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## ECONOMIC ANALYSIS OF PV-T COLLECTORS IN BRAZIL

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**Abstract.** *The Brazilian photovoltaic market has shown considerable growth over the last few years. In 2013 there was almost no energy being generated by photovoltaics. Today there are enough photovoltaics installed to generate almost 3 GW of power. The solar thermal collector market in the country is also considerable. In 2018 the installed capacity was over 11 GW, representing an area of roughly 16 million square meters. However, customer surveys show that only 15% of the photovoltaic users have solar thermal collectors installed. The fast expansion of the photovoltaic market and large adoption of solar thermal collectors suggest that there is a considerable market for photovoltaic thermal (PV-T) systems. This work attempts to quantify the potential costs and gains of a novel PV-T system. The intended system enables a common photovoltaic panel to also generate thermal energy by using a heat exchanger installed on its back face. Simulations were made for residential use of PV-T systems in different parts of Brazil. An average Brazilian household is considered for 13 different states. These averages consider several different parameters that characterize the energetic needs of the consumer. Simulations were made for three different scenarios that could transition to the PV-T system proposed. An overview of the simulations made in TRNSYS is presented. Based on the thermal simulations the break-even price for the heat exchanger on all states and scenarios analyzed is obtained. The results obtained show that the system can be economically viable. The best scenario occurred when the user transitions from having no solar energy generation to a PV-T system. In this scenario the break-even price for a heat exchanger ranged from R\$ 3856.23 to R\$ 2733.40. The worst case happened in the scenario where both PV panels and solar thermal collectors were already installed. In this scenario the prices ranged from R\$ 813.02 to R\$ 140.83.*

**Keywords:** *PV-T solar collectors, solar energy, economic analysis, annual simulations.*

### 1. INTRODUCTION

Solar thermal (ST) collectors can be combined with photovoltaic (PV) to obtain a hybrid photovoltaic-thermal collector (PV-T) capable of generating both electricity and heat (Allan *et al.*, 2015). A ST collector is a fluid heater in which the energy of incident solar radiation is absorbed as heat. On the other hand, PV modules directly convert solar radiation into electricity by the Photovoltaic Effect using semiconductor materials (Pinho and Galdino, 2014).

PV-T collectors increase the electrical energy produced by the PV module by removing thermal energy from the back of the solar cells and, consequently, the reduction in the PV module operating temperature (Dimri *et al.*, 2017), which

causes an increase in output power (Fesharaki *et al.*, 2011). The reduction in operating temperature promoted by PV-T module configuration also causes a decreasing thermal degradation of the PV panel increasing its lifetime (Preet, 2018).

The overall energy produced by PV-T is higher than the production energy in the same area if conventional ST collectors and PV modules are installed side by side (Allan *et al.*, 2015; Dimri *et al.*, 2017). However, the electrical and thermal efficiencies of the PV-T are lower than those presented by the PV and ST collectors individually (Huide *et al.*, 2017).

PV-T systems may be categorized as PV-T system using water (water-based PV-T), PV-T system using air, PV-T system using refrigerant, PV-T system using heat pipe and PV panel with phase change material (Preet, 2018). Still, water-based PV-T collectors can be classified into two types according to the absorber type applied. The first is the sheet-and-tube type absorber consisting of tubes and plates fixed under the back of the PV module (Kim and Kim, 2012). Care must be taken when using this type of absorber, because the PV-T module performance is compromised in the presence of an air gap that may exist between the PV module and the absorber plate (Aste *et al.*, 2017). The second type is the fully wetted type of absorber which consists of an absorber totally wetted formed by rectangular channels under the PV module back surface that increase the heat exchange area (Kim and Kim, 2012).

When the water flows through channels the global heat transfer is enhanced, even as an increase in the heat transfer coefficient occurs when velocity is increased. Under a given temperature difference, more heat is transferred at higher speeds, thus increasing thermal efficiency. Nevertheless, when the volume of water circulating through the channels is low, the water temperature at the PV-T module output will be higher. Electrical efficiency, in turn, increases with increasing fluid flow (Nasrin *et al.*, 2018).

Water was chosen as the working fluid because water-cooled plants enhanced solar PV performance than air-cooled plants (Moharram *et al.*, 2013), and the hot water generated is directly used for domestic needs. A dynamic model joined with real weather data and domestic hot water demand (DHW) is essential to estimate the energy production of a PV-T plant (Guarracino *et al.*, 2016).

According to Duffie and Beckman (2013), a complete approach to solar process economics must consider all future expenses through the common basis of the present worth. This means that all costs and savings are predicted and turned into a present monetary value. This way different alternatives can be compared, and some economic figures of value can be obtained, such as the Return On Investment (ROI), Payback time and Life-Cycle Savings (LCS). For this, several parameters are needed, such as the expected inflation rates and maintenance costs. For tradition photovoltaics the break-even price is defined by the price at which the net present benefit of offset grid electricity purchases equals the PV system capital cost (Davidson, 2015). This means that it can be considered a particular case of the LCS, in which the savings are equal to zero. The concept of the breakeven price is used in this work to compare different scenarios with varying solar infrastructure installed.

The present paper attempts to predict the economic gains of the novel heat exchanger for PV panels, converting them into PV-T systems. The heat of the PV panel is transferred to the water, lowering the PV module operating temperature. The proposed PV-T collector is the fully wetted absorber type formed by a sequence of polypropylene channels with rectangular profiles. These channels are fixed under the PV module bottom surface whereby the water is heated by the solar cells. Figure 1 shows a representation of the heat exchanger installed on the back of the PV module.



Figure 1 - Representation of the heat exchanger installed on the PV module.

The simulations performed in TRNSYS software seek to obtain the resulting break-even prices for the PV-T collector presented in Figure 1 for some selected Brazilian cities. Both PV panels and ST collectors used in simulations are commercially available to Brazilian households. The simulations quantify the expected thermal and electric energy generation of three different scenarios to be then compared with the proposed PV-T panel generation.

Depending on the latitude where the PV-T panel is installed in Brazil between 3 and 5 PV-T modules per roof is sufficient to satisfy the monthly hot water needs (60%, reference value for solar design) and electricity consumption of low-income residences (Tachon *et al.*, 2016). By simplification, in present work 3 PV-T modules will be considered for every state analyzed.

## 2. MATERIALS AND METHODS

Three different scenarios are considered in this work, as shown in Figure 2. These scenarios all consider switching from one type of infrastructure to the PV-T solution proposed. For each of these scenarios the goal is to establish the break-even price for the heat exchanger. This price is defined by having the present value of the investment equal to zero, meaning that, if the heat exchanger is sold for a price higher than the break-even price the deal is no good for the buyer, while if sold for less it becomes a good deal for the buyer.

| Has   | Needs   | Final setup   |
|---|---|---|
| <p>Scenario 1</p> <div style="border: 1px solid black; width: 60px; height: 40px; margin: 0 auto; text-align: center;">Electric Shower</div>  | <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">Boiler/<br/>Hydraulic</div> <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">PV</div> <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">Heat<br/>Exchanger</div> | <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">Electric<br/>Shower</div>   |
| <p>Scenario 2</p> <div style="display: flex; justify-content: space-around; margin: 0 auto;"> <div style="border: 1px solid black; width: 40px; height: 20px;">PV</div> <div style="border: 1px solid black; width: 40px; height: 20px;">Electric<br/>Shower</div> </div>   | <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">Boiler/<br/>Hydraulic</div> <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">Heat<br/>Exchanger</div>  | <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">Boiler/<br/>Hydraulic</div> <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">PV</div> <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">Heat<br/>Exchanger</div> |
| <p>Scenario 3</p> <div style="display: flex; justify-content: space-around; margin: 0 auto;"> <div style="border: 1px solid black; width: 40px; height: 20px;">Electric<br/>Shower</div> <div style="border: 1px solid black; width: 40px; height: 20px;">Boiler/<br/>Hydraulic</div> </div> <div style="display: flex; justify-content: space-around; margin: 0 auto;"> <div style="border: 1px solid black; width: 40px; height: 20px;">PV</div> <div style="border: 1px solid black; width: 40px; height: 20px;">ST</div> </div> | <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #f2dede;">ST</div> <div style="border: 1px solid black; width: 60px; height: 20px; margin: 5px auto; background-color: #d9ead3;">Heat<br/>Exchanger</div>   |   |

Figure 2 - Different scenarios considered

To analyze the break-even price for each scenario it is necessary to evaluate the costs involved with installing the heat exchanger and other necessary components. Figure 2 shows the currently installed infrastructure for each scenario, what needs to be purchased (in green) and what could be sold (in red) to establish the PV-T system being studied. In the first scenario there is only an electric shower to generate hot water, therefore it is necessary to purchase the PV panels, the boiler (and the hydraulic installation) and the proposed heat exchanger. The second scenario is a client who has a PV panel system installed and the water heating is entirely done by an electric shower. In this scenario it is necessary to purchase the boiler and install it as well as buy the heat exchanger. The third scenario is an installation with PV panels, solar thermal (ST) collectors and the boiler installed. In this scenario it is considered that the ST collector is sold, and the heat exchanger is purchased, since they both serve the same function and having both would be redundant.

To quantify the energetic needs and energy generation for each scenario, three models in TRNSYS were made. Figure 3 shows a simplified version of the models. These simulated models do not directly correlate to the three different scenarios. On the first model there is only an electric heater to heat the water from ambient to a set temperature for the bath. The second model has a boiler that gets replenishment water at ambient temperature and delivers hot water to the electric heater. A ST collector is connected to the boiler to heat the water. In this model there is also a PV panel to generate electricity. The third model is like the second, the only difference is that the PV panel and ST collector are replaced by

the PV-T panel. Based on the information obtained by these models each of the scenarios' energetic needs can be calculated.

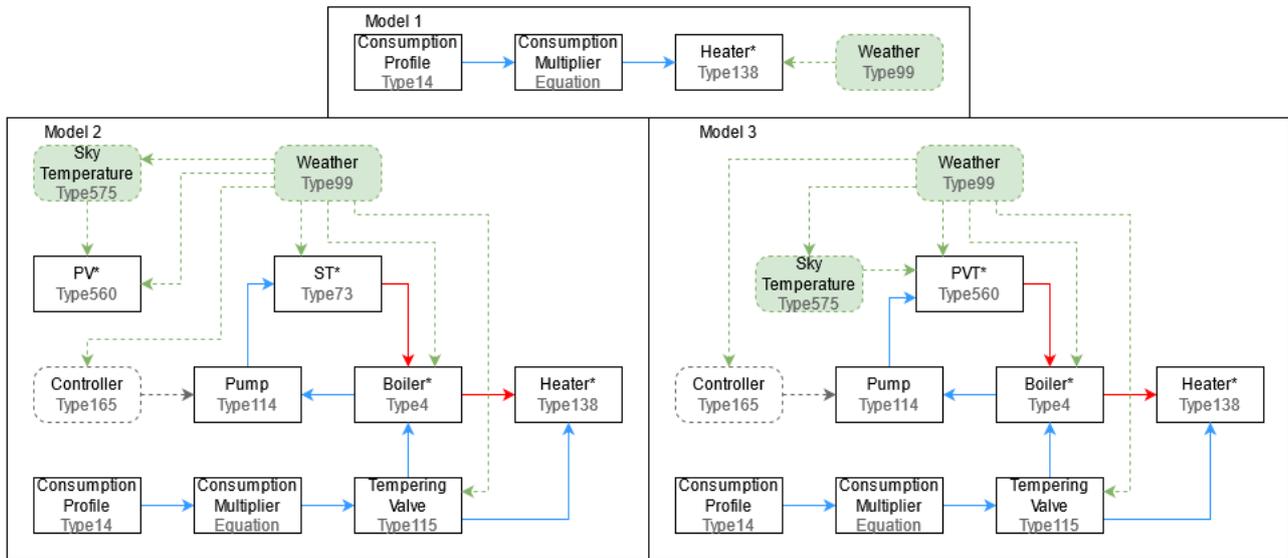


Figure 3 - Models implemented in TRNSYS

In TRNSYS simulations various blocks need to be implemented to provide all the parameters necessary to the simulations. For every model the setpoint temperature of the electric heater was 40 °C. The heating element in TRNSYS is considered to have enough power to supply water at this temperature independent of mass flow. To prevent using water from the boiler potentially above the setpoint temperature, a tempering valve is implemented to mix ambient temperature water with the water supplied by the boiler. This is done such that a perfect mix of the two sources provides an outlet temperature of 40 °C. This means that the electric heater does not provide energy to the flow when the tempering valve is active. This only happens in models 2 and 3, which use tempering valves. In TRNSYS the valve is simulated by Type11f, and the control is done by Type115.

Both the PV in model 2 and the PV-T in model 3 are simulated by Type560, but on the second model there is no water flowing through the PV. This is done to make more accurate comparisons. In both cases, the parameters used for the electricity generation were obtained from the datasheet of the PV panel Canadian Solar CS3W-400W. This model was chosen because future experimental studies with the heat exchanger will be done using this PV model, which will be used to validate the TRNSYS model. The parameters used on the hydraulic part of Type560 were based on previous studies conducted by Hipolito (2015) in preliminary versions of the heat exchanger, therefore they are subject to change with future studies. The ST collector used in model 2 (Type73) is modelled to have the same area as the PV-T panel. The other parameters were left as default, representing a generic ST collector. Three Type560 were connected in parallel in models 2 and 3. In model 2 only one Type 73 was used, meaning that the ST collector area is a third of the PV-T area. This setup requires approximately 2 m<sup>2</sup> more than the PV-T setup.

Due to incompatibilities with the SWERA provided Typical Meteorological Year (TMY) files and the standard expected by the TRNSYS weather data reader it was necessary to convert the meteorological data to a TRNSYS specified format. The format used in this work follows the Type99 documentation. Using this Type implies the need to provide the sky temperature from outside the weather reader module. Type575a was used to estimate the sky temperature.

The boiler considered (Type4) has an internal volume of 500 liters without an electric heater installed inside it. The control strategy employed for the pump (Type114) is done with hysteresis using the Type165. If the pump is off and the water at the outlet of the panel is 5 °C hotter than ambient temperature the pump is turned on. If the pump is on and the water at the outlet of the panel is at ambient temperature, the pump turns off.

To have more meaningful results, data about the potential clients was obtained. For this the national Brazilian survey "Pesquisa de Posse e Hábitos" (Eletrobras, 2019) was used. In English it translates to the Ownership and Habits Survey, referred to as PPH in this work. In the survey it is possible to determine various points of data that are relevant to the study, such as energy consumption and water heating systems utilization.

For this study the arbitrary threshold of 15% of houses with water heating systems is chosen to select the states to be analyzed. In total, this results in 13 states to be studied, of which only 2 do not have cities represented on the SWERA program. The 2 states without data are Espírito Santo and Goiás. For these cities meteorological data will be considered as the same as a neighbor state. Table 1 summarizes the states to be analyzed. Also, for every location the slope for the solar panels is set to be the same as the local latitude.

Table 1 - States analyzed and corresponding cities on the SWERA program.

| City chosen on SWERA | Percentage of houses with WHS | Latitude [°S] |
|----------------------|-------------------------------|---------------|
| Salvador (BA)        | 34%                           | 13.01         |
| Brasília (DF)        | 94%                           | 15.86         |
| Belo Horizonte (MG)  | 74%                           | 19.85         |
| Campo Grande (MS)    | 86%                           | 20.46         |
| Cuiabá (MT)          | 51%                           | 15.65         |
| Curitiba (PR)        | 100%                          | 25.51         |
| Rio de Janeiro (RJ)  | 94%                           | 22.9          |
| Santa Maria (RS)     | 100%                          | 29.7          |
| Florianópolis (SC)   | 100%                          | 27.66         |
| São Paulo (SP)       | 100%                          | 23.61         |
| Porto Nacional (TO)  | 19%                           | 10.7          |

The average hot water consumption and its profile and the expenditure on electricity bills are also obtained from the PPH. The hot water consumption is estimated based on the average number of permanent residents in the house, considering that each person requires 100 liters of water per day. The consumption profile is averaged based on the question on the survey that asks the time of day that showers are taken. Lastly the amount of electricity consumed is also taken from the survey, taking the average for each month. All of these parameters are obtained for each of the cities on Table 1. The consumption profile is done in a manner such that the profile is multiplied by the daily consumption to determine the instantaneous water draw.

For the economic model the three different scenarios shown in Figure 2 were analyzed. For each scenario it was calculated the amount of energy needed to be purchased every month during the typical meteorological year for the initial setup. The energy needs are then compared to the amount of energy that the PV-T model is expected to save. Since the results are obtained monthly considering the TMY it is expected that these results will repeat during the following years. This way the results from one month are the same as the ones from the same month next year. The period of analysis adopted is 10 years. This is done to adopt a conservative approach, since some parameters may vary significantly along this period, such as the inflation rates and the meteorological data due to climate change. It is expected that the life cycle of the product exceeds this period, which would increase the break-even price. The results obtained in this paper would then translate to the price in which the heat exchanger has a payback time of ten years.

For every scenario the amount of energy saved was calculated using the solar fraction definition. The solar fraction is defined by the percentage of energy used that was generated by solar means. The solar fraction for the thermal energy, the electrical energy and the overall energy used were obtained on the simulations. Based on the solar fractions obtained the energy output of models 2 and 3 are comparable for every state analyzed.

The 10 years of energy savings were then converted into monetary terms. The most common source of energy available to residential consumers is electric, therefore the price of electricity is used. According to the tariff ranking, the current average price of electricity for the B1 group (residential) is R\$ 0.59 per kWh (ANEEL, 2021). The overall rate of inflation adopted is of 4.5% every year, while 5% was adopted as inflation for electricity prices. A discount rate of 2% per year was considered. Lastly, it is also considered that maintenance costs will be 1% of the initial investment on the product. All these rates are adjusted to occur every month of the analysis period. The price for the PV panels was R\$ 1000 per solar panel, with an installation cost of another R\$ 1000, resulting in R\$ 4000 to install the three PV panels. For the boiler/hydraulic installation the cost was R\$ 2000. Finally, the selling price for the ST collector was R\$ 1000.

Microsoft Excel was used to calculate the equivalent values at the present time. The Goal Seek tool was used to find the break-even price. This is done for all three scenarios on every one of the 11 states simulated.

### 3. RESULTS AND DISCUSSIONS

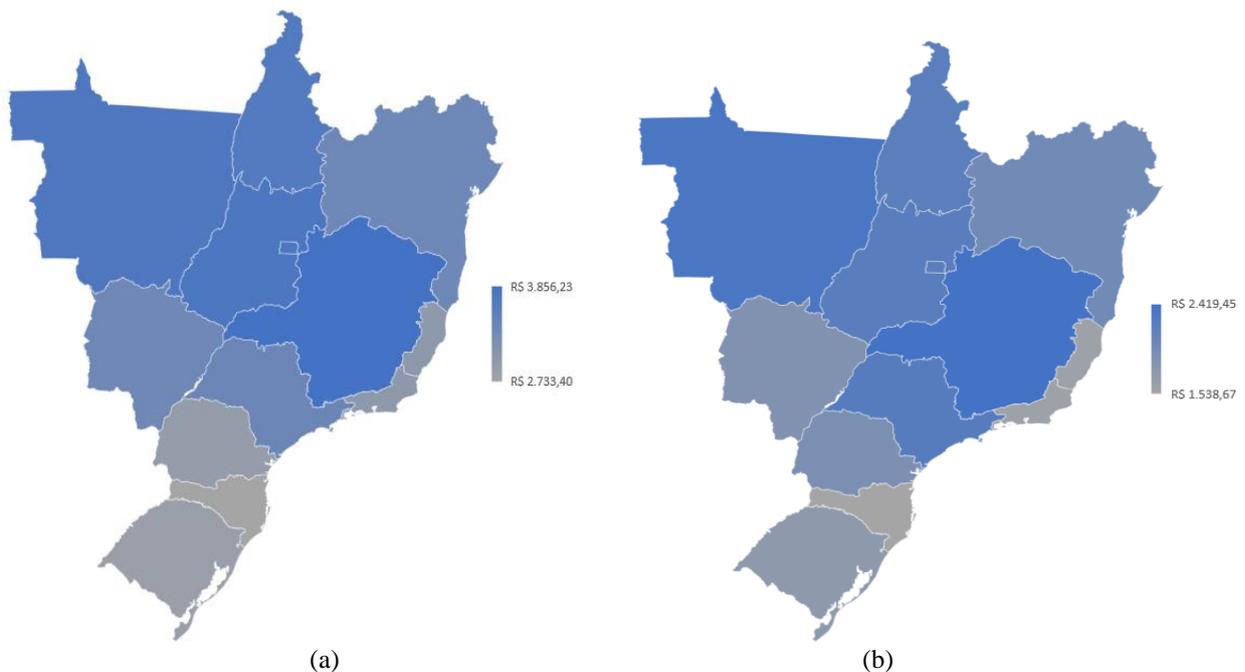
The results obtained show that, in all three cases, the heat exchanger shows positive results in all states. The highest break-even prices occurred in the first scenario, while the lowest on the third. This was already expected since PV panels and ST collectors are known to save money during their life cycle. Since the first scenario had neither of them nor the second did not have a ST collector it is expected that the energy savings are more significant, thus increasing the break-even price. Another result obtained is that the northernmost states tend to have higher break-even prices than the southern ones. This is mainly due to the difference in solar fractions. The highest solar fraction was 89.27% in Tocantins with model 3, while the lowest was 42.99% in Paraná with model 2. This can be explained by the different amount of solar energy received by each region. The states further north tend to get more solar energy throughout the year and have higher ambient temperatures, thus needing less energy to heat water to 40 °C. This could mean that having a higher number of PV-T panels could improve the results in the southern states.

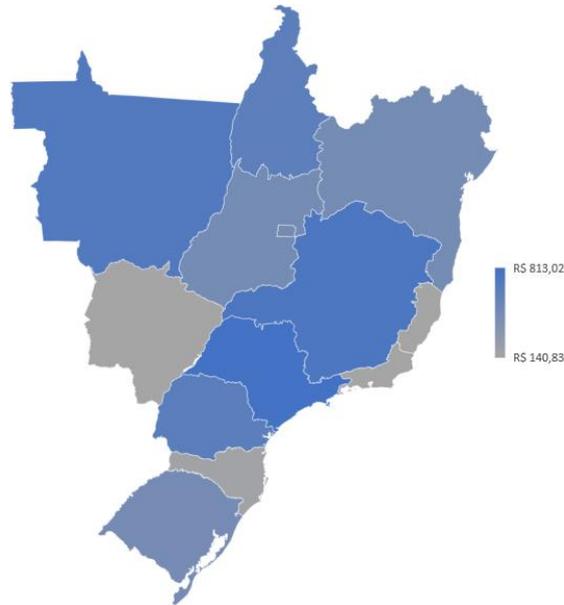
Overall, the results obtained are promising. Table 2 shows some of the main results obtained. All the values listed on the Table are for a single heat exchanger. The maximum break-even price for a heat exchanger obtained was of R\$ 3856.23 in Minas Gerais for the first scenario, while the lowest was of R\$ 140.83 in Rio de Janeiro for the third scenario.

Table 2 - Summary of the break-even price distribution for the scenarios in the states analyzed (in R\$).

|                    | Scenario 1 |      | Scenario 2 |      | Scenario 3 |      |
|--------------------|------------|------|------------|------|------------|------|
| Maximum            | 3856.23    | (MG) | 2419.45    | (MG) | 813.02     | (SP) |
| Minimum            | 2733.40    | (SC) | 1538.67    | (SC) | 140.83     | (RJ) |
| Average            | 3336.99    |      | 2000.34    |      | 463.74     |      |
| Standard deviation | 394.94     |      | 306.19     |      | 246.96     |      |

Figure 4 shows the break-even prices obtained for a single heat exchanger across all states analyzed and the three scenarios.





(c)

Figure 4 - Break even prices for the first scenario (a), for the second scenario (b) and for the third scenario (c).

#### 4. CONCLUSIONS

The results obtained show that, with the parameters used, the PV-T solution is an economically viable alternative, mainly to scenarios 1 and 2, in which the average break-even prices are R\$ 3.336,99 and R\$ 2.000,34 respectively. In both these scenarios the standard deviations are reasonable, ranging from around 10% to 15% on the aforementioned scenarios. The different meteorological conditions tested could explain this variation. The results from scenario 3, whilst not disappointing, were not as promising as the other scenarios.

The break-even prices show that a single heat exchanger can be sold for a substantial amount of money (as much as R\$ 3.856,23) and still break-even. Even the worst results show that the PV-T panels can break-even over the analyzed time period, albeit for such a low price that (as little as R\$ 140,83) that profit for the seller is unlikely. Since the final version of the heat exchanger is to be sold at a sale price lower than the break-even prices obtained it is expected to result in overall savings for the consumer. Further studies can be made by setting some arbitrary prices and calculating other useful results, such as the Return Over Investment (ROI) and Payback time. Then these results can be analyzed to have better information about the expected sales prices and volumes.

Other improvements to the models can also be done. Making simulations with variable amounts of PV, ST and PV-T panels for different states can show more uniform results along the Brazilian territories. Some parameters can also be better defined for the economic model. The installation costs for PV and ST panels can vary significantly from the ones presented based on different installation sites and conditions. Future studies should focus on better determining these quantities. Moreover, the electricity price also varies significantly from state to state (from an average of R\$ 0,87 in RJ to R\$ 0,51 in DF) (ANEEL, 2021). This means that the energy price can be an interesting parameter to vary on the regions analyzed. Due to the parametric setup utilized in TRNSYS these state-to-state analyses can be made with little effort using the tools already created.

Lastly, Duffie and Beckman (2013) show that the economic results obtained are a function of the solar fraction. Other than being an explanation to the lower result obtained in the southern states (where solar fractions were as low as 55% in SC and RS), this raises an opportunity to improve the thermal and economic model to find the optimal solar fraction that maximizes the break-even price.

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#### 6. REFERENCES

- Allan, J., Dehouche, Z., Stankovic, S., and Mauricette, L., 2015. "Performance testing of thermal and photovoltaic thermal solar collectors". *Energy Science & Engineering*, Vol. 3, No. 4, pp. 310–326.
- ANEEL, 2021, *Ranking das Tarifas*, Agência Nacional de Energia Elétrica ANEEL, <https://www.aneel.gov.br/ranking-das-tarifas>. Accessed 28 June 2021.
- Aste, N., Del Pero, C., Leonforte, F., 2017. "Water PVT Collectors Performance Comparison". *Energy Procedia*, Vol. 105, pp. 961–966.
- Davidson, C., Gagnon, P., Denholm, P., and Margolis, R., 2015. *Nationwide Analysis of U.S. Commercial Building Solar Photovoltaic (PV) Breakeven Conditions*. Denver: National Renewable Energy Laboratory (NREL), 2015, <https://www.nrel.gov/docs/fy16osti/64793.pdf>. Accessed 28 June 2021.
- Dimri, N., Tiwari, A., and Tiwari, G. N., 2017. "Thermal modelling of semitransparent photovoltaic thermal (PVT) with thermoelectric cooler (TEC) collector". *Energy Conversion and Management*, Vol. 146, pp. 68–77.
- Duffie, J. A. and Beckman, W. A. *Solar Engineering of Thermal Processes*. 4. ed. New Jersey: John Wiley & Sons, 2013. ISBN 978-1-118-41541-2.
- ELETRORBRAS, 2019, *Pesquisa de Posse e Hábitos de Uso de Equipamentos Elétricos na Classe Residencial: PPH Brasil*, <https://eletrobras.com/pt/Paginas/PPH-2019.aspx>. Accessed 28 June 2021.
- Fesharaki, V. J., Dehghani, M., Fesharaki, J. J., and Tavasoli, H., 2011. "The Effect of Temperature on Photovoltaic Cell Efficiency". In *Proceeding of the 1st International Conference on Emerging Trends in Energy Conservation-ETEC*, Teerã, Irã.
- Guarracino, I., Mellor, A., Ekins-Daukes, N. J., and Markides, C. N., 2016. "Dynamic coupled thermal-and-electrical modelling of sheet-and-tube hybrid photovoltaic/thermal (PVT) collectors". *Applied Thermal Engineering*, Vol. 101, pp. 778–795.
- Hipólito, H. L., 2015. *Analysis and application of combined photovoltaic/thermal flat plate collectors (pv/t) for low-income residences in brazil*. Final graduation paper, Bachelor graduation program in Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brazil.
- Huide, F., Xuxin, Z., Lei, M., Tao, Z., Qixing, W., and Hongyuan, S., 2017. "A comparative study on three types of solar utilization technologies for buildings: Photovoltaic, solar thermal and hybrid photovoltaic/thermal systems". *Energy Conversion and Management*, Vol. 140, pp. 1–13.
- Kim, J. H., and Kim, J. T., 2012. "The experimental performance of an unglazed PV-thermal collector with a fully wetted absorber". *Energy Procedia*, Vol. 30, pp. 144–151.
- Moharram, K. A., Abd-Elhady, M. S., Kandil, H. A., and El-Sherif, H., 2013. "Enhancing the performance of photovoltaic panels by water cooling". *Ain Shams Engineering Journal*, Vol. 4, No. 4, pp. 869–877.
- Nasrin, R., Hasanuzzaman, M. and Rahim, N. A., 2018. "Effect of high irradiation and cooling on power, energy and performance of a PVT system". *Renewable Energy*, Vol. 116, pp. 552–569.
- Pinho, J. T. and Galdino, M. A. *Manual de engenharia para sistemas fotovoltaicos*. Rio de Janeiro: CEPEL- CRESESEB, 2014.
- Preet, S., 2018. "Water and phase change material based photovoltaic thermal management systems: A review". *Renewable and Sustainable Energy Reviews*, Vol. 82, pp. 791–807.
- Tachon, L, Hipolito, H. L. and Passos, J. C., 2016. "Analysis and application of combined photovoltaic/thermal (PV/T) flat-plate collectors for low-income residences in Brazil". In *VI Congresso Brasileiro de Energia Solar*, Belo Horizonte, Brazil.

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