Zero Energy Solar-House Technology
Aiming Greenhouse Gases Emissions Reduction by Residential Sector in Brazil

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ABSTRACT
This study aims to define a Zero Energy Solar-House and analyses its contribution to global warming mitigation by reducing Greenhouse Gases (GHG) emissions. This study identifies guidelines for a Solar-House project regarding electricity use, environmental conditioning, solar systems and equipment in order to obtain energy efficiency. Data to evaluate the Solar-House model are provided by Ekó House Project, which is a solar house prototype. The balance of GHG emissions reduction focus on electricity consumption, and to account avoided emissions this study considers solar photovoltaic (PV) generation instead of grid electricity, as well as energy efficiency measures harnessing the sun’s energy on a passive way. This study goes through a comprehensive analysis of Brazilian electricity system, the use of electricity by the Residential Sector and GHG emissions associated. As a result, this study sets basic guidelines for a Zero Energy Solar-House and accounts the potential to avoid GHG emissions with this housing model. Benefits due to large-scale implementation of this model in Brazil are evaluated. To measure the impact of these solutions on a larger scale is taken as geographic boundary Southeastern Brazil – a region with high population density and need for importing energy from other regions of the country – where this study considers the adoption of energy efficiency measures and PV generation for a percentage of dwellings. Results show potential to avoid up to 0.9 Mt CO₂ emissions each month. From an interrelated analysis of solar PV generation and energy efficiency assessments, this study concludes that the solar-house taken as a reference has a significant potential to reduce GHG emissions, contributing to Brazil’s sustainable development and global warming mitigation.

INTRODUCTION
The current economic development model considers the environment as an endless source of natural resources and final destination, with unlimited capacity to receive waste generated by human activity, embracing inefficiency and wasteful use of natural resources, especially energy, which is one of the essential supplies for the basic conditions of human life. Such model and the unbalanced operation and use of environment are the vectors of environmental problems.

Brazil is a developing country and as so, the tendency is that energy demand will increase along with the economy, implying the construction of new hydroelectric and thermoelectric plants, causing significant environmental, social and economic impacts. The residential sector consumes 26% of total...
Brazilian electricity, and the increment of population purchasing power leads to an increase in energy consumption by this sector. This highlights the need to adopt energy efficiency measures and alternative and renewable energy sources, so that people can have access to consumer goods and improve their quality of life in an efficient way.

The Brazilian energy matrix is considered clean. In the National Interconnected System (SIN), 67% of energy comes from hydropower. Nevertheless, increasing concern with environmental and social impacts of the construction of new plants has been noticed. On the other hand, studies show the enormous potential for the exploitation of solar energy in the country, due to favorable levels of solar radiation throughout the year and photovoltaic systems for distributed generation are approaching an economic feasibility (EPE 2012). Therefore, it is argued that solar energy has demonstrated potential to contribute to supply this growing demand.

Given this scenario, this study aims to determine the contribution of a Zero Energy Solar-House (ZESH) to the sustainable development through energy efficiency and the use of solar energy, allowing the reduction of GHG emissions associated to energy consumption by residential sector in Brazil. To verify the potential of these actions on a larger scale, is taken as geographical boundaries the Southeastern Brazil, considering the replacement of a percentage of single-family houses by units (or systems) in the lines of the CSZE. Methodologically this study adopts a solar-house prototype, the "Ekó House", that verifies the ZESH. Thus, it is possible to predict the effective reduction of GHG emissions associated with energy use by Brazilian residential sector.

The Ekó House prototype was developed by Team Brazil, a partnership between São Paulo University and Federal University of Santa Catarina to participate on Solar Decathlon Europe in 2012. This prototype is adopted because it meets the requirements of a ZESH and simulation data regarding its energy and environmental performance are available.

GUIDELINES FOR A ZERO ENERGY SOLAR HOUSE

This study takes as dwelling unit reference a house that generates locally its own energy from PV modules. The ZESH also uses sun energy in architectural design for passive conditioning of indoor environment, reducing energy consumption. In this sense, geometries that result in elongated facades facing north and south orientation obtain a better use of the sun throughout the year. In summer, when the sun is more directly overhead, radiation is less intense on north oriented facades than is east and west oriented facades (Southern Hemisphere). In winter the sun is lower, and radiation is more intense in north oriented facades than in east and west oriented facades, as shown in Figure 1.

![Figure 1](image.png)

The envelope elements of a CSZE have appropriate thermal performance, based on climate conditions of the implantation site, through strategies such as insulation, the use of thermal mass and/or natural ventilation. The reference prototype has high thermal insulation levels and windows properly dimensioned and positioned, ensuring natural lighting and ventilation. This results in good comfort conditions with low energy consumption by integrating passive and active strategies. Simulation models
indicate a Daylight Autonomy of 60% for the Ekó House prototype (Projeto Ekó House, 2012).

In Brazil, the high investment required to improve the performance of buildings, leads people to employ low cost and low performance materials. Furthermore, there is usually no concern in adopting bioclimatic strategies to improve the thermal performance of buildings in a passive way. This implies higher energy consumption during building’s life occupancy (CANDIDO, 2010; PIRES et al, 2014).

In a ZESH it is essential to anticipate installation demands of solar systems, considering all components of each system on the architectural programming. The images in Figure 2 illustrate a modular construction system and solar systems in a CSZE.

![Figure 2](image1.png)

**Figure 2** Solar Systems for a ZESH. (Projeto Ekó House, 2012)

The 48 monocrystalline PV panels, with an 18.5% efficiency and 11 kWp of total installed capacity generate, on average, 1.790kWh/month, enough to meet the prototype energy demand, which is around 735kWh/month, and still provide around 1.055kWh/month of clean energy to the grid (Projeto Ekó House, 2012). This positive energy balance was adopted to meet a specific purpose for which the prototype was conceived in a first moment, that is, hosting in isolated an environmentally sensitive areas in Brazil. The prototype would be connected to a local grid and could export the surplus energy to meet the demand of local facilities, like schools and healthy centers, or dwellings in these isolated locations. The graph in Figure 3 illustrates the prototype energy balance for a typical operation year.

![Figure 3](image2.png)

**Figure 3** Energy balance for Ekó House prototype. (Projeto Ekó House, 2012)

The use of efficient appliances helps reducing energy consumption. Ekó House prototype uses National Program for Energy Conservation (PROCEL) 'level A' label. Artificial lighting, designed to complement the natural lighting, uses LED, which guarantees higher energy savings, lower maintenance and longer life. A home automation system integrated to the use of equipment and the general prototype operation contributes to a more efficient operation. This system can be programmed to guide the occupant, informing about energy generation and consumption and also control lighting and temperature, activating equipment and systems based on pre-established comfort ranges or person presence in indoor environments. Figure 4 shows schematically the energy generation and consumption in a ZESH.

![Figure 4](image3.png)
The National Interconnected System (SIN) is a large hydrothermal system, with a strong predominance of hydroelectric plants. Only 3.4% of the country’s capacity of electricity production is out of SIN, in small isolated systems located mainly in Amazon region (ONS, 2013). Hydroelectric plants correspond to 67% of energy generation, such participation enables to consider the Brazilian electricity matrix a clean matrix. Nevertheless, with the need to build new power plants to meet growing demand for electricity, more pressure comes from society and NGOs because of environmental and social impacts caused by the implementation of such new plants. Even as it is planned to extend the thermal generation in the country, including the completion of Angra III nuclear and coal-fired plants as a complement and rational diversification of usable hydropower potential naturally limited (BRASIL, 2007). It is also important to note that the losses in transmission and distribution stages reach 16.9% in SIN (BRASIL, 2012). The graph in Figure 5 discriminates participation by source in SIN.

Another condition that highlights the need to explore other energy sources is the fact that most of the hydric resources in Southern and Southeastern are already exploited, and most of the remaining reserves are in the Amazon, away from industrial and population centers (OECD, 2001). It is important to note the potential for solar energy exploitation due to favorable annual irradiation levels in the country, ranging on average from 1.260 to 1.420kWh/m²/year (EPE, 2012). Further, the National Electrical Energy Agency (ANEEL) approved in 2012 a resolution that allows installing grid-connected PV micro-generation in dwellings.

On the other side of the equation is the electricity consumption. The residential sector accounts for 26% of total electricity consumption in the country, and it is expected that this participation will remain for the next 10 years, with an estimated increase of 48.3% by 2021. This amount considers energy efficiency measures due to use of more efficient equipment in Brazilian dwellings (BRASIL, 2012).

It is important to notice that peak demand in Brazil usually occurs by the end of the day, from 6:00 p.m. to 9:00 p.m. and is associated to use of artificial lighting, home appliances and electric shower. However, this year during the summer, new records in peak consumption were registered in Southeastern/Midwest and South SIN subsystems, as shown on Figure 6 graphics. Such shift on peak
time is associated to constant high temperature and thermal discomfort index in these regions, at the time higher insolation, which increased the use of HVAC systems (ONS, 2014).

Figure 6    Instantaneous peak demand in SIN subsystems. (ONS, 2014)

Regarding the specific consumption by appliance and equipment, a research on “equipment checkout and use habits” (PROCEL, 2007) indicates the participation of different appliances in energy consumption by the Brazilian residential sector, as shows the graph on Figure 7. In Southeastern Brazil the average electricity consumption is around 180kWh/month for each dwelling (EPE, 2013). This indicates that there is room for increasing electricity consumption by this sector.

Figure 7    Participation of appliances in Brazilian dwellings. (PROCEL, 2007)

Such data regarding electricity generation in Brazil and specific consumption by the residential sector are applied to assess the benefits of a ZESH, regarding the adoption of energy efficiency measures and the PV generation by reducing energy consumption and avoiding GHG emissions.

GHG EMISSIONS BY SIN AND PV SYSTEMS

As already pointed, it is estimated that participation in electricity consumption by the residential sector will continue in the coming years, with an increase in energy consumption and, consequently, in associated GHG emissions, which must pass from 18 Mt CO2-eq in 2011 to 23 Mt CO2-eq in 2021 (BRASIL, 2012).

This study adopts the emission factor of SIN, for which the average of the last five years was 0.2926 t CO2/MWh (MTC, 2014). For the amount of greenhouse gas emissions of PV systems, are assumed values defined in the Special Report of the Intergovernmental Panel on Climate Change (IPCC), according to which the average emission factor for such systems is 0.046 t CO2/MWh (IPCC, 2012). Emissions attributed to solar photovoltaic generation are from the manufacture of photovoltaic systems and can be compensated by the manufacturer or end user.

From the combination of these data it is possible to estimate the reduction of GHG emissions that energy efficiency measures such as those adopted in ZESH and power generation by PV system can represent when applied on a larger scale.

ENERGY GENERATION AND CONSUMPTION IN ZESH

To analyze the contribution of ZESH to the sustainable development, data of Ekó House prototype
are applied. Such data come from computational simulations and estimate values of generation and power consumption over a year of operation. The simulations consider developed countries comfort standards, with the presence of some appliances that, in Brazil, are not common to all population strata in the country. However, with economic development and greater purchasing power of the population, such equipment must be increasingly present in Brazilian homes, increasing the power consumption of the residential sector. On the other hand, solar collectors for water heating are adopted and artificial lighting uses only LED. The graph in Figure 8 shows the monthly consumption in Ekó House prototype.

By comparing the simulated consumption for the prototype of 735 kWh/month, with the monthly average consumption of households in developed countries such as the United States, which consumes on average 958 kWh/month (EIA, 2011) per dwelling, it is possible to realize that even keeping comfort levels of these countries, the prototype reaches more efficiency in electricity consumption.

To estimate the reduction in energy consumption, this study considers the adoption of solar collectors for water heating in Brazil. It is assumed that 70% of the annual demand for hot water is provided by solar collectors. Thus, the reduction in power consumption obtained is approximately 17%. Assuming that an appropriate use of the sun for daylighting and passive conditioning associated with the use of LED system and passive thermal conditioning strategies, contribute to energy efficiency with a 30% saving in consumption by air conditioning and artificial lighting systems. Thus, another 10% of total consumption would be avoided, as shown in Figure 9.

To demonstrate the contribution potential of harnessing solar energy in architecture, it is taken as geographical boundaries the Southeastern Brazil, which has about 20 million households, of which approximately 80% (or 16 million) are single houses (IBGE, 2010). To account the contribution of using solar PV, it is considered that 50% (8 million) of single-family houses would adopt PV micro-generation system, similar to Ekó House, but a lower cost system to be economically viable. With PV generation, avoided emissions could reach 0.2926 kg of CO₂ for each 1.0 kWh generated. Assuming a PV system
with 24 polycrystalline modules, with a 13.5% efficiency and a 3.24 kWp installed capacity, the generating would be on average 387 kWh, considering the data for São Paulo, according to RETScreen® 4 software simulation. Thus, avoided GHG emissions in SIN would be around 113 kg of CO₂/month per household, or 0.9 Mt CO₂/month considering the adoption of this PV system in 50% of single houses in the Southeastern, totaling 10.8 Mt CO₂ per year.

According to a financial analysis, simulated also on RETScreen® 4, such system would have a price around 0.35 R$/kWh, without considering incentives, which is close to the average electricity tariff in the country of 0.32 R$/kWh (ANEEL, 2014). It is also important to notice that some studies already point to an economic viability of PV systems for distributed generation in Brazil (EPE, 2012).

Taking into account the average dwellings consumption in the Southeastern, 180 kWh/month, and the projected increase in consumption of the residential sector in the ten-year horizon, the average consumption is expected to reach 270 kWh/month in the coming years. With the values assumed for energy savings through solar energy use, this consumption could be reduced by 27%, resulting in a consumption of 197 kWh/month. Such measures would contribute to stabilize consumption on a decennial horizon, even improving comfort conditions in dwellings. Thus, on average, 190 kWh/month would be delivered to the grid by each household with the PV micro-generation system, or 1520 GWh by installing micro-generation in 50% of single houses in the Southeastern, avoiding up to 0.44 Mt CO₂ of emissions per month in SIN. Still, not considering the PV generation, and considering the harness of the sun, as described above, could save 27% on energy consumption, and this would represent a reduction of about 73 kWh/month per household, or 584 GWh for 8 million dwellings, avoiding 0.17 Mt of GHG emissions.

The graph in Figure 10 illustrates the emissions avoided by PV micro-generation in single house units and the adoption of energy efficiency measures focused on harnessing solar energy, through projections to the Southeastern Brazil. The added value comes when the manufacturer is responsible for offsetting GHG emissions from the manufacturing of PV systems. In this case, the SIN emissions factor is adopted to account GHG emissions avoided. But when the consumer assumes such compensation, the emission factor applied is the one for SIN discounting the PV systems emission factor.

![Figure 10](image.png)

**Figure 10** Potential to avoid emissions in the Southeastern Brazil through ZESH.

The study considered that the increase in consumption by the residential sector will be made according to PDE 2021 predictions. Nevertheless, this projection was made taking into account a consumption which also expresses a pent up demand for electricity in the country. With a PV with an installed capacity such as the one adopted for this study, it would be possible to reach better comfort conditions, supplying this demand with a clean and renewable source, without additional GHG emissions.

The PV generation in locations where single houses are a predominant typology can contribute to meet the demand on the network at times when other sectors require more energy than residential, like the commercial sector during daytime. The records on peak consumption during summertime point that electricity demand in SIN is increasing during daytime. This highlights that PV systems adopted on a large scale would contribute to supply electricity demand in SIN and avoid GHG emissions, by
exporting energy clean energy to the grid. The use of solar collectors, LED system and the adoption of passive conditioning strategies contribute to reduce the demand for electricity at regular peak consumption time in the end of the day, when electricity demand increases in dwellings due to the use of artificial lighting, thermal conditioning systems and, specially, the electric shower.

CONCLUSION

This study demonstrates that a ZESH can make a decisive contribution to sustainable development. The combination of solar systems and energy efficiency measures demonstrates high potential to contribute in meeting the demand for electricity in the SIN through PV generation, and it also contributes to reduce demand at electricity consumption peak time.

From the projections made in this study, it is possible to conclude that energy efficiency measures help to avoid GHG emissions, mainly in the case of ZESH. The expected increase in demand for electricity by residential sector allows us to observe the relevance of such measures, in order to improve population’s comfort and welfare without necessarily increase electricity consumption. However, the PV generation demonstrated an even greater contribution on avoiding GHG emissions, especially when there is surplus electricity generation that can be exported to the grid.

In short, the ZESH demonstrates potential to contribute to sustainable development of the country and use of solar energy proves to be essential inasmuch a long-term reliability on non-renewable sources can be considered unsustainable economically, socially and environmentally.

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