. Solar heating and cooling: Present and future development. Renewable Energy, v. 126, p. 1126-1140, 2018.

HERTWICH, Edgar G. et al. Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies. **Proceedings of the National Academy of Sciences**, v. 112, n. 20, p. 6277-6282, 2015.

KALOGIROU, Soteris A. Solar thermal collectors and applications. **Progress in energy and combustion science**, v. 30, n. 3, p. 231-295, 2004.

KYLILI, Angeliki et al. Environmental assessment of solar thermal systems for the industrial sector. **Journal of Cleaner Production**, v. 176, p. 99-109, 2018.

Koroneos, C., Nanaki, E., 2012. Life cycle environmental impact assessment of a solar water heater. J. Clean. Prod. 37, 154–161.

LUZ, Adão Benvindo da; LINS, Fernando Antonio Freitas. Introdução ao tratamento de minérios.

LING-CHIN, J.; HEIDRICH, O.; ROSKILLY, A. P. Life cycle assessment (LCA)–from analysing methodology development to introducing an LCA framework for marine photovoltaic (PV) systems. **Renewable and Sustainable Energy Reviews**, v. 59, p. 352-378, 2016.

NEVES, João CM das. Avaliação Técnico-Econômica De Um Aquecedor Solar De Água Com Coletor De Tubos a Vácuo Na Cidade De Cascavel–PR. **Universidade Estadual do Oeste do Paraná, Cascavel**, 2013.

ISO. 14040 International standard. **Environmental Management—Life Cycle Assessment—Principles and Framework**, 2009.

RIZZO, Marcos et al. Reaçao ao fogo, isolamento térmico e desempenho acustico de aglomerados de poliuretano rıgido com adiçao de fibras naturais. **Scientia cum Industria**, v. 3, n. 1, p. 17-22, 2015.

R. Turconi, A. Boldrin, T. Astrup, Life Cycle Assessment (LCA) of electricity generation technologies: overview, comparability, and limitations, Renew. Sustain. Energy Rev. 28 (2013) 555e565.

SUMATHY, K; SHUKLA R; ERICKSON, P.; GONG, J; Recent advances in the solar water heating systems: A review. **Renewable and sustainable Energy Reviews.** n. 19p. 173-190, 2013.

TRIPANAGNOSTOPOULOS, Y. et al. Energy, cost and LCA results of PV and hybrid PV/T solar systems. **Progress in Photovoltaics: Research and applications**, v. 13, n. 3, p. 235-250, 2005.

UCTUG, Fehmi Gorkem, et al. Life cycle environmental impacts of domestic solar water heaters in Turkey: The effect of different climatic regions. Science of the Total Environment, v. 622-623, p. 1202-1216, 2018.

WALAA MOUSA HASHIM, ALI TALIB SHOMRAN, HASASN ALI JURMUT, TAYSER SUMER GAAZ, ABDUL AMIR H. KADHUM, AHMED A. AL-AMIERY. Case Study on Solar Water Heating for Flat Plate Collector. **Case Studies in Thermal Engineering**, 2018