DOI: 10.51189/iii-coninters/11197

LEVELED ENERGY COST OF MICROGRID PV/BESS/GREEN HYDROGEN TO SUPPLY A PUBLIC CHARGING STATION: COMPARATIVE STUDY BETWEEN RECIFE - BRAZIL AND VÄSTERÅS - SWEDEN

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RESUMO

O avanço da mobilidade elétrica resulta no maior consumo de energia das redes, frente a isso, as microrredes com geração sustentável se apresenta como solução para o suprimento de estações de recarga. Porém, nem todos os locais do mundo dispõe de alto potencial de geração e incentivo financeiro para esse setor. Com isso, este artigo apresenta o dimensionamento de duas microrredes com geração fotovoltaica (FV), BESS (Battery Energy Storage System) e hidrogênio verde, considerando a mesma carga, mas locais diferentes, sendo eles a cidade de Recife no Brasil e Vasteras na Suécia. O objetivo é avaliar o custo nivelado de energia para ambas as localidades e comparar com o custo atual de energia nas estações de recargas. A simulação foi realizada com o HOMER Pro, no qual o resultado mostrou que a microrrede de Vasteras tem potência três vezes maior que a dimensionada para Recife, o que reflete nos dados de LCOE. Em Vasteras, o custo nivelado de energia (LCOE) é de 4.25 Kr/kWh e em Recife o custo ficou em 2.67 Kr/kWh. No Brasil, o LCOE ficou 1.07 Kr/kWh abaixo do atual custo de carregamento na Suécia.

Palavras-chave: LCOE; HOMER Pro, Estações de Recarga, Mobilidade Elétrica.

ABSTRACT

The advancement of electric mobility results in greater energy consumption of networks, considering this, microgrids with sustainable generation are presented as a solution for the supply of charging stations. However, not all locations in the world have high generation potential and financial incentives for this sector. Thus, this article presents the design of two microgrids with photovoltaic (PV) generation, BESS (Battery Energy Storage System) and green hydrogen, considering the same load, but different locations, namely the city of Recife in Brazil and Västerås in Sweden. . The objective is to assess the leveled cost of energy (LCOE) for both locations and compare it with the current cost of energy at the charging stations. The simulation was performed with HOMER Pro, in which the result showed that the Västerås microgrid has a power three times greater than the one dimensioned for Recife, which is reflected in the LCOE data. In Västerås, the leveled cost of energy is 4.25 Kr/kWh and in Recife, the cost was 2.67 Kr/kWh. In Brazil, the LCOE was 1.07 Kr/kWh below the current charging cost in Sweden.

Key Words: LCOE; HOMER Pro; Charging Station; Electric Mobility.

INTRODUCTION

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Although the increase in the use of electric vehicles (EVs) for private and public transport purposes is a worldwide trend. Motivated by the reduction of environmental impacts and driven by countries such as Sweden, United Kingdom, France and Germany, several developing countries, like Brazil, walk slowly in this market. Despite the benefits, the connection of EVs to electric power grids has the potential to cause disturbances in power quality and, mainly, increase energy demand. Countries with high-energy costs and low economic potential, increase the deficit in global compliance with CO2 emission reduction targets, in which one of the sectors that causes the greatest impact is transport (COSTA, 2021).

The challenge in this context is how to provide a sustainable energy structure to support the popularization of the use of EVs in the most economical way. For this, associating the use of microgrids with diversification of sources is presented as one of the solutions. However, the energy costs obtained in the dimensioning of microgrids must be evaluated, comparing with the current energy costs without the use of these systems.

One of the most used methods for power generation analysis is the leveled cost of energy (LCOE) over the generation of a specific system. This economic assessment includes all costs over the life of the system, such as initial investment, operation and maintenance, and capital cost (HANSEN, 2019). The result obtained from LCOE represents the minimum price that energy must be sold or compared with the current costs of using the electricity grid, guiding the decision-making on the optimization of the system and its implementation (EBENHOCH, 2015). The representation of the results is given in monetary units per kilowatt-hour (or megawatt-hour), for example, R$/kWh (Brazilian Real), USD/kWh (US Dollar), Kr/kWh (Swedish Króna) or EUR/ kWh (Euro).

This article presents the dimensioning of a microgrid supplying a point of public charging stations with an average consumption of 14,003 kWh/day (US DEPARTMENT OF ENERGY, 2022). The objective is to analyze two cases, one considering a country at an advanced stage in the use of electric vehicles, with low- energy generation resources. Another case at an early stage of the electric mobility market, with high potential for energy generation. Under the conditions considered, Brazil and Sweden were chosen, motivated by the ease of obtaining data. The results obtained show the LCOE and the comparison of microgrid sizing using photovoltaic generation, BESS, and green hydrogen for the same load profile and application in both countries.

MATERIALS AND METHODS

Case Study: PV/BESS/Green Hydrogen Microgrid

The case study explores the potential of microgrid application using photovoltaic (PV) generation, production, and storage of green hydrogen and the use of energy storage by batteries. To supply a public charging station with an average consumption of 14,003 kWh/day, based on the load profile of 1,000 EVs in Los Angeles, Long Beach and Anaheim, California, provided by the US Department of Energy (US DEPARTMENT OF ENERGY, 2022). The load profile used considers the use of charging stations during the week and the weekend, as shown in Figure 2.

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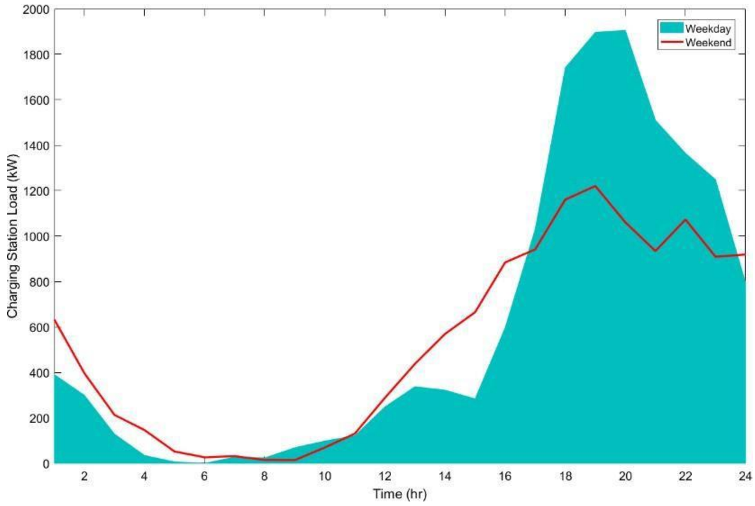

Figure 1 - Load profile used in the simulations. Source: US DEPARTMENT OF ENERGY, 2022.

For the comparative analysis, microgrids were designed for two locations, namely Recife in Brazil and Västerås in Sweden. Through fieldwork carried out in Sweden, it was possible to base energy cost data from charging stations. In addition, using data collected by Electromaps (real-time map of charging stations). According to the data obtained, Sweden is among the countries with the largest electric transport fleet, and 2,927 charging points across the country. Specifically, the city of Västerås has 30 charging points with 91 charging stations with possibilities for type 2 chargers (58), CHAdeMO (11), CCS2 (10), Tesla Supercharger (9) and Schuko – EU Plug (3). On the other hand, Brazil is in the initial phase of opening this market and has 348 points with 479 available chargers registered in Electromaps. Type 2 (328),
CHAdeMO (31), CCS2 (23), Type 1 – SAE J1772 (21), Schuko – EU Plug (10) and NEMA S-
20 (US Plug) chargers can be found. The city of Recife has 4 charging points with 5 chargers, all 22 kW type 2 (ELECTROMAPS, 2022). Figure 2 shows the location of charging points in the two cities.

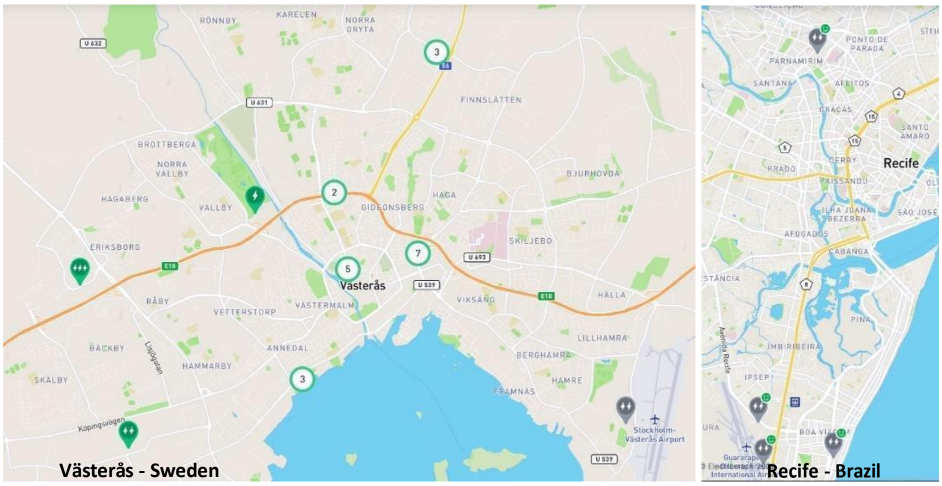

Figure 2 – Charging station in Recife - Brazil and Vasteras – Sweden. Fonte: ELECTROMAPS, 2022.

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These cities were chosen because they have a high potential for renewable generation and low investment in electric mobility (Recife), in contrast to the low potential for renewable generation and high investment in electric mobility (Västerås). To explore the diversification of supply sources, the microgrid design considers the same parameters: load profile, topology, and configuration (Figure 3) and equipment cost.

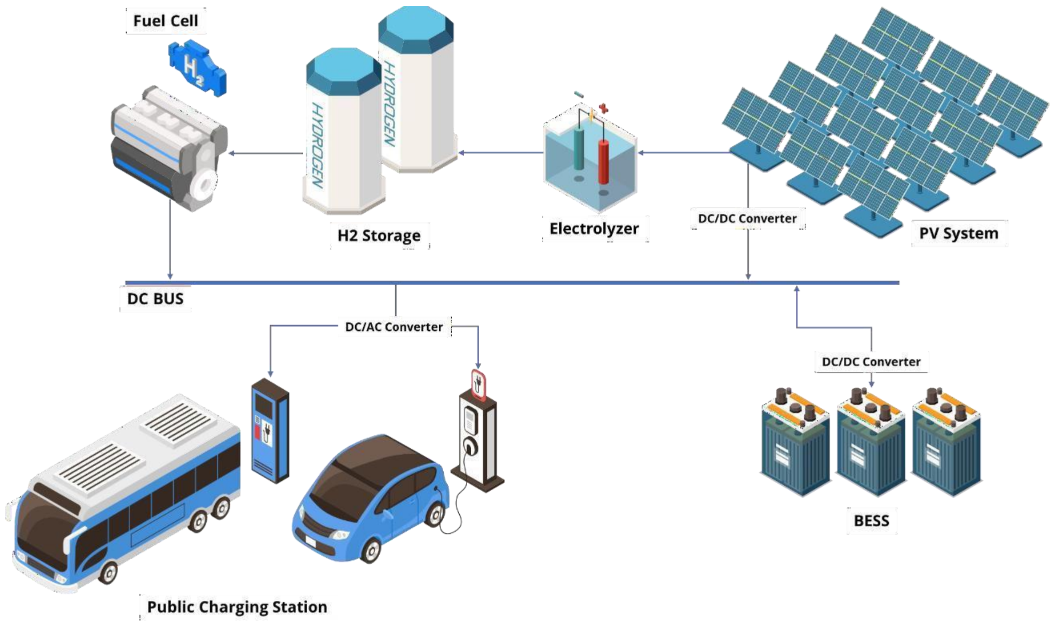

Figure 3 – Microgrid topology. Source: Own authorship

The differential in the composition of the systems is the climatic data applied in the sizing simulations from the HOMER Pro software, a tool specialized in microgrid projects.

Economic analysis: Levelized Cost of Energy

With systems sized for each city, HOMER Pro provides a levelized cost of energy as a result. The comparison of the LCOE will be carried out with the current cost of energy charged at charging stations connected to the electricity grid, in the case of Sweden, and the cost of energy from the concessionaire, for Brazil. The reference from Västerås is the Klippan Parkering EV-Core charging point with a 22 kW Type 2 connector and a cost of 3.6 Kr/kWh. In the case of Recife, the B1 tariff value of September/2022 is considered at a cost of 1.43 Kr/kWh (1 Kr = R$ 0.49).

LCOE is defined as

$$COE = \frac{C_{ann,tot}}{E_{served}} = \frac{CRF\,(i, R_{proj}) \times C_{NPC,tot}}{E_{ACprim} + E_{DCprim} + E_{def}}$$

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Where, $Cann,tot$ is total annualized cost of the system [Kr/yr] composed of $CNPC,tot$ = the total net present cost [Kr], i = the annual real discount rate [%], $Rproj$ = the project lifetime [yr], $CRF()$ = a function returning the capital recovery factor. The total electrical load served ($Eserved$) is the total amount of energy that went towards serving the primary ($EACprim$, $EDCprim$) and deferrable loads ($Edef$) during the year (HOMER PRO, 2022).

RESULTS AND DISCUSSION

The simulation results obtained in HOMER Pro were based on equipment costs collected commercially, described in Table 1. The value of the fuel cell is entered together with the electrolyzer, which was not possible to obtain separately.

Table 1 - Capital and operating and maintenance cost of microgrid equipment. Source: Own authorship.

Components	**CAPEX**	**OPEX**
PV System (Kr/kW)	5,118.42	70.00
BESS Li-ion (Kr/kWh)	5,358.58	53.58
Electrolyzer (Kr/kW)	160,573.78	160.61
H2 Storage Tank (Kr/kg)	247.28	2.46

The microgrid sizing in both scenarios considered the fuel cell with DC output and average consumption of 16 liters per minute, consuming 23,040 liters/day in nominal operation. On the other hand, the electrolyzer is dimensioned with 25% above the nominal power required by the microgrid, to preserve the equipment against overload. The generated energy is stored as compressed gas in hydrogen tanks at a pressure of 200 bar, through a compressor.

Both the production of green hydrogen and the supply of lithium batteries are carried out through the photovoltaic system, which guarantees the sustainable aspect of the energy generated. However, the irradiation data showed the difference between the two cities, as expected the Swedish city has a potential below 0.5 kWh/m²/day in the months of January, November, and December and its peak generation throughout the year (June). This high generation is close to the worst month of the year for the city of Recife. Figure 4 further reinforces that Brazil has large solar energy potential, as it demonstrates a striking contrast between the two locations.

ISSN: 2675-813X

 DOI: 10.51189/iii-coninters/11197

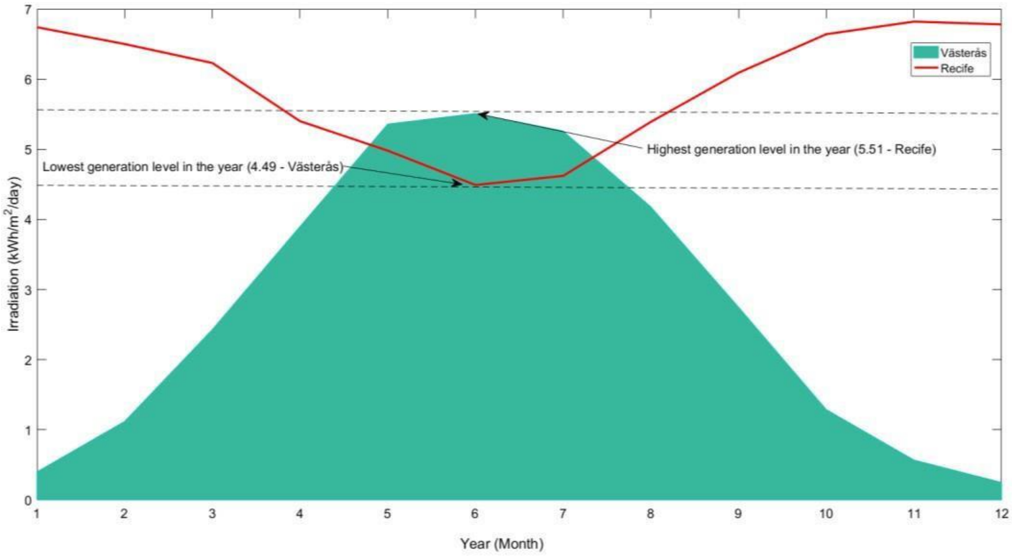

Figure 4 – Irradiation data results in Västerås and Recife. Source: Own authorship.

The sizing of the two microgrids showed that Västerås needs a PV system with a nominal power three times greater to supply the same load, which reflects its low generation potential. While the components of the green hydrogen system have less variation in their rated power for the fuel cell and electrolyzer, tripling the storage capacity compared to Recife. Both microgrids have a high nominal BESS capacity, this is due to the need for continuous power supply to the electrolyzer and charging stations, as shown in part of the behavior of the microgrids in Figure 5.

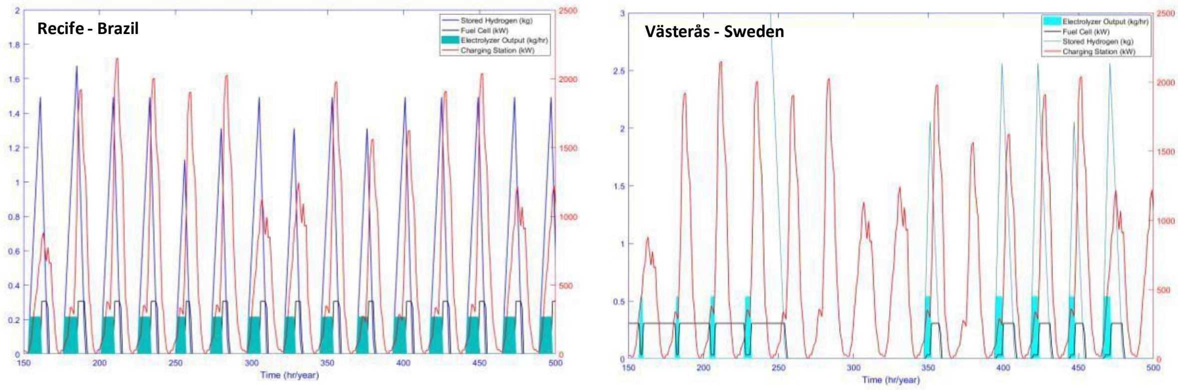

Figura 5 - Result of the behavior of sized microgrids. Source: Own authorship.

Energy costs to recharge an EV are currently higher in Sweden, motivated by the production of electric energy from nuclear, hydraulic, biofuels, and fossil fuel plants. While Brazil has a renewable energy matrix of hydroelectric, solar and wind power plants. The leveled cost of energy generated in the microgrid sizing for the two cities resulted in a lower rate for the city of Recife with 2.67 Kr/kWh compared to 4.25 in Västerås. This is due to the size of the microgrid in Västerås being three times larger, mainly of the PV system to meet all the demand throughout the year. The results from the simulations are presented in Table 2.

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Table 2 - Result of microgrid sizing and comparative analysis of energy cost. Source: Own authorship.

Microgrid Sizing	**Vasteras - Sweden**	**Recife - Brazil**
PV System (kW)	17,468	6,825
Fuel Cell (kW)	1	1
BESS Li-ion (kWh)	11,754	9,357
Electrolyzer (kW)	25	10
H2 Storage Tank (kg)	300	100
Comparative Parameters	**Vasteras - Sweden**	**Recife - Brazil**
Current Energy Cost (Kr/kWh)	3.6	1.43
Microgrid LCOE (Kr/kWh)	4.25	2.67

The low generation potential in Västerås results in a microgrid with a higher LCOE compared to the current cost of kWh at the charging station, which is repeated for Recife as well. However, the LCOE of the microgrid sized in Recife is 1.07 Kr/kWh lower than the current recharging system in the Swedish city and 1.58 Kr/kWh than the LCOE of the microgrid in Västerås.

From this perspective, it can be observed that charging stations represent a valid investment to boost the popularization of electric transport in the country, both from a technical and an economic standpoint. According to the National Energy Balance report, 44.8% of primary production comes from oil. The transport sector is responsible for 79.1% of the final energy consumption of fossil diesel oil, totaling an emission of approximately 194 Mt of CO2 (carbon dioxide) into the atmosphere (EPE, 2021).

Investment in charging stations with sustainable microgrids contributes to the countries progress in agreements to reduce CO2 emissions, route 2030, and job creation. It also postpones the need for investment in electrical network structures with the massive arrival of electric mobility.

CONCLUSION

The article aimed to demonstrate the results of the analysis of microgrids for charging station supply, considering the sustainable generation of energy given the difference in energy potential between Recife in Brazil and the city of Västerås in Sweden. The sizing of the system considered the average consumption of 14,003 kWh/day at a towing point, resulting in a PV/BESS/H_2 Verde microgrid with approximately three times greater power in Västerås compared to Recife. This is due to the low-power generation potential in Sweden.

In both cases, the LCOE of the dimensioned microgrids was above the current energy cost, but with a better advantage for Brazil with 2.67 Kr/kWh. Nevertheless, what is observed is the need for government and private incentives to advance electric mobility in the country. This is seen in the data collection on the number of charging stations found in the two cities studied, with Recife being a capital in Brazil and Västerås a city in the countryside in Sweden.

ACKNOWLEDGMENT

The author is appreciative to the Mälardalen University for the Gustav Dahls Grant that allowed her to carry out the field research in Västerås, Sweden.

DOI: 10.51189/iii-coninters/11197

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