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Contributions to evaluate technical and economic benefits of distributed generation for low-income citizens

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ABSTRACT

Power generation at or near the consumers characterizes the Distributed Generation (DG). The use of renewable resources to provide energy close to the end users has changed the perspectives for the future power system. The traditional model of central generation, away from most of the consumers, is not seen as the only solution for energy generation in big scale anymore. This fact can affect citizens positively and create improvements for society, especially for those who belong to social classes with low earnings.

The present study contributes to the evaluation of the potential economic and technical benefits that distributed generation can create to low-income households. First, it presents the economic benefits detailed in the literature and case studies of different countries of the world. It also evaluates the financial impact of electricity non-technical losses in Brazil. After that, it proposes a pioneer analysis of potential economic and technical benefits that the insertion of DG in low-income communities can create, including the reduction of commercial losses, and alternatives to allow viable financing.

Assessments of the benefits that DG can create for low-income consumers are scarce, but the case studies presented in this work show relevant results regarding that matter. Besides that, this study indicates that the development of DG in low-income communities of Brazil could generate relevant economic and technical benefits, and it could work as an alternative method to reduce non-technical losses. The massive insertion of DG in households with lower earnings depends on affordable loans, which depend on integrated actions uniting Government, Distribution Utilities (DU) and Society.

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1. INTRODUCTION

1.1. Problem Statement

The search for the development of electric energy generation based on renewable resources has deeply transformed the power sector. Among different solutions that are inserted into that context, distributed generation (DG) is one of the elements that has increased fast around the globe and it has the potential of changing the traditional model of power generation that has existed for more than one hundred years.

The definition of DG varies in the literature, but this study consider that it refers to small and medium power plants located at or near electricity end users. They may be connected or not to the utility grid, and include all generation technologies [1].

The possibility of generating electricity from renewable resources near the consumer may generate various positive impacts. This study approaches the technical and economic benefits that DG may create for low-income citizens. The literature about the benefits for this portion of the population is limited and this study presents some case studies that exemplify the positive results. It also includes a pioneer contribution to evaluate the introduction of DG as a method to reduce non-technical losses.

1.2. Objectives

The general objective of this study is to contribute to the evaluation of the potential economic and technical benefits that distributed generation can create to low-income households.

It aims to unite the results of projects and studies developed in different parts of the world with a special focus on low-income communities. These results can highlight the benefits and the barriers of the implemented projects.

Besides that, it has the specific objective of evaluating the financial impact of non-technical losses on the Brazilian power system. Based on that analysis, it wants to propose a pioneer analysis of potential economic and technical benefits that the insertion of DG in low-income communities can create, and alternatives to allow viable financing.

1.3. Scope

This work presents the economic benefits of distributed generation that are described in the literature and summarizes four case studies that generated economic benefits for low-income citizens.

Moreover, it analyzes the current situation of the non-technical energy losses in Brazil and its financial impact to the power system stakeholders. The work also simulates scenarios to evaluate the impact of DG systems, especially those based on Photovoltaic (PV) systems connected to the grid, on tackling this technical issue in areas where traditional methods are not enough and creating benefits to the lower classes of society. The study includes the discussion about alternatives to provide viable loans that could allow low-income consumers purchase PV systems.

The work presents the perspective of consumers, distribution utilities (DU) and society to the economic and technical benefits that DG can generate. It does not attempt to discuss the benefits that can affect all the stakeholders involved in power systems. However, the document briefly mentions other actors, especially because the benefits generated to the consumers and DU may indirectly affect them.

1.4. Design requirements

The simulations regarding the installation of PV systems and the loans to finance their acquisition consider the requirements of low-income consumers located areas with high non-technical losses of energy in Brazil.

1.5. Structure of the Report

The study is divided into seven chapters. This introduction, Chapter 1, presents the problem statement, objectives, scope, and design requirements.

Chapter 2 presents a review of the literature on the economic benefits of distributed generation. It also summarizes some case studies that evaluate benefits with focus on low-income citizens.

Chapter 3 develops a case study about the non-technical losses in Brazil, which estimates its financial impact and the contribution of distributed generation in the reduction of commercial losses. Moreover, it simulates alternatives to finance distributed generation in low-income communities.

Chapter 4 details and discusses the results of the previous chapter. It analyses the use of distributed generation to promote the reduction non-technical losses.

Chapter 5 and 6 present the budget to develop this study. Chapter 6 explains the environmental impact that the presented solutions could generate. Chapter 7 contains the conclusion and further research. After that, the acknowledgements and bibliography are presented.

2. DISTRIBUTED GENERATION: ECONOMIC BENEFITS

2.1. Introduction

In order to understand the reasons for the success of the distributed generation (DG), it is necessary to analyze all the benefits it can bring to all the actors of the electricity system. After that, it is possible to compare them to the drawbacks and, if the solution looks interesting, answer one decisive question to any kind of business: "Is it viable?" Although the question looks simple, it requires a great effort to answer it in a proper way.

In general, benefits of DG mentioned in the literature are the reduction of electricity bills for customers, reduction of emissions because of the massive renewable energy solutions, delay on the expansion investments of the distribution and transmission systems, job creation, reduction of technical losses, improvements in energy efficiency, etc. [2], [3].

The first category of benefit this report presents are the different economic advantages that DG can create to consumers, DU, and society. An economic benefit can be defined as a net increase in total social welfare, which includes both market and nonmarket values. It is important to mention that this concept is different from "economic contribution" and "economic impact", which are not discussed in this report [4]. In community Microgrids, for example, the stakeholders have different interests and characteristics. The customer is interested in competitive costs for electricity, high-quality service and the social benefits generated by the technological solution. The private sector usually looks for profit and it is not interested in social welfare [5].

Firstly, a brief literature review presents the recent studies regarding the economic benefits that DG offers to stakeholders. The research on that topic clearly showed that the evaluation of financial viability is a subject discussed in a vast number of works around the globe [6], considering many different premises and solutions. The viability studies are not included in the review because the objective of this study is to show the actual or potential benefits created by DG after their implementation. The development of new technologies enabling grid integration of renewable energy sources during the last few years made the price of equipment drop drastically, in photovoltaics systems for example, and the microgeneration can be already considered an established solution [2]. Of course, the viability evaluation remains crucial for any project related to DG, but the focus is on actual or simulated viable systems and the benefits they generate.

After that, the work presents some examples of DG systems implemented in different countries and the economic benefits that they generate. The countries not only have different geographic and socioeconomic characteristics, but also distinct levels of development and regulation of DG systems. The literature and the examples can help the reader to compare the expansion of such technology between countries.

2.2. Review of the literature on the economic benefits of distributed generation

The review of the literature on the economic benefits of DG aims to compile the studies that estimate the improvements that the implementation of that technology can generate to the electricity sector, especially for customers, DU, and society. The identification of benefits may be a complicated process because it depends on the interactions between the stakeholders, not only on energy and financial analysis [7].

Morris et al. [7] studied an actual islanding-capable Microgrid and identified benefits to all the four stakeholders considered in their report, namely, society, Microgrid owner, utility operator and Microgrid customer. The paper describes environmental, economic and technical benefits. However, at this point of the research, the study focuses only on the economic effects, which are divided into two categories: locality and selectivity benefits. The first one represents the gains earned from the Microgrid, which can deliver power to the loads without charges generated by the use of the upstream network. The second one results from the fact that Microgrids have the possibility of selling energy when prices are high and purchasing when the energy prices are low. These economic results clearly benefit Microgrid owner and customer of the study case.

In a study about the link between DG systems and fuel poverty in the UK, Walker [8] mentions one potential positive economic benefit: cheaper energy prices. In this case, low-income citizens could reduce their expenses with energy and use the money for other needs. On the other hand, the author mentions an important potential drawback if the regulations do not consider a way to make microgeneration affordable for the low-income homeowners. The technology known today requires a significant upfront investment that can be prohibitive to these citizens. If this issue is not properly addressed and the DG is affordable only for social classes with higher incomes, the low-income citizens will continue to use a more expensive electricity provided by the DU. This perverse effect can become reality if governments, associations and utilities do not offer ways to solve the problem.

EPE [2], the Brazilian federal energy planning company, developed a technical study about the conditions and impacts that the insertion of photovoltaic DG has in Brazil. After analyzing the contributions presented by different agents in public hearings promoted by the Brazilian Electricity Regulatory Agency – ANEEL and the international experiences in the field, the company presents a list of 30 potential impacts of the development of the solution, most of them considered economical. Considering the reliable data available, the company quantified 11 of them, presented in Table 2.1.

Stakeholder	Impact	Type	Classification
Distributors	Impact on cash flow	Economic	Cost
Consumers	Reduction in energy bill	Economic	Benefit
ESCOs	Increase on billing	Economic	Benefit
Manufacturers and Importers	Increase on billing	Economic	Benefit
States and Union	Impact on cash flow of tax collection in the electricity consumption	Economic	Cost
	Impact on the cash flow of tax collection in the sales of equipment and services	Economic	Cost
Loan and Credit Agents	Increase of loan revenue	Economic	Benefit
Society	Job creation	Socioeconomic	Benefit
General	Savings on energy contracting	Economic	Benefit
	Reduction of technical losses	Technical / Economic	Benefit
	Reduction of emissions	Environmental	Benefit

Table 2.1 - Calculated impacts of the insertion of photovoltaic DG. Translated and adapted from [2]

It is possible to verify that the development of photovoltaic DG can benefit different agents, although some will face increased costs. The list is not extensive and the same research mentions many other impacts, but not quantified yet. It also estimates that the installation of 161.000 photovoltaic systems could generate around € 1 billion in investments by 2023 (10-years period since 2013). Considering this scenario, credit agents will receive € 130.5 million in loan interests. Consumers would save around € 405 million in electricity bills and this value will increase until the end of the lifetime of the system. Finally, around 185 GWh of technical losses in transmission and distribution would be avoided and four thousand high-level jobs would be created.

Allan et al. [6] develop a critical review the literature about the economics of DG and conclude that the amount of research about macroeconomics of DG is quite small. This kind of analysis involves multiple possibilities of technologies, geographic characteristics, costs, regulations, risks, etc. The authors consider that the high complexity to model economy-wide impacts of diffusion of DG is the probable cause of the few number of studies until now. However, the insertion of DG has been increasing around the globe and it will affect employment, environment, infrastructure and other areas of society. Because of that, the research about the wide effects of DG becomes essential.

Gil and Joos [9] focus on the evaluation of economic benefits that DG systems generate to DUs and the power system. Besides that, they affirm that consumers are interested in DG mainly to improve the reliability of the supply and to reduce the electricity bill. They develop methods to quantify the benefits exclusively to connected DG systems based on dispatchable and remotely controllable technologies. In the case of benefits for DUs, the research reports potential deferral in upgrade investment of over 20 ¢/kWh (of DG output, if DGs operate at peak load. DG can avoid electricity purchases and the quantified benefit is between 3.52 ¢/kWh and 7.05 ¢/kWh for the utility (the case study evaluated Ontario`s power system). Because of the introduction of DG, the reduction of technical losses in distribution networks can generate savings of 0.25 ¢/kWh to 0.84 ¢/kWh to the utility during peak load periods. Regarding the benefits do the Power System Operator and society, the study affirms that a DG diffusion large enough to affect the clearing prices of the electricity market can make possible savings up to 2.5 ¢/kWh of DG output for wholesale buyers. DG can also offer reserve capacity to the electricity market, but the quantification shows that the benefits are not significant to DG considering the technologies and regulations available nowadays. Finally, the authors state that all the economic benefits that were quantified along the study should be efficiently allocated in order to give DG owners their proper share. The amounts quantified are approximate, but realistic and significant to customers, and could incentivize the development of DG in a sustainable way. The results can subsidize the creation of proper regulation in the field.

Flaute et al. [10] studied the macroeconomic effects in the energy market of Germany generated by prosumer households. These stakeholders of the power system not only produce energy but also use at least part of that energy. The research analyzes the insertion of prosumer households using the PANGTA RHEI model, which is used to perform macro-econometric simulations and forecasting, and evaluate distinct scenarios in order to discuss the macroeconomic effects. Based on a model named comprehensive E3 (economy-energy-environment), which analyzes intricate relations within the economy, and the impacts are evaluated on the household level, energy, environment, and macroeconomics. The conclusions are that prosumers are essential actors in the process of evolution of the energy sector in Germany, changing the patterns of electricity use and behavior, and reducing the use of fuel and, consequently, emissions. The impact on an individual household can be considered interesting. However, in general terms, the impact in the economy until 2025 is still small in that country. In this case, the study considers the regulations must be adjusted to ensure that the investment to become a prosumer is secure.

2.3. Case studies that evaluate benefits with focus on low-income citizens

2.3.1 Introduction

The literature review already shed some light on DG economic benefits and the potential transformation that it can make on the energy market. It also clarifies that there is a vast field of research to be explored in order to contribute to the proper development of distributed generation. However, actual examples of DG solutions and their impact on real life are a strong tool to help to understand the contribution proposed by this study. Following that argument, the research looks for projects around the globe that could materialize the economic benefits that the literature describes, but a new subject is included to refine the search: solutions that somehow affect low-income citizens.

Countries as Germany and United States have been facing the increase of DG for many years. However, the development of such technology in developing countries, especially in low-income communities, is more recent. Because of that, detailed reports about the economic benefits in that share of the population are not common. The importance of electricity access is already shown by many different studies [11], but the investigation of the DG benefits for poor citizens is a field that still needs many contributions.

Along the next items of this section, some case studies describe the benefits that the use of distributed generation brings to countries that face diverse problems regarding low-income citizens. The study does not have the intention to affirm that these results could be replicated at other locations with the same results, but they may inspire actions and solutions to improve the economic situation of the poorest population of the world.

2.3.2 Brazil

i) *“Projeto Geração de Renda e Energia em Juazeiro”*

The Project, freely translated as *Income and Energy Generation Project in Juazeiro,* initiated in 2012 after Caixa Economica Federal and Brasil Solair signed a financial cooperation agreement to develop a microgeneration system in the city of Juazeiro, located in the state of Bahia, in the northeast of Brazil. Caixa Economica Federal is a financial institution owned by the Brazilian government and Brasil Solair is a private company that develops projects for residential, industrial and commercial generation.

The objective of the project is to create a new source of earnings for low-income families, to incentive the cooperativism and the exchange of experiences that can benefit the citizens of the location. Two condominiums with 500 units each, named Praia do Rodeadouro and Morada do Salitre, seen in Figure 2.1, received a system based on photovoltaic panels and wind generators. The residences were built as part of a program called “Minha Casa, Minha Vida” (My House, My Life), which is a federal housing program created to reduce housing shortage and inequality.

Figure 2.1 - Aerial view of the project. Source: Google Maps

Around € 2,015,000 (R$ 7,057,361) were invested in the project. Caixa Economica Federal paid almost € 1,800,000 and Brasil Solair, as a counterpart of the cooperation agreement, paid the rest. The origin of the value invested by the bank was a Socioambiental Fund (Fundo Socioambiental CAIXA - FSA CAIXA), which aims to support social and environmental projects. In the specific case of this project, the investment was non-refundable and the economic benefits were addressed to the families.

After the proper authorization of the Brazilian Electricity Regulatory Agency, ("Agência Nacional de Energia Elétrica - ANEEL") and the registration of the Chamber of Electric Energy Commercialization ("Câmara de Comercialização de Energia – CCEE"), the photovoltaic system started to operate in February of 2014. There are also six wind turbines, with a total power of 24 kW, that provide electricity only to the common areas of both condominiums [12], [13].

These are the technical details of the project [14]:

- 9,154 photovoltaic panels of 230 Wp each with a total power of 2,103 kW, installed on the roofs of residential units, which represented 0,0017% of the power capacity of Brazil in 2014;
- Inverter CC/AC of 4 kW for each set of panels;
- Metering system for each inverter.

Between February and December 2014, the system generated 2.417 GWh of electricity, which is enough to provide electricity for around 15,100 homes during one month, if the average consumption is 160 kWh/month [15]. The energy is sold in the free market instead of being consumed by families because the homeowners pay a social fare, which is cheaper than the price of sold energy. The net revenue generated by energy sold is distributed to condominiums and homeowners respecting the following proportion 60% for the owners, 30% for a fund controlled by the condominiums and 10% for maintenance of the condominiums. Along this, the following are the economic benefits reported by the financial institution along:

- Each family received € 250 along the period, around € 23 per month.
- The fund controlled by the condominiums received nearly € 126,000 and it has been used to improve the infrastructure of the common areas, including the construction of a place community center.
- The maintenance fund received € 42,300.

From the beginning of the operation until December 2015, the system generated 5.782 GWh of electricity sold in the free market. Here are the economic benefits reported by the financial institution:

- The net revenue generated during the period achieved € 675,000 and it was distributed to condominiums and homeowners respecting the following proportion: 60% for the owners, 30% for a fund controlled by the condominiums and 10% for maintenance of the condominiums.
- Each family received € 405 along the period, around € 18 per month.

The project also generated relevant socioeconomic benefits that worthy to be mentioned:

- Thirty area residents were trained to work during the installation of the system and some of them now work on the maintenance of the panels.
- The owners decide the use of the earnings provided by the energy sold during meetings and the fiscal board audit the spending.

Although the project was financed with non-refundable resources and the benefits transferred to the low-income communities, according to the reported results the payback period of the project would have been seven years. However, ANEEL authorized the project to work as a pilot with specific regulation until November 2016. After that, the project should be adapted to start respecting the present regulation, which does not authorize the energy to be sold as it was since 2014. Brasil Solair tried to postpone the end of the authorized period, but the regulatory agency did not agree and the project must adapt to the regulation. Along the development of this research the situation was not solved, a fact that generates losses to the communities [16].

2.3.3 Bangladesh

A 100 kW photovoltaics (PV) plant with a 40 kW diesel generation backup was the pioneer experience of solar commercial solar mini-grid in Bangladesh and its success results inspired policy makers, investors, financing and developing agencies. The business and technical aspects of the experience are summarized by Khan et al. [17], who also outline some of the benefits generated by the project.

Bangladesh is a developing country, with a population of almost 160 million people and around 60% of the households have access to electricity [18]. In rural areas, this proportion is even lower and the government has made a great effort to reduce power shortage. Solar systems have played an important role in the increase of energy access and currently, Bangladesh has one of the most successful off-grid solar systems programs called IDCOL Solar Home System (SHS) Program.

The private utility company named Purobi Green Energy Limited (PGEL), with the initiative and support of the engineering consulting firm named Prokaushali Sangsad Limited (PSL), made the investment in the system and installed the solar mini-grid in the remote off-grid rural market of Sandwip island of Bangladesh. The Infrastructure Development Company Limited (IDCOL) financed the project. The total estimated cost of the project in 2009 was US$ 730,000 and included distribution line, panels, inverters, cables, civil works, technical assistance etc. The project was planned to provide electricity to commercial enterprises, nearby households, schools and health centers.

Here is a summary of the technical details of the project:

- 64.8 kW power provided by PV modules connected to 6 grid-tied 11 kW inverters with MPPT (Maximum Power Point Tracker). This part of the system supply directly to the 220 V mini-grid distribution line.
- Three-phase AC distribution line configured through the multi-cluster box, which is the interface for all connectors and controls.
- The unused power is stored in the batteries through 12 bidirectional inverters, distributed in 4 clusters.
- 40 kW of additional PV power is stored directly into the same batteries through DC battery chargers.
- There are 96 batteries in total, separated in four-battery banks with a total capacity of 12,000 Ah in 48 V, dimensioned to cover evening load with average insolation.
- During the worst season of solar irradiation and low state of charge of the batteries, a 40 kW diesel backup generator provides backup power when insolation is low and the batteries have a low charge.
- Area of the plant: +/- 1500 m^2

The project generated relevant benefits to the country:

- Enterprises benefit from the increase in their income generation because of the use of reliable electricity. However, the consumers did not trust the service immediately and only after almost one year, they disconnected from diesel services used until that date.
- The plant provides electricity without interruption for 13h, a supply quality not available even in Bangladesh`s important cities. This advantage of the service attracted costumers.
- Consumers used to pay tariffs between US$ 0.56 and 0.96/kWh and PGEL set the tariff at US$ 0.40/kWh, potentially reducing the electricity bills.
- A major benefit of the project was its influence on the development of a generation solution that can help the economic growth and improve the life of a large number of low-income communities. The good results of the project served as an example from which investors, financing and developing agencies can learn and replicate the success. Policy makers are already using the know-how acquired from the project to make decisions about the off-grid rural electrification business models based on clean energy [17].
- Until the middle of 2015, around 3.7 million SHSs were installed under the IDCOL SHS program in the off-grid rural areas of Bangladesh. This number means that 17 million people are accessing electricity (around 11% of the total population). In December 2016 the program reached a total of 4,090,539 systems[1], distributed around the country as in Figure 2.2. At the beginning of the program, the World Bank and Global Environment Facility (GEF) offered credit and granted support to IDCOL start the program. After that, eight other organisms offered additional financial help for the expansion of the program [19].

[1] IDCOL - Infrastructure Development Company Limited. Solar Map. Available at: http://www.idcol.org/old/bd-map/bangladesh_map/

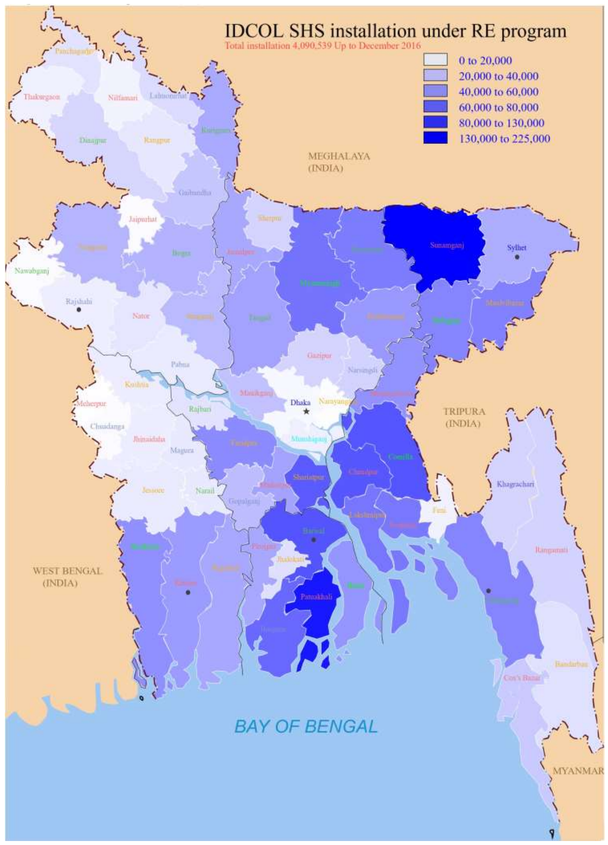

Figure 2.2 - Installation of SHS over Bangladesh. Each color represents a band of systems installed per region. Reproduced from [20]

2.3.4 Bihar and Nepal

Rao et al. [21] analyze data about grid, microgrid and solar home systems (SHS) located in three nearby rural villages in two counties in the South of Asia: Bihar and Nepal. The evaluated information has details about the conditions of the electricity supply and benefits from these systems. The study aims to compare the different systems, and it was based on household surveys and small business interviews. In the case of this study, the focus will be on the benefits observed by the authors in these actual systems. Moreover, the research is not considering the benefits of the grid, but it mentions the results of the tradition distribution system considered relevant and comparable to the benefits or drawbacks of Microgrid and SHS.

The following benefits are in the focus of the authors:

- livelihoods and income
- women and children’s health
- women’s time spent on daily activities
- children’s education

These are the results from the analysis:

- Microgrids are more reliable than the grid, but the former usually provides higher availability.
- The use of Kerosene for lighting is detected in 25% of households with SHS. On the other hand, 80% of grid and microgrid connected customers use Kerosene for lighting. It is possible to infer the second group suffers from unpredictability and low reliability. The reduced use of Kerosene can avoid accidents.
- The perception of schooling benefits is not distinguishable, except for households with SHS that perceive high benefits from the lightning to children`s schooling.
- Small businesses consider reliability essential and the cost for a reliable supply is not a barrier. They register that an unreliable supply generates a loss of customers and market, and it is an obstacle to the expansion of their companies. Finally, electricity is considered a factor that increases their customer base.

2.3.5 Nicaragua

In 2012, 77.9% of the population of Nicaragua had access to electricity, but in the rural areas, the proportion reached only 42.7% [18]. The country had 5.877 million inhabitants in that year and lived in rural areas, which means that around 1.298 million did not have electricity supply and nearly all of them lived in rural areas [22]. These proportions were even worse in the previous decade and the government, with the cooperation of the World Bank, created "PERZA – Proyecto de Electrificación Rural para Zonas Aisladas" (Off-grid Rural Electrification Project), a program to tackle the low level of electricity access in rural population.

The focus of the investment was primarily on individual solar home systems (SHS) and small-scale hydroelectric plants [23]. Gent. and Horvielleur [24] developed a research to evaluate the situation of 400 SHS after four to five years from the installation, which took place between 2006 and 2007 in rural areas of Nicaragua. The systems were installed in the beginning of PERZA using subsided investment. The objective of the study is to analyze what have happened to the systems during the period and the impact they generated to the citizens.

The results of the research, based on the data collected from 152 questionnaire surveys, describes the benefits reported by the users of the SHS and some of them are highlighted according to this research scope:

- The system supplied enough electricity to satisfy all their lighting and appliance needs and the energy bill was reduced.
- Air quality improvement inside homes, a fact registered by more 95% of the users.
- Lighting enabled an increase in the number of studying hours of children (benefit reported by 67.5% of the users).
- Users (16%) sold mobile telephone battery recharges using the electricity generated by the SHS.
- Lightning improved the productivity of the economic activities and made them easy for 20% of the consumers. For small businesses, lighting enabled them to close later and improve the results of the business.
- A relevant proportion of the users, 56.8%, stated that they were not able to use SHS to improve their income.
- Consumers that were reached by the distribution grid during the period declared that the SHS was an important backup during the interruptions of the electricity grid. Although increased grid presence, 91.4% of the systems were still installed in the original households and 75.6% of these remaining systems were still functioning and being used.
- Finally, the research did not identify any user that complained about the SHS. Moreover, almost all of the citizens (99.2%) would recommend the system to another family.

The authors register that the study provided an unexpected relevant result: consumers reported financial difficulties in replacing components of the systems. Most of the reported technical problems were related to battery issues. Investments in similar programs should consider the finance issues regarding the long-term maintenance in order avoid that the projects are compromised after the first years of operation.

The World Bank evaluated the results of PERZA as a whole in 2013 and considered substantial the efficacy of the provision of electricity and related benefits to rural sites in Nicaragua [23].

3. DISTRIBUTED GENERATION: TECHNICAL BENEFITS

3.1. Introduction

The insertion of distributed generation in the energy matrix has several technical consequences that affect the power system, especially regarding power flow and voltage characteristics. Because of that, the stakeholders directly affected by the solution or interested in the adoption of DG must consider the technical impacts, positive or negative, in their plans.

The literature about the technical impacts of DG is vast and the results depend directly on the characteristics of distribution and DG systems that are evaluated or simulated. The focus is the usually observed benefits. These are the main positive results, also known as *system support benefit* [25], [26], [27]:

- Resilience increase of infrastructure, including in areas with difficult access
- Avoid the expansion of transmission lines, a fact that reduces losses, costs and environmental impacts, especially in long lines
- Reduction or offset of investments in transmission and distribution systems
- Reduction in the use of transmission and distribution systems, releasing capacity that can be used for other purposes.
- Diminished peak power
- Backup use in case of power interruptions, increasing power quality
- Increase of voltage control on different points of the grid and near the loads
- The components of DG system are usually standardized components which are cheaper and easier to purchase and install
- Inverters may reduce voltage harmonics
- Reduction of system vulnerability to terrorism
- Avoid land use effects and the costs of right-of-way (ROW) acquisition that may affect distribution and transmission utilities
- Emissions reduction with the use of renewable energy DG systems.

The presented list is not exhaustive and only registers the main benefits that DG can offer and in some cases, the effects listed as benefits can turn into negative impacts depending on the systems analyzed. However, the expansion of DG systems may generate relevant improvements to the power system and to the population.

In addition to the presented benefits, this report aims to evaluate the potential benefit of using DG to reduce non-technical losses, particularly in dangerous areas with significant cases of electricity theft. There are diverse technological and managerial strategies to reduce theft [28], but the problem persists in many areas of the globe and this research contributes to address the issue with a pioneer point of view. The background of the study is the actual situation of non-technical losses in Brazil.

3.2. Case study: Reduction of non-technical losses in Brazil

There are more than 207.2 million[2] people living in Brazil and they are irregularly distributed in around 8,516,000 km^2. In 2010, 97.8% of them had access to electricity, mainly in urban areas (99.1%), but the rural population supply, 89.7%, may be also considered significant if the territory magnitude is taken into account[3]. In 2013, the total rate reached 99,5%[4] and it is expected to keep growing because the Brazilian government created specific regulations to universalize the access to electricity and set deadlines to distributors to supply electricity to 100% of the population, even in isolated areas. Moreover, the creation of the program called “Luz para Todos” (*Light for All)* in 2003 accelerated that process. Although more than 99% of the Brazilians have electricity supply, in 2010 more than 2.7 million did not have access to this essential public service, including almost 400 thousand in cities.

Historically, hydroelectric power plants have generated the most part of the electricity in Brazil, especially because of the abundance of hydro resources. The importance of this renewable energy remains relevant, but the mix has changed during the last 15 years and some new resources, like solar and wind power, were included. Each one of the five geographic regions of Brazil has peculiar characteristics that influenced directly the structure of the generation system. The Brazilian installed capacity reached almost 141 GW and the electricity generation total is 581,486 GWh in 2015 [29]. In order to make all the generated centralized electricity reach the majority of the population, Brazil constructed

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[2] IBGE. Projeção da população do Brasil. Available at http://www.ibge.gov.br/apps/populacao/projecao/

[3] Portal Brasil. Energia elétrica chega a 97,8% dos domicílios brasileiros, mostra censo demográfico. Available at: http://www.brasil.gov.br/infraestrutura/2011/11/energia-eletrica-chega-a-97-8-dos-domicilios-brasileiros-mostra-censo-demografico

[4] World Bank. Access to electricity (% of population). Available at: http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=BR&year_high_desc=false

over the years one of the largest transmission systems in the world, considered unique in terms of size and characteristics. This system is called SIN and has more than 125.000 km of extension.

The net electricity consumption is around 465 TWh and there are 114 companies (private, public and mixed economy) in the distribution sector[5]. The difference between energy generation and consumption indicates that there are around 20% of total losses (approx. 116.3 TWh) along the power system, including transmission and distribution grids (20.1% in the interconnected power system and 30% in the isolated systems). Table 3.1 shows examples of total losses in Brazil around the world[6].

Country	Total Electricity Losses (%)	Country	Total Electricity Losses (%)
BRAZIL	**20**	SPAIN	9
RUSSIA	10	ITALY	7
INDIA	18	POLAND	6
CHINA	6	JAPAN	5
MEXICO	14	AUSTRALIA	6
CHILE	7	EGYPT	11
COLOMBIA	12	NIGERIA	15
ARGENTINA	16	SOUTH AFRICA	8
EUA	6	ANGOLA	11
CANADA	9	INDONESIA	18
GERMANY	6	BANGLADESH	13

Table 3.1 - Example of total electricity losses (% of output) around the globe

Although the Word Bank considers Brazil an upper middle-income country[7] (gross national income - GNI per capita between US$ 4,036 and US$ 12,475 in 2015), its electricity losses level are close to the 19% average of low income countries (GNI per capita of US$ 1,025 or less), quite distant from the 9% average of countries with similar economic

5 ANEEL. Serviço Público de Distribuição de Energia Elétrica. Available at: http://www.aneel.gov.br/distribuicao2

6 World Bank. Electric power transmission and distribution losses (% of output). Available at: http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS?end=2013&locations=BR&start=2013&view=bar

7 World Bank. How does the World Bank classify countries? Available at: https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries

situation. The comparison could consider many other aspects to explain the reasons of the high amount of energy loss but at this point the research focuses on one specific characteristic of the Brazilian power system: the high level of non-technical losses, which occurs in the distribution grid. The electric distribution networks are spread around the country, but utilities in different regions face a challenge to reduce non-technical losses.

The Brazilian Regulatory Electricity Agency (ANEEL) estimates that 5% of the energy injected to the distribution grids is lost because of fraud and theft, which represents more than 18.3 TWh every year. Considering the average residential electricity consumption in Brazil of 194 kWh/month, this amount could supply 7.9 million households during one year or the entire Center-West region of Brazil for six months. The amount of non-technical losses varies among distributors and it can reach values above 20%. Socio-economic and cultural characteristics of the population are the main reason for the issue [30].

This research aims to analyze the potential benefit that distributed generation can generate to reduce non-technical losses. The study shows the results of different scenarios in which the use of photovoltaic systems could reduce non-technical losses and its impact on distribution utilities and consumers in Brazil.

3.2.1 Non-technical losses definition

According to ANEEL[8], the energy consumed is always smaller than the generated amount. That difference is called energy loss and it is divided in Transmission and Distribution losses. The first ones occur between the generation plants and the entrance of the distribution grid. The second ones occur inside the distribution system and they are classified according to two categories:

i) Technical Losses: energy consumed by the distribution infrastructure due to heat loss (Joule effect) in equipment (transformers, cables, etc.)
ii) Non-technical Losses: a value determined by the difference between the total losses and the technical losses. It represents all the other distribution energy losses which are directly associated with the commercial management of the distribution utility, as energy theft, measuring and billing irregularities, unpaid bills, etc.

[8] ANEEL. Perdas de Energia. Available at http://www.aneel.gov.br/metodologia-distribuicao/-/asset_publisher/e2INtBH4EC4e/content/perdas/654800?inheritRedirect=false

Non-technical losses are also known as *commercial losses*. Theft may represent a relevant share of these losses in distribution systems. The following are the most common ways to steal energy [28]:

i) Utility mislead: Consumers mislead the distribution utility in order to reduce the electricity bill. This kind of fraud is usually related to solutions used to change the power registered by the meter.
ii) Clandestine connections: users illegally connected to the power grid.
iii) Incorrect billing: problems occurred in the billing process caused by weak controls used by the utility, mistakes or corruption of the employees that register the meter measurements or process the bills, among other causes.
iv) Default: consumers do not pay their electricity bills

3.2.2 Financial impact of non-technical losses

Non-technical losses may generate negative consequences, for example:

- High financial losses for distribution utilities and legal consumers. Bills raise to compensate the illegal use of electricity by part of the consumers
- Overload and degradation of the distribution grid, which decrease the quality of supply and the reliability of the whole system.
- Illegal consumers do not have right to a decent supply
- Illegal connections to the grid can harm citizens [31]

Regarding the financial issue, in 2014 ANEEL estimated that the non-technical losses generate a negative impact of more than R$ 4.5 billion per year (approx. € 1.26 billion) [30]. The most recent data available is from February 2017 and the Agency estimates that this category of losses reached R$ 8.15 billion (approx. € 2.3 billion). The discussion of the causes of the financial amount increase between 2014 and 2017 is not a subject of this research, but inflation, the price of energy and raise of consumption, among others, may have influenced the presented values.

ANEEL is responsible for defining the methodology to calculate the regulatory energy losses used in the Tariff Review, which occur periodically or in extraordinary situations at any time. The submodule 2.6 of the specific regulation called Tariff Adjustment Procedure (PRORET) describes the rules to define the regulatory non-technical losses. In order to understand this regulation in general lines and the impact of its application to the distributors and consumers, some definitions and formulas are presented next [32].

- Injected Energy (EI, "Energia Injetada"): the sum of all the energy that is injected into the distribution network of the utility through frontier points (minus the energy that is exported to the transmission network) or local generation (own or third part generation).
- Losses in Distribution (PD, "Perdas na Distribuição"): the difference between the injected energy in the distribution system and the total sold and supplied energy, expressed in MWh. It is composed by technical and non-technical losses.
- Technical Losses (PT, "Perdas Técnicas"): a portion of the distribution losses that is inherent to the process of energy transportation, tension transformation and measurement in the distribution grid, expressed in MWh.
- Non-technical Losses (PNT, "Perdas Não Técnicas"): represents all the other losses of the distribution system, as theft, measurement and billing mistakes, consumer units without meter, etc. It is the difference in MWh between Losses in Distribution and Technical Losses.
- Percentage of non-technical losses (PPNT, "Percentual de perdas não técnicas"): percentage of the non-technical losses in relation to the low-voltage market of the utility (Mbt).

$$PPNT = \frac{PNT}{Mbt} x100 \ [\%]$$

- The regulation uses Yardstick Competition, a comparative procedure, to define the levels of regulatory non-technical losses. The Agency develops a complexity ranking in order to assess the efficiency of each distribution utility in fighting the non-technical losses. Based on the results of the comparative analysis, it determines a goal that is a reference level to the non-technical losses in a specific concession area. If the current regulatory levels are above the goal, ANEEL defines a reduction trajectory to the regulatory levels in order to make the utility meet the goals into a certain period. Each company has a specific trajectory depending on the level of difficulty to fight non-technical losses and cannot overcome the limits determined by the Agency.

- The concessionaires are compared according to their supplied market, which is divided into two groups. Group 1 includes companies that distribute more than 1,000 GWh/year in the low-voltage market and supply more 500,000 consumers or have more than 15,000 km of electrical network. All the others are included in Group 2.

The rankings are based on a socioeconomic complexity index of the concession area that is calculated using three econometric models (C, G and K). Each of them considers some socioeconomic variables, detailed in Table 3.2.

Socioeconomic Variables	Model C	Model G	Model K
Violence - Deaths caused by aggression			X
% of people with *per capita* income lower than half of the minimum wage	X		X
Gini (inequality)		X	
Precariousness - % of people living at subnormal residences	X	X	X
Urban waste collection	X	X	X
Non-payment on the credit market	X	X	
Low-income market/(Total residential and low-income residential market)	X		
Low-income market/(Total low-voltage market)			X

Table 3.2 - Variables used to calculate the complexity index. Translated and adapted from [33]

The current complexity rankings were updated in 2015 and Table 3.3 shows the first fifteen of 33 companies of Group 1 and the state in which their concession area is located.

Group 1	Complexity Index	State
CELPA	0.503	Pará
LIGHT	0.377	Rio de Janeiro
AMAZONAS ENERGIA	0.364	Amazonas
CEMAR	0.315	Maranhão
CELPE	0.313	Pernambuco
COELBA	0.284	Bahia
CEAL	0.266	Alagoas
ELETROPAULO	0.265	São Paulo
CEPISA	0.257	Piauí
COELCE	0.253	Ceará
ELETROACRE	0.243	Acre
ESCELSA	0.235	Espírito Santo
ESE	0.224	Sergipe
AMPLA	0.218	Rio de Janeiro
EPB	0.197	Paraíba

Table 3.3 - Fifteen companies with the highest complexity index. Translated and adapted from [32].

The Agency defines the portion of the non-technical losses that is included in the tariff, which affects the consumers directly. The distributors pay the remaining portion, which may be null. Although consumers are not responsible for frauds committed by other citizens, it is not possible to force the distributor to reduce all the losses immediately. Companies may be not the only responsible for all the non-technical losses because that problem sometimes is related to socioeconomic issues that do not concern the utility. The complexity index was created to help ANEEL define the regulatory non-technical losses limits that concern to each distributor and to make possible the comparison between companies. It is harder to fight the commercial losses where the complexity is higher. When the index is elevated, the Agency also analyzes more information that includes the plans of the utilities to reduce losses. [34]

Considering the regulatory non-technical losses in comparison to the injected energy, Figure 3.1 shows the limits for the first five companies of the complexity index between 2010 and 2015.

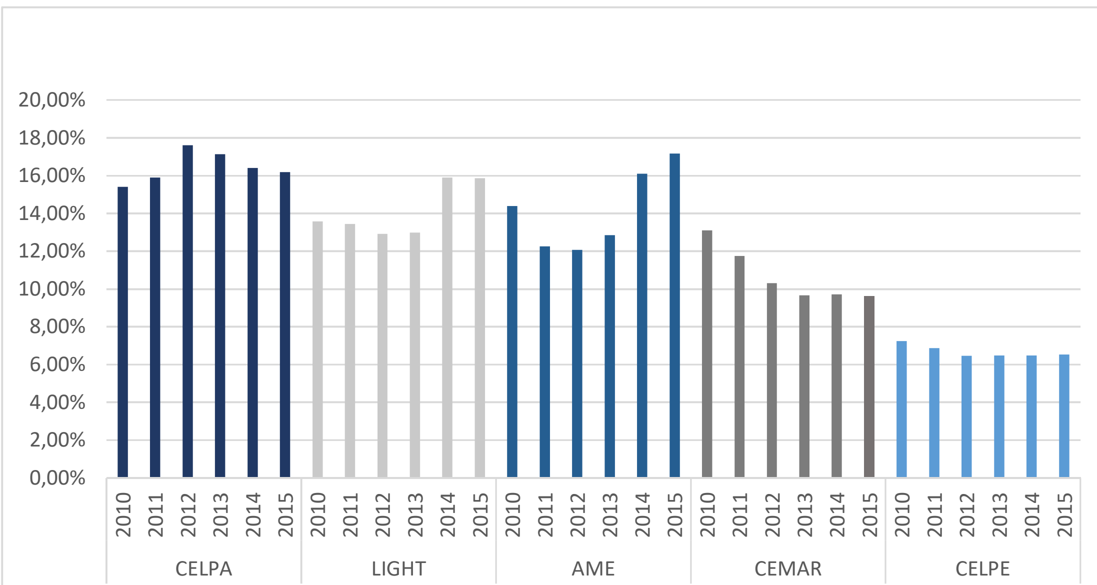

Figure 3.1 - Non-technical losses with respect to injected energy[9]

[9] ANEEL. Metodologia de cálculo tarifário da distribuição – Perdas de Energia (table file). Available at: www.aneel.gov.br/documents/654800/14936188/Base_Perdas_Internetjul2017_07_02.xlsx/b80f742b-2c25-6b73-44e1-636d9f827a60

The portion of the non-technical losses compared to the injected energy in Figure 3.1 exemplifies the impact of them on the amount of energy received by the distributors in different regions of Brazil. Considering that these are large distributors with the highest indexes of complexity, the first three did not face any significant reduction in non-technical losses and the values remained high during six years. However, it is important to remember that ANEEL defines the regulatory non-technical limits to each DU over their low-voltage market. Table 3.4 shows the total market, the regulatory non-technical losses with respect to the low-voltage market and the expenses generated by these losses are estimated by ANEEL, for the five mentioned companies.

Distribution Utility	Market + Losses (MWh)	Regulatory Non-technical Losses (%)	Non-technical Losses (x R$ 1,000)	Non-technical Losses (x € 1,000)
CELPA	15,612,132.27	34.00%	687,983.86	191,106.63
LIGHT	41,170,234.05	36.06%	1,845,814.46	512,726.24
AME	12,253,604.95	41.54%	905,989.16	251,663.66
CEMAR	9,413,792.51	15.07%	229,796.98	63,832.49
CELPE	18,409,852.24	14.00%	346,780.94	96,328.04

Table 3.4 - Regulatory level and estimated financial impact of commercial losses. Adapted from ANEEL[10]

The DUs supply a significant amount of energy without receiving the proper payment. Because of that, regular consumers pay a higher bill to compensate the non-technical losses that are below the regulatory limits. The amount that is above that limit affects negatively the results of the companies. LIGHT, for example, estimates that the electricity bill in its concession area could be 17% smaller if there were no commercial losses. In the case of CELPA, the bill would be 10% smaller if the non-technical losses were extinct.

The commercial losses generate other damages that may also have financial consequences. Illegal connections, for instance, can generate tax evasion, interruptions of the electricity supply, voltage level oscillations, fires and accidents in the network. The technical problems increase the necessity of maintenance, increase the expenditures of the distributors, damage home appliances and reduce the quality of the supply.

[10] ANEEL. Calendário e Resultado dos Processos Tarifários de Distribuição. Available at: http://www.aneel.gov.br/resultado-dos-processos-tarifarios-de-distribuicao

Until 2013, LIGHT spent R$ 200 million (around € 55.6 million) per year for 5 years in CAPEX (capital expenditure) and OPEX (operational expenditure) to reduce losses. ELETROBRAS, a mixed economy corporation controlled by the Brazilian Government and the biggest company of the electric power sector in Latin America, controls seven distribution utilities. The corporation created a project called ELETROBRAS Distribution Rehabilitation Project (Energia+) with the support of the World Bank and in which it financed US$ 495 million. More than 95% of the total has been spent for the last six years in service quality improvement and loss reduction in all the distributors of the group.

These are exemplifications about how distributors have been investing a significant amount of money to tackle non-technical losses. The electricity regulator also promotes discussions and improvements related to the subject. Although non-technical losses have decreased in some concession areas around the country, Figure 3.2 shows that the average situation in Brazil has not improved significantly over the years.

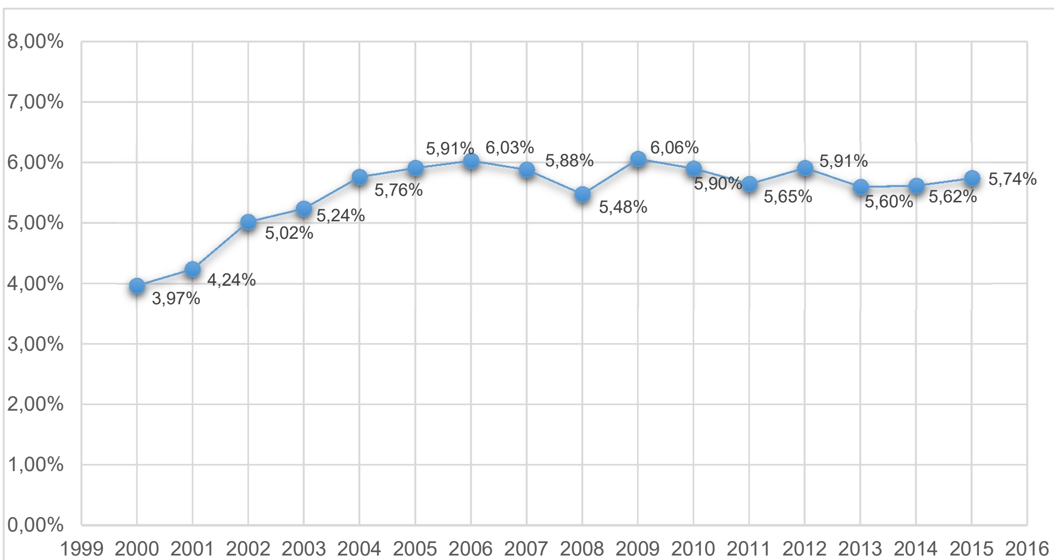

Figure 3.2 – Medium voltage and low voltage commercial losses percentage in relation to injected energy. Average considering 63 distribution utilities. Adapted from ABRADEE[11]

[11] ABRADEE. Available at: http://www.abradee.com.br/setor-de-distribuicao/perdas/furto-e-fraude-de-energia

The reduction of the commercial losses can generate multiple benefits for the country because the recuperated values may be used for different purposes, for example [35]:

- Reduction of subsidies or energy tariffs
- Providing a quality service for consumers and sustainable business for distributors
- Subsidizing consumers in social risky situations
- Increase energy access

3.2.3 Potential benefit of distributed generation in the reduction of non-technical losses

There are various strategies to reduce the non-technical losses described in the literature. There are also descriptions of methods used in real cases, in different regions of the world, that achieved success or not. This research focuses on energy theft, the main cause of commercial losses, to evaluate the potential benefit of using distributed generation to reduce the damage caused by non-technical losses.

Smith [28] identifies three methods to fight power theft:

i. Technical / Engineering

   Innovative solutions and technologies upgrade power system and allow the reduction of commercial losses, including the use of information technology to monitor systems and electronic meters that transmit readings to a remote place and automated meter reading, among many other solutions.

ii. Managerial

   Distribution utilities usually are large and complex companies. Because of that, the bureaucracy may reduce their efficiency and the development of an effective anti-theft program may improve their results. The companies must monitor the consumers frequently to avoid losses and discourage them from stealing energy. Moreover, DU has to fight corruption, which is a complex issue that may be present in any sector and level of the utility.

iii. System change

Systems with a high standard of governance have more chances to have reduced levels of theft. Societies with higher corruption levels and a not competitive power system have lower chances to reduce non-technical losses to reasonable patterns.

The methods and solutions developed to reduce non-technical losses usually pursue ways to avoid that users consume energy without regularly paying for it. However, the traditional approach has not produced effective results in some regions of Brazil. Areas with a complex socioeconomic situation (areas controlled by criminal groups, high levels of poverty, etc.) have not faced a sustainable reduction of non-technical losses. This research looks for the issue from a different point of view:

What if consumers start generating their own energy instead of stealing it?

Instead of searching ways to block energy that flows illegally from the distribution grid, government and distributors could point their efforts to transform the illicit consumers into regular *prosumers* (acronym explained in the next paragraph), reducing non-technical losses, improving the quality of service and contributing to improve socioeconomic situation of low-income communities.

Technological systems that allow local generation of electricity reached a level of development high enough to allow that the acronym *prosumer* becomes a common term in discussions about distributed generation. In this specific case, prosumer means that the consumer of energy starts to act also as a producer. The prices of some equipment have dropped drastically for the last decade and systems became economically viable in many countries. Brazil`s territory has favorable conditions for solar energy applications. Because of that, the study considers the use of photovoltaic (PV) systems on the rooftops of residences to evaluate the possibility of using DG to reduce commercial losses.

At this point of the document, different scenarios are proposed and simulated in order to analyze the potential benefit of DG to minimize the impact of non-technical losses. The study is based on the potential photovoltaic generation on rooftops in a specific region of Brazil and on a hypothetical photovoltaic system installed in the same region. The technical and economic analysis is performed in order to quantify the potential impact and support further discussions about the viability of the proposed solutions.

A. Technical assessment

The study begins with the definition of the location that will be the base for the proposed scenarios that are analyzed on topic about the economic assessment. The definition of the area respected some prerequisites in order to narrow the search and to generate reliable results, close to the ones that can be found in the reality of Brazil:

- Urban area
- Supplied by DU of Group 1 (big market)
- High level of non-technical losses
- Complex socioeconomic situation
- Low level of reduction of losses along the last 5 years
- Significant amount of data available for public access

Based on that scope, the concession area of the company LIGHT (Light Serviços de Eletricidade S/A), shown in Figure 3.3, was chosen. It comprehends 31 counties of the Rio de Janeiro state, including the metropolitan area of its capital. The distributor supplies electricity to around 4.2 million consumers (approx. 10 million people).

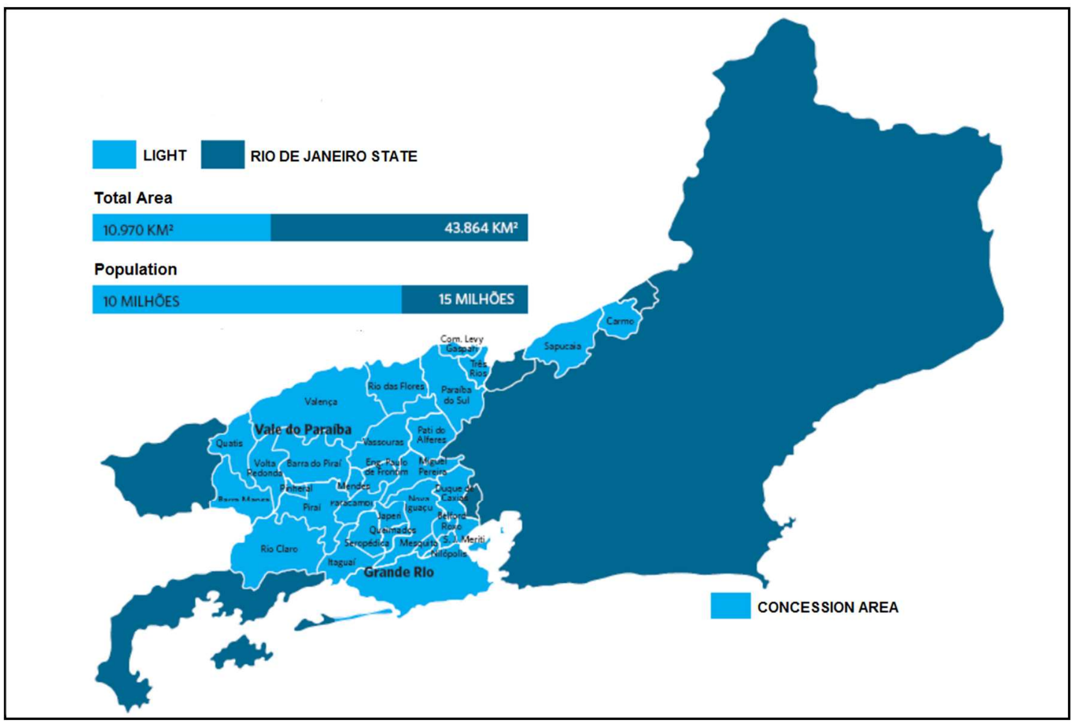

Figure 3.3 - LIGHT`s concession area in the state of Rio de Janeiro. Adapted from CEMIG[12]

[12] CEMIG. Aumento de participação na Light S.A. - Área de Concessão da Light. Available at: http://cemig.infoinvest.com.br/ptb/7215/Aquisicao_Light_AGC_e_Equatorial_Final_html/Aquisicao_Light_AGC_e_Equatorial_Final.html

The behavior of the losses in the middle of 2016 is detailed in Table 3.5, following a division proposed by the company itself and available for public access. The results clarify the relevant difference between "risky areas", where the action of the distributor is limited by a variety of causes related to violence, and the rest of that are called "possible areas".

	Non-Technical Losses (GWh)	Total Losses (GWh)	Grid Load (GWh)	% Non-Technical Losses / Grid Load	% Total Losses / Load
Risky areas	2,793	3,094	3,771	**74.06%**	82.06%
Possible areas	3,422	5,933	33,974	**10.07%**	17.46%
Total	6,214	9,028	37,744	**16.46%**	23.92%

Table 3.5 - Losses in risky and possible areas. Adapted from LIGHT [13]

The company divides its concession area into five different groups to present the results of the losses, as seen in Figure 3.4 : *Vale do Paraíba, Baixada, Oeste, Leste,* and *Centro-Sul*.

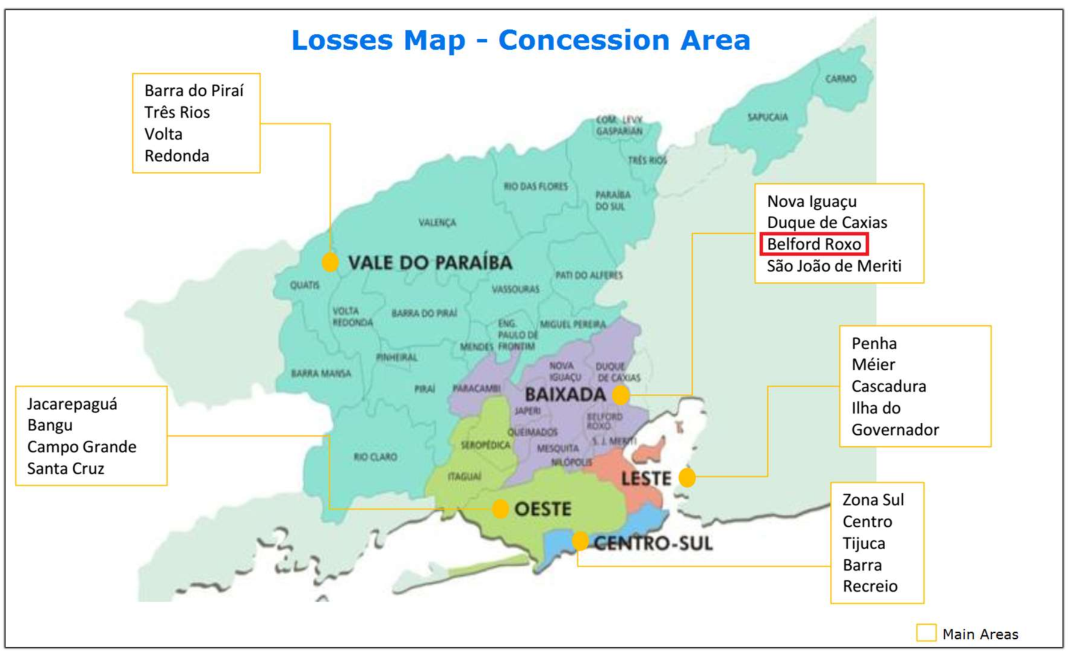

Figure 3.4 - Map of losses in the concession area of LIGHT. Adapted from LIGHT[14]

[13] LIGHT. Apresentação Corporativa - BTG Utilities Day, 19/10/2016. Available at: http://ri.light.com.br/ptb/apresentacoes/2016

[14] LIGHT. Apresentação Perdas – BTG Pactual, 6/6/2016. Available at: http://ri.light.com.br/ptb/apresentacoes/2016

Based on that division, it is possible to compare the behavior of the losses between counties with different socioeconomic characteristics and highlight the regions with the higher losses in Table 3.6.

	TOTAL	Vale do Paraíba	Centro-Sul	Leste	Oeste	Baixada
Number of consumers	4,270,586	442,643	848,673	883,764	1,012,606	1,082,900
Invoice LV (GWh)	14,515	1,262	5,094	2,724	2,798	2,637
Non-Technical Losses (GWh)	5,753	11	75	1,837	1,895	1,935
Non-Technical Losses / Invoiced LV (%)	39.63	0.9	1.5	**67.4**	**67.7**	**73.4**

Table 3.6 - Losses in the concession area divided into 5 main regions. Adapted from LIGHT[15]

After defining the area of Brazil to be studied, it was necessary to narrow the search even more and to choose a specific location for the PV project. The first two options were subnormal settlements (slums), but the lack of reliable data about the residences and population was a relevant barrier to develop the research. Finally, the location for the project is the city of **Belford Roxo** and its main characteristics are summarized in Table 3.7. In 2015, LIGHT published that Belford Roxo was the location with the third highest level of energy theft in its concession area.

[15] LIGHT. Apresentação do 8º Encontro Anual Light e Investidores, 24/8/2015. Available at: http://ri.light.com.br/ptb/apresentacoes/2015

Belford Roxo	
Latitude	22º 45' 51" S (-22.7641667)
Longitude	43º 23' 58" W (- 43.3988888)
Population	469,332 (100% urban)
Area	77.82 km²
Demographic Density	6,031.38 inhabitants/km²
Monthly Average Wage	R$ 2249 / € 625 (2.4 minimum wages)
Number of Residences	145,667
Adequate residences	61,984 (43%)
Semi-adequate	82,257 (56%)
Inadequate	1,426 (1%)
Energy Non-technical Losses / Injected Energy	**51.8%**
Energy Non-technical Losses / Invoiced LV	**73.4%*** *(*Assumed the average of the region BAIXADA)*
Region of the concession area	BAIXADA
Infant Mortality Rate	13.85 per 1000 live births
Homicide Rate	43.6 per 100,000 inhabitants (Average Brazil: 29.1)

Table 3.7 - Details about Belford Roxo

In order to estimate the potential amount of electricity that can be generated by systems installed on the roof of residences in Belford Roxo, this document considers the results of a study developed to GIZ, a German provider of international cooperation services [36], for the state of Rio de Janeiro (RJ). The research estimates the value of the total usable irradiation on residential roofs in Brazil without including the efficiency of the PV system. This document analyzes the results only for the State of Rio Janeiro (RJ) to subsidize further calculations and approximations to the city of Belford Roxo. Briefly, the research followed the methodology summarized in the next paragraphs.

To estimate the total irradiation available over the roofs of Rio de Janeiro, the average irradiation per m² is multiplied by the usable area of the roofs, as shown in Equation 1.

(1) $$TotIrr = IrrMed * ArTelApr$$

Where *TotIrr* is the total solar irradiation on an inclined surface of the usable area of homes, *IrrMéd* is the average annual irradiation per day in Wh/m2/day and *ArTelApr* is the usable area of home roofs.

To find the usable area for PV generation, the research considers two types of residences, house and apartment, and an approximated roof area for each of them.

(2) $$ArTotCasa = DomCasa * ArCasa$$

Where *ArTotCasa* is the roof area of houses, *DomCasa* is the number of houses and *ArCasa* is the average area occupied by houses.

(3) $$ArTotAP = DomAP * ArAP$$

Where *ArTotAP* is the roof area of apartments, *DomAP* is the number of houses and ArAP is the average area occupied by apartments.

(4) $$ArTelTot = ArTotCasa + ArTotAP$$

Where *ArTelTot* is the total area of residential roofs

Finally, to calculate the roof area available for PV generation, it is necessary to consider a reduction index. Obstructions and other kinds of restrictions can reduce the available area for the installation of the panels.

(5) $$ArTelApr = ArTelTot * TaxApr$$

Where *ArTelApr* is the usable area of residential roofs and *TaxAprCasa* is the exploitation rate.

The research also develops four different scenarios to estimate the generation on roofs, as seen in Table 3.8 [36]. It is important to highlight that the scenarios presented by LANGE [36] are NOT the same of those that are detailed and analyzed in this study about the reduction of non-technical losses.

	Scenario 1 [37] **House area = 85 m²** **Apartment Area = 15m²**	**Scenario 2** [36] **House Area = 80 m²** **House Area (Subnormal) = 35 m²** **Apartment Area = 20m²**
Scenario A Optimist Exploitation Rate = 0,9	Scenario 1A	Scenario 2A
Scenario B Conservative Exploitation Rate = 0,3	Scenario 1B	Scenario 2B

Table 3.8 - Four scenarios used to estimate PV generation on residential roofs. Translated from [36]

For all the scenarios, the results for the variables DomCasa, DomAP e DomTot are the same because they represent a number of residences, which does not vary among the scenarios. Table 3.9 contains the values of these variables.

Variable	**DomCasa**	**DomAP**	**DomTot**
Result	4,145,600	1,055,297	5,233,168

Table 3.9 - Number of houses and apartments in RJ

After that, the research calculated the results for all the proposed scenarios and the results are shown in Table 3.10 and Table 3.11. The total irradiation that can be used to PV generation varies from 537 GWh/day until 2,018 GWh/day in RJ. The study highlights that the houses located in subnormal areas are calculated separately and that fact influences the differences between the scenarios. In a national scope, the influence of these areas on the total radiation is considered small by the author (between 2.70% and 5.92 % of the total irradiation)

Variable	**ArTotCasa (km²)**	**ArTotAP (km²)**	**ArTelTot (km²)**	**IrrTot - Scenario 1 (GWh/day)**	**IrrTot - Scenario 1A (GWh/day)**	**IrrTot - Scenario 1B (GWh/day)**
Result	352.376	15.810	368.186	2,018	1,816	605

Table 3.10 - Solar potential in RJ - Scenarios 1, 1A and 1B. Adapted from [36]

Variable	ArTotCasa (km²)	ArTotAP (km²)	ArTelTot (km²)	IrrTot - Scenario 2 (GWh/day)	IrrTot - Scenario 2A (GWh/day)	IrrTot - Scenario 2B (GWh/day)
Result	306.116	21.105	327.222	1,793	1,613	537

Table 3.11 - Solar potential in RJ - Scenarios 2, 2A and 2B. Adapted from [36]

Based on the irradiation results, the average irradiation per m^2 in all the scenarios and for each type of residence is calculated, as shown in Table 3.12.

	Scenario 1	Scenario 1A	Scenario 1B	Scenario 2	Scenario 2A	Scenario 2B
Irradiation per m² (kWh/day)	5.480925	4.932290	1.643191	5.479460	4.929375	1.641088
House (kWh/day)	465.88	419.24	139.67	438.36	394.35	131.29
Apartment (kWh/day)	82.21	73.98	24.65	109.59	98.59	32.82
House in subnormal area (kWh/day)	191.83	172.63	57.51	191.78	172.53	57.44

Table 3.12 - Irradiation in different types of residences

After that, the following assumptions guide the estimation of the potential electricity generation from roof PV systems in the city of Belford Roxo. These considerations are necessary because there are no reliable data about some characteristics of the city and the State (RJ) is taken as a reference for the estimations.

- The proportion of houses and apartments is the same for the whole state.
- The proportion of houses located in subnormal areas represents 5% of the total of residences.
- Based on data of the PV*SOL® Software, the efficiency of the whole PV system is 10%, including losses in panels, inverter, cables, PV module mismatch, pollution, and shadowing.

Table 3.13 presents the estimative for the number of houses, including those in subnormal areas, and apartments in Belford Roxo.

	Total	Houses	Apartments	Houses in Subnormal Areas
State (RJ)	5,233,168	4,145,600	105,5297	-
Belford Roxo	145,667	109,624	29,375	5,77

Table 3.13 - Estimation of the number of residences by type in Belford Roxo

The multiplication of the total number of each type of residence by its specific irradiation detailed in Table 3.12 determines the potential irradiation for each scenario. Table 3.14 presents the results of the potential irradiation on a daily, monthly and yearly basis for the entire county.

	Scenario 1	Scenario 1A	Scenario 1B	Scenario 2	Scenario 2A	Scenario 2B
Houses (GWh/day)	51.07	45.96	15.31	48.05	43.23	14.39
Apartments (GWh/day)	2.41	2.17	0.72	3.22	2.90	0.96
Houses in subnormal area (GWh/day)	1.11	1.00	0.33	1.11	1.00	0.33
Daily Total (GWh)	54.59	49.13	16.37	52.38	47.12	15.69
Monthly Total (GWh)	1,637.81	1,473.86	491.02	1,571.41	1,413.65	470.63
Yearly Total (GWh)	19,926.63	17,931.99	5,974.04	19,118.81	17,199.46	5,726.04

Table 3.14 - Estimation of solar potential in Belford Roxo in different scenarios

The figures presented in Table 3.14 are the total potential irradiation. In order to estimate the amount of electricity that can be generated by residential roof PV systems in the same location, it is necessary to consider the average efficiency of this kind of technology. Using the value of 10% already assumed, the total amount of generated electricity for different realities and at individual residences or the whole city is determined, as seen in Table 3.15 and Table 3.16.

	Scenario 1	Scenario 1A	Scenario 1B	Scenario 2	Scenario 2A	Scenario 2B
One House (kWh/day)	46.59	41.92	13.97	43.84	39.44	13.13
One House - Monthly (kWh)	1,397.64	1257.73	419.01	1315.07	1183.05	393.86
One House - Yearly (kWh)	17,004.57	15,302.43	5,098.00	16,000.02	14,393.78	4,791.98
One Apartment (kWh/day)	8.22	7.40	2.46	10.96	9.86	3.28
One Apartment - Monthly (kWh)	246.64	221.95	73.94	328.77	295.76	98.47
One Apartment - Yearly (kWh)	3,000.81	2,700.43	899.65	4,000.01	3,598.44	1,197.99
One House in subnormal area (kWh/day)	19.18	17.26	5.75	19.18	17.25	5.74
One House in subnormal area - Monthly (kWh)	575.50	517.89	172.54	575.34	517.58	172.31
One House in subnormal area - Yearly (kWh)	7,001.88	6,301.00	2,099.18	7,000.01	6,297.28	2,096.49

Table 3.15 – Potential daily, monthly and yearly amount of electricity generated by individual residences

	Scenario 1	Scenario 1A	Scenario 1B	Scenario 2	Scenario 2A	Scenario 2B
All Houses (GWh/day)	5.11	4.60	1.53	4.81	4.32	1.44
All Apartments (GWh/day)	0.24	0.22	0.07	0.32	0.29	0.10
All Houses in subnormal area (GWh/day)	0.11	0.10	0.03	0.11	0.10	0.03
Daily Total (GWh)	5.46	4.91	1.64	5.24	4.71	1.57
Monthly Total (GWh)	163.78	147.39	49.10	157.14	141.37	47.06
Yearly Total (GWh)	1,992.66	1,793.20	597.40	1,911.88	1,719.95	572.60

Table 3.16 – Potential daily, monthly and yearly amount of electricity generated by all residences

After estimating the amount of energy that can be generated considering optimist and conservative scenarios, the next step is the calculation of the average load consumption in residences. The average residential consumption in Brazil is 194 kWh/month and in the Southwest Region, which includes the State of Rio de Janeiro, it is 243 kWh/month. The real average consumption for Belford Roxo is not available, so this study assumes the same value of the Southwest Region. Table 3.17 contains the estimative for the residential consumption in Belford Roxo.

	Residential Consumption
Average Consumption	243 kWh/month
Yearly Average Consumption	2,916 kWh/year
Monthly Consumption in Belford Roxo	35.397 GWh/month
Yearly Consumption in Belford Roxo	424.765 GWh/year

Table 3.17 - Average residential consumption in Belford Roxo

The solar potential and load consumption are already known. The next step is to define a hypothetical system that can cover the consumption of one residence for the whole year. The main objective of this study is to evaluate the potential of distributed generation to reduce power losses in low-income communities, transforming irregular consumers into generators and properly finance that initiative. The scope does not include the evaluation of the economic viability of DG in comparison to other types of investments. Instead of that, the economic assessment analyzes the viability to implement the solution in low-income areas while contributing to the reduction of non-technical losses.

Recent studies show that PV systems are viable in different regions of Brazil in terms of payback time and TIR [38], [39]. That results occur especially because of the high value of solar irradiation on most part of the country, the increasing values of energy during the last years, the reduction of costs of PV systems and the incentives by regulation and taxes reductions. Martins [38], for example, shows the payback time of 8 years for a 3,500 Wp system installed in Rio de Janeiro and the IRR (Internal Return Rate) becomes positive in the 16th year.

The current legislation of Brazil allows “Net Metering”, so the credits accumulated along the year compensate the months with higher consumptions. Because of that, the chosen PV system is enough to cover at least the average consumption of the whole year.

Moreover, in the chosen location, the houses represent more than almost 80% of the number of residences and more than 95% of the potential generated energy. Therefore, the simulated system is proper for installation on the roof of houses. To subsidize the dimensioning of the system, it was considered that measured PV systems have performance ratios of 60-80% and average specific yields of around 1,230 kWh/kWp [40], [41]. These values were considered to avoid overestimation of the solar irradiation and underestimation of the real size of the PV system, thus increasing the reliability of the system sizing.

After looking for options in the market, a system with the technical specifications and costs presented in Table 3.18 was selected.

PV System - Grid Connected	
Nominal Max. Power	2.56 kWp
Inverter	FRONIUS GALVO 2.5.1 - 2.5 kW
Panels	(8) x SOLAR CANADIAN CS6X-320P - 72 Cells - 320W (~15 m^2)
System Cost	R$ 13,690 (€ 3,803)
Installation Cost	R$ 3,000 (€ 833)
Maintenance during 25 years	R$ 4,000 (€ 1,111)
Total Cost	R$ 20,690 (€ 5,747)

Table 3.18 - PV System technical and economic information[16]

The simulation of the system using PV*SOL® Online tool, including losses, achieved 3,315 kWh of generation per year. That result covers around 113% of the estimated annual load.

B. Economical assessment

At this point of the study, scenarios are proposed to estimate the potential reduction in commercial losses that distributed generation can produce if massively introduced in areas in which the current solutions are not effective. Different scenarios are presented to quantify the economic benefits, assuming that the systems are installed for consumers that currently steal energy. Moreover, the analysis includes the investment that is necessary to implement the systems. Table 3.19 summarizes the LV consumption and the non-technical losses estimates for Belford Roxo and the actual data for the concession area of LIGHT. The alternatives for the Government, distributors and low-income consumers fund the PV system are discussed in topic 3.2.4.

[16] Kit sold by Shopping Solar. Price consulted on April 2017. Available at: http://www.shoppingsolar.com.br/departamento/kits+geradores+de+energia+solar+/69

	Belford Roxo	LIGHT S.A. Concession Area
LV Monthly Consumption (GWh)	35.397	1,210
LV Yearly Consumption (GWh)	424.765	14,515
Non-Technical Losses LV (GWh)	311.778	5,753
Non-Technical Losses / Invoiced LV (%)	73.4	39.63

Table 3.19 - LV consumption and non-technical losses in Belford Roxo and LIGHT area

- **Scenario 1: 100% reduction in Belford Roxo**

The first scenario considers that all non-technical losses in residences of Belford Roxo are eliminated. It means that all the illegal consumption is substituted by distributed generation with PV systems on the top of houses and apartments. Although the presence of commercial losses is an existing phenomenon even in developed countries, the first estimative supposes a utopia. It is a reference to the other scenarios and provides the maximum benefit that could be achieved. The total cost of the systems, including installation, is reduced by 30% in comparison to individually purchased systems. The study considers a difference between wholesale and retail markets. Maintenance is not reduced in any of the scenarios.

- **Scenario 2: 75% reduction in Belford Roxo**

In the second scenario, the distributed generation provides a reduction of 75% in commercial losses. The new level of these losses is reduced from 73.4% to 18.35% in LV residential consumers. The total cost of the systems, including installation, is reduced by 25% for same reason presented in Scenario 1.

- **Scenario 3: 50% reduction in Belford Roxo**

The installation of PV systems reduces commercial losses by 50%. The actual level is reduced from 73.4% to 36.7% in LV residential consumers. The total cost of the systems, including installation, is 25% smaller. The study considers a difference between wholesale and retail markets.

- **Scenario 4: 20% reduction in Belford Roxo**

The fourth scenario considers that the non-technical losses in residences of Belford Roxo achieve 58.7% of the invoiced LV electricity. In this case, the total cost of the systems, including installation, is reduced by 20% because the study considers a difference between wholesale and retail markets.

- **Scenario 5: reduction in Belford Roxo to the actual level of "Leste" region**

The region called "Baixada", in which Belford Roxo is located, has the highest levels of non-technical losses of the concession area of LIGHT. The "Leste" region currently has 67.4% of commercial losses in LV. This scenario estimates the necessary expansion in distributed generation based on PV systems to reduce the losses in Belford Roxo to that level. The total cost of the systems, including installation, is 15% smaller in comparison to individually purchased systems.

- **Scenario 6: reduction in Belford Roxo to the regulatory level of the concession area**

Finally, the last scenario estimates the amount of systems and investment that is necessary to improve the efficiency of the supply in Belford Roxo to reach the regulatory level determined by ANEEL for the area of the state of Rio de Janeiro attended by LIGHT, 36.06%. The total cost of the systems, including installation, benefits from a 25% lower price because of the wholesale difference to the retail market.

The hypotheses of the six scenarios generate different economic benefits by the reduction of losses that impact on the tariffs and require different investment volumes, which are summarized in Table 3.20.

	Scenario	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Non-Technical Losses LV Reduction (GWh)	311.778	233.833	155,889	62.356	25.486	158.607
Economic Benefit per year x R$ 1,000 *(x € 1,000)*	164,307 *45,641*	123,230 *34,231*	82,153 *22,820*	32,861 *9,128*	13,431 *3,731*	83,586 *23,218*
25 years of Economic Benefit x R$ 1,000 *(x € 1,000)*	4,107,669 *1,141,019*	3,080,752 *855,764*	2,053,834 *570,510*	821,534 *228,204*	335,777 *93,271*	2,089,651 *580,458*
Number of Required Systems	106,920	80,190	53,460	21,384	8,740	54,392
Total Installation Cost x R$ 1,000 *(x € 1,000)*	1,249,142 *346,984*	1,003,774 *278,826*	669,183 *185,884*	285,518 *79,311*	123,990 *34,442*	680,853 *189,126*
Total Cost in 25 years x R$ 1,000 *(x € 1,000)*	1,676,820 *465,783*	1,324,533 *367,926*	883,022 *245,284*	371,054 *103,070*	158,950 *44,153*	898,421 *249,561*

Table 3.20 - Potential benefits for diverse scenarios of DG and cost of implementation – Belford Roxo

The scenarios simulated until this point were specific to the city of Belford Roxo. Based on that, the next step is to extrapolate the analysis to the whole concession area of LIGHT in different scenarios. The results subsidize the considerations that are presented in topic "4.**RESULTS AND DISCUSSION**" of this document.

In the case of the whole concession area, the focus of the economic benefit is the areas in which the actions of the DU are limited by the risk. The technical teams are not able to enter these locations without the support of the state, even with police reinforcement. The introduction of DG would be developed in risky areas not only to reduce losses, but also to benefit the population with less favorable socioeconomic level. This study considers that the reduction of non-technical losses in the rest of the locations can continue by the use of other methodologies already developed. The use of DG can be evaluated in a second moment depending on the results achieved in risky areas.

The amount of commercial losses considers the proportion between risky areas and the total non-technical losses of Table 3.5. The risky areas represent 44.95% of total electricity, according to numbers of the DU. The total non-technical losses in LV considered in the simulations is 5,753 GWh, shown in Table 3.19, and the share of risky areas totals 2,586 GWh.

- **Scenario 7: reduction of 100% in risky areas of the distribution utility (DU)**

This scenario considers a situation similar to Scenario 1. However, in this case, all non-technical losses in residences of risky areas of concession area of LIGHT are eliminated. The irregular consumption in risky areas distributed all over the state of Rio de Janeiro is substituted by distributed generation with PV systems on the top of houses and apartments. As already mentioned, this scenario may never become reality, but it can be used as the maximum point of benefit.

In this case, the total cost of the systems is reduced by 35%, including installation, because the study considers a difference between wholesale and retail markets.

- **Scenario 8: reduction of 50% in risky areas of the DU**

The installation of DG reduces commercial losses by 50% in risky areas, which represents PV generation of approximately 1,292.9 GWh per year. The total cost of the systems, including installation, is 30% smaller because it is considered a large number of systems purchased in the wholesale market.

- **Scenario 9: reduction of 20% in risky areas of the DU**

In this scenario, the reduction of non-technical losses represents 20% of the total and PV systems are 30% cheaper than the ones bought individually in the retail market. The reduction totalizes around 517.16 GWh in one year.

- **Scenario 10: reduction of 10% in risky areas of the DU**

Scenario 10 estimates a 10% reduction of non-technical losses. Installed systems have prices 25% smaller than the ones bought individually. The reduction totalizes around 258.58 GWh per year.

- **Scenario 11: reduction of 5% in risky areas of the DU**

The 11th scenario considers that the non-technical losses in residences are reduced by 5% of the invoiced LV electricity. In this case, the total cost of the systems, including installation, is reduced by 25% because the study considers the wholesale prices.

- **Scenario 12: reduction to the regulatory level of the DU**

Finally, the last scenario simulates that the current level of non-technical losses in LV is reduced to the regulatory level determined by the Regulator. The reduction from 39.63% until 36.06% would occur because of the reduction of commercial losses in risky areas with the introduction of DG and in possible areas with other methods, respecting the proportion mentioned in Scenario 6. The amount of reduction in risky areas totalizes around 232.91 GWh and the costs of other methods are not included in this Scenario. The total cost of the systems, including installation, is reduced by 25% if compared to the retail price. The spending in other methods to reduce commercial losses in possible areas of the concession area is not accounted in this study. However, it would be necessary to reduce the total losses to 36.06%. If considered alone, the risky areas would reduce the total index from 39.63% to 38.03%.

The last six scenarios, from 7 to 12, estimate economic benefits and require a different amount of investment for the concession area of the DU, registered in Table 3.21.

	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Non-Technical Losses LV Reduction (GWh)	2,585.795	1292.897	517.159	258.579	129.290	232.908
Economic Benefit per year x R$ 1,000	1,362,714	681,357	272,543	136,271	68,136	122,743
(x € 1,000)	*378,532*	*189,266*	*75,706*	*37,853*	*18,927*	*34,095*
25 years of Economic Benefit x R$ 1,000	34,067,847	17,033,923	6,813,569	3,406,785	1,703,392	3,068,567
(x € 1,000)	*9,463,291*	*4,731,645*	*1,892,658*	*946,329*	*473,165*	*852,380*
Number of Required Systems	886,761	443,380	177,352	88,676	44,338	79,873
Total Installation Cost x R$ 1,000	9,620,026	5,180,014	2,072,006	1,110,003	555,001	999,804
(x € 1,000)	*2,672,229*	*1,438,893*	*575,557*	*308,334*	*154,167*	*277,723*
Total Cost in 25 years x R$ 1,000	13,167,069	6,953,536	2,781,414	1,464,707	732,354	1,319,294
(x € 1,000)	*3,657,519*	*1,931,538*	*772,615*	*406,863*	*203,432*	*366,471*

Table 3.21 - Potential benefits for diverse scenarios of DG and cost of implementation - Concession Area

3.2.4 Alternatives to finance distributed generation in low-income communities

The insertion of distributed generation based on PV systems installed on the roof of houses and apartments requires a large initial investment, which makes it one of the main barriers for the development of such generation solution. Although the benefits may be clear after a viability analysis, especially in regions with high solar incidence, the amount of money that is required to start generating electricity is not available for many homeowners. Because of that, the availability of financing options is required to promote the massive growth of distributed generation.

In the case of low-income communities, the financial barrier turns into an impassable wall if the conditions for financing the PV systems are not properly designed to this layer of the society. This research evaluates different hypotheses to simulate the participation of consumers, government and distributors to finance the insertion of DG. In the case of areas with high non-technical losses, the benefits of DG research all the three mentioned stakeholders directly.

The Normative Resolution 482/2012, revised by the Normative Resolution 687/2015, published by ANEEL, defines the current regulation about distributed generation in Brazil [42]. It establishes the conditions for distributed generation of electricity from renewable sources, or qualified cogeneration, and a system of electrical energy compensation (net metering). It defines distributed microgeneration for systems until 75 kW of installed capacity and mini generation for those between 75 kW and 5 MW (3MW for hydraulic source), connected to the distribution grid through the consumers.

The energy that is generated, but not consumed in a specific month, becomes a credit that can be used as supply in the following months. The credits last 60 months (5 years) and they can be also used to reduce the electricity bill of different units of the same owner, but only inside the region supplied by the same DU. Multiple consumers in the same condominium can also generate energy as a group and define how the electricity is divided. Moreover, the regulation authorizes the many consumers associated in a collective to install one plant of micro or mini generation and reduce the electricity bills of the members of the association.

Next, the financing simulations consider the current regulation just mentioned and different possibilities to reduce the impact for low-income consumers. The results support the further discussion about the alternative that may turn the investment in PV systems viability in these communities. It is assumed that the consumers do not have any value to spend initially and the financing covers 100% of the value of the system. The simulations consider a single system supported by one consumer and equated monthly installments (equal payments).

- **Retail price, current interest rates offered in the Brazilian market**

The first scenario considers the interests and loan terms available in the market for a natural person and the retail price for the PV system bought individually. The values used in the calculation approximate the cheapest loans available in the market, most of them offered by private and public banks. All available options of natural people loans in urban areas have high interests and brief terms to be paid. One of the possible causes for that is the recent development of distributed generation in Brazil. Moreover, the loans usually focus on citizens with high earnings and electricity consume, which can afford higher investments. The research supposes the taxes involved in loans, as IOF ("Imposto sobre Operações Financeiras"), are included in the interest rate.

The results that are shown in Table 3.22 consider the following costs:

- The cost of the system: R$ 16,690 (€ 4,636). That value includes installation but does not include the 25 years of maintenance.
- Interest rate: fixed-rate 1.6% per month
- Loan length: 60 months (5 years)

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 2,823.50 *€ 784.31*	R$ 2,262.24 *€ 628.40*	R$ 5,085.74 *€ 1,412.71*	R$ 423.81 *€ 117.73*	R$ 14,427.76 *€ 4,007.71*
2	R$ 2,380.98	R$ 2,704.76	R$ 5,085.74	R$ 423.81	R$ 11,723.00
3	R$ 1,851.90	R$ 3,233.84	R$ 5,085.74	R$ 423.81	R$ 8,489.16
4	R$ 1,219.32	R$ 3,866.42	R$ 5,085.74	R$ 423.81	R$ 4,622.74
5	R$ 463.00	R$ 4,622.74	R$ 5,085.74	R$ 423.81	R$ 0.00

Table 3.22 – Loan simulation considering retail price for the PV system and current interests offered in the Brazilian market

Because of the short loan length, the maintenance along 25 years, which is the PV system expected lifetime, is not included in the loan. Supposing that maintenance will cost R$ 4,000 (€ 1111) during that period, the average annual value of R$ 160 (€ 44.4) should be added to the total paid every year. The total every year raises from R$ 5,085.74 (€ 1412.71) to R$ 5,245.74 (€ 1,457.15) and the installments raise to R$ 437.15 (€ 121.43), without considering the increase of maintenance over the years. These payments would last for 5 years, after that the consumers would continue to pay for maintenance for the rest of the lifetime of the system.

Other institutions in Brazil offer loans with lower interest rates and longer loan lengths for the juridical person and rural producers. In order to present the results for two new hypothetical situations, the calculations at this point of the study apply the same financing conditions that are available for small businesses and small rural producers. In this case, these conditions are extended to residential consumers and the results are presented in Table 3.23.

Loan conditions adapted from the Development Agency of São Paulo State ("DESENVOLVE SP")[17]:

- The cost of the system: R$ 16,690 (€ 4,636). That value includes installation but does not include the 25 years of maintenance.
- Interest rate: 0.53% per month updated by the inflation (IPCA)
- Inflation: 4.57%[18]
- Loan length: 120 months (10 years)

[17] Loan offered by Desenvolve SP, Linha Economia Verde. Available at: http://www.desenvolvesp.com.br/empresas/opcoes-credito/projetos-sustentaveis/linha_economia_verde

[18] IPCA - 12 previous months until March 2017. IBGE - IPCA. Available at: http://www.ibge.gov.br/home/estatistica/indicadores/precos/inpc_ipca/defaultseriesHist.shtm

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1,735.13 *€ 481.98*	R$ 987.61 *€ 274.34*	R$ 2,722.74 *€ 756.32*	R$ 226.90 *€ 63.03*	R$ 15,702.39 *€ 4361.78*
2	R$ 1,624.33	R$ 1,098.41	R$ 2,722.74	R$ 226.90	R$ 14,603.98
3	R$ 1,501.10	R$ 1,221.64	R$ 2.722.74	R$ 226.90	R$ 13,382.34
4	R$ 1,364.05	R$ 1,358.70	R$ 2.722.74	R$ 226.90	R$ 12,023.64
5	R$ 1,211.62	R$ 1,511.13	R$ 2,722.74	R$ 226.90	R$ 10,512.52
6	R$ 1,042.08	R$ 1,680.66	R$ 2,722.74	R$ 226.90	R$ 8,831.85
7	R$ 853.53	R$ 1,869.22	R$ 2,722.74	R$ 226.90	R$ 6,962.64
8	R$ 643.82	R$ 2,078.92	R$ 2,722.74	R$ 226.90	R$ 4,883.71
9	R$ 410.59	R$ 2,312.16	R$ 2,722.74	R$ 226.90	R$ 2,571.56
10	R$ 151.19	R$ 2,571.56	R$ 2,722.74	R$ 226.90	R$ 0.00

Table 3.23 - Loan simulation considering retail price for the PV system and interest offered for small business – "DESENVOLVE SP"

As in the first simulation, the loan length is also shorter than the PV system lifetime and the maintenance is not included in the loan. If this cost is added to the simulation, the total rises to R$ 2,882.74 (€ 800.76) every year and the installments raise to R$ 240.23 (€ 66.73). These payments would last for 10 years and after that, the consumers would continue to pay for maintenance.

The calculations in Table 3.24 consider the loan conditions adapted from the Development Bank of Northeast Region of Brazil ("BANCO DO NORDESTE")[19]. Below are the costs:

- The cost of the system: R$ 16,690 (€ 4,636). That value includes installation but does not include the 25 years of maintenance.
- Interest rate: fixed-rate 7.2675% per year (minimum rate offered by the bank)
- Loan length: 20 years (maximum length offered by the bank)

[19] Loan offered by Banco do Nordeste, Programa de Financiamento à Sustentabilidade Ambiental - FNE VERDE. Available at: https://www.bnb.gov.br/programa-de-financiamento-a-conservacao-e-controle-do-meio-ambiente-fne-verde

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1.161,74 *€ 322.71*	R$ 395,38 *€ 109.83*	R$ 1.557,11 *€ 432.53*	R$ 129,76 *€ 36.04*	R$ 16.294,62 *€ 4,526.28*
2	R$ 1.133,00	R$ 424,11	R$ 1.557,11	R$ 129,76	R$ 15.870,52
3	R$ 1.102,18	R$ 454,93	R$ 1.557,11	R$ 129,76	R$ 15.415,58
4	R$ 1.069,12	R$ 487,99	R$ 1.557,11	R$ 129,76	R$ 14.927,59
5	R$ 1.033,65	R$ 523,46	R$ 1.557,11	R$ 129,76	R$ 14.404,13
6	R$ 995,61	R$ 561,50	R$ 1.557,11	R$ 129,76	R$ 13.842,63
7	R$ 954,80	R$ 602,31	R$ 1.557,11	R$ 129,76	R$ 13.240,32
8	R$ 911,03	R$ 646,08	R$ 1.557,11	R$ 129,76	R$ 12.594,24
9	R$ 864,08	R$ 693,03	R$ 1.557,11	R$ 129,76	R$ 11.901,21
10	R$ 813,71	R$ 743,40	R$ 1.557,11	R$ 129,76	R$ 11.157,81
11	R$ 759,68	R$ 797,43	R$ 1.557,11	R$ 129,76	R$ 10.360,38
12	R$ 701,73	R$ 855,38	R$ 1.557,11	R$ 129,76	R$ 9.505,00
13	R$ 639,57	R$ 917,55	R$ 1.557,11	R$ 129,76	R$ 8.587,45
14	R$ 572,88	R$ 984,23	R$ 1.557,11	R$ 129,76	R$ 7.603,23
15	R$ 501,36	R$ 1.055,76	R$ 1.557,11	R$ 129,76	R$ 6.547,47
16	R$ 424,63	R$ 1.132,48	R$ 1.557,11	R$ 129,76	R$ 5.414,99
17	R$ 342,32	R$ 1.214,79	R$ 1.557,11	R$ 129,76	R$ 3.775,96
18	R$ 254,04	R$ 1.303,07	R$ 1.557,11	R$ 129,76	R$ 2.442,06
19	R$ 159,34	R$ 1.397,77	R$ 1.557,11	R$ 129,76	R$ 1.011,21
20	R$ 57,76	R$ 1.499,36	R$ 1.557,11	R$ 129,76	R$ 0,00

Table 3.24 - Loan simulation considering retail price for the PV system and interest offered for small business – "BANCO DO NORDESTE"

Compared to the last two simulations, the loan length is much longer but still shorter than PV system lifetime. The maintenance is not included in the loan and its costs should be included in the total investment. If maintenance is included in the simulation, the total rises to R$ 1,717.11 (€ 476.98) every year and the installments raise to R$ 143.09 (€ 39.75). These payments are fixed for 20 years, after that the consumer keep paying for maintenance.

- **Retail price, reduced interest rate**

The proposition of this item is the offer of reduced interests in comparison to those available in the market. The development of DG in risky areas, usually located in low-income communities, depends on investments that consumers with very limited earnings can support. In the case of this study, which focuses on the reduction of commercial losses in areas with socioeconomic issues that need the direct participation of the government, it is assumed that the reduction of interests is subsidized by the public sector.

The Brazilian Government created a national social housing program called "Minha Casa, Minha Vida" (My House, My Life) in 2009. The object is to fund housing for poor and middle classes with subsidized interests. The simulation considers the interest rate available for families with monthly earnings between R$ 1,800 (€ 500) and R$ 2,350 (€ 652.78), to be paid during the average lifetime of the PV system. The maintenance is included in the total cost and the results are in Table 3.25. The costs are as follows:

- The cost of the system: R$ 20,690 (€ 5747.22). That value includes installation and 25 years of maintenance.
- Interest rate: fixed-rate 5.0% per year + TR (Referential Rate)
- TR: 1,5% per year
- Loan length: 25 years

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1,296.32 *€ 360.09*	R$ 351.35 *€ 97.60*	R$ 1,647.67 *€ 457.69*	R$ 137.31 *€ 38.14*	R$ 20,338.65 *€ 5,649.63*
2	R$ 1,273.48	R$ 374.18	R$ 1,647.67	R$ 137.31	R$ 19,964.47
3	R$ 1,249.16	R$ 398.51	R$ 1,647.67	R$ 137.31	R$ 19,565.96
4	R$ 1,223.26	R$ 424.41	R$ 1,647.67	R$ 137.31	R$ 19,141.55
5	R$ 1,195.67	R$ 452.00	R$ 1,647.67	R$ 137.31	R$ 18,689.56
6	R$ 1,166.29	R$ 481.38	R$ 1,647.67	R$ 137.31	R$ 18,208.18
7	R$ 1,135.00	R$ 512.67	R$ 1,647.67	R$ 137.31	R$ 17,695.52
8	R$ 1,101.68	R$ 545.99	R$ 1,647.67	R$ 137.31	R$ 17,149.53
9	R$ 1,066.19	R$ 581.48	R$ 1,647.67	R$ 137.31	R$ 16,568.05
10	R$ 1,028.39	R$ 619.27	R$ 1,647.67	R$ 137.31	R$ 15,948.78
11	R$ 988.14	R$ 659.53	R$ 1,647.67	R$ 137.31	R$ 15,289.25
12	R$ 945.27	R$ 702.40	R$ 1,647.67	R$ 137.31	R$ 14,586.86
13	R$ 899.62	R$ 748.05	R$ 1,647.67	R$ 137.31	R$ 13,838.80
14	R$ 850.99	R$ 796.67	R$ 1,647.67	R$ 137.31	R$ 13,042.13
15	R$ 799.21	R$ 848.46	R$ 1,647.67	R$ 137.31	R$ 12,193.67
16	R$ 744.06	R$ 903.61	R$ 1,647.67	R$ 137.31	R$ 11,290.06
17	R$ 685.33	R$ 962.34	R$ 1,647.67	R$ 137.31	R$ 9,993.23
18	R$ 622.77	R$ 1,024.90	R$ 1,647.67	R$ 137.31	R$ 8,946.60
19	R$ 556.15	R$ 1,091.51	R$ 1,647.67	R$ 137.31	R$ 7,831.93
20	R$ 485.21	R$ 1,162.46	R$ 1,647.67	R$ 137.31	R$ 6,644.81
21	R$ 409.65	R$ 1,238.02	R$ 1,647.67	R$ 137.31	R$ 5,380.52
22	R$ 329.18	R$ 1,318.49	R$ 1,647.67	R$ 137.31	R$ 4,034.06
23	R$ 243.47	R$ 1,404.20	R$ 1,647.67	R$ 137.31	R$ 2,600.08
24	R$ 152.20	R$ 1,495.47	R$ 1,647.67	R$ 137.31	R$ 1,072.89
25	R$ 55.00	R$ 1,592.67	R$ 1,647.67	R$ 137.31	R$ 0.00

Table 3.25 - Loan simulation considering retail price for the PV system and reduced interest

- **Retail price, current interest rate, DU investment**

Distribution utilities may also benefit from the introduction of DG because of the reduction of commercial losses and possible reduction in costs of maintenance of the distribution grid caused by illegal connections. Because of that, this topic simulates the impact of participation of the DU on a small part of the total cost of the PV system. The DU could pay for part of the PV system or even pay for part of maintenance over the years. The simulated impact is a reduction of 10% on the final cost of the system and the calculations are shown in Table 3.26. The costs are:

- The cost of the system: R$ 18,621 (€ 5,173). That value includes installation and 25 years of maintenance.
- Interest rate: fixed-rate 7.2675% per year
- Loan length: 25 years

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1.301,17 *€ 361.44*	R$ 283,29 *€ 78.69*	R$ 1.584,46 *€ 440.13*	R$ 132,04 *€ 36.68*	R$ 18.337,71 *€ 5,093.81*
2	R$ 1.280,58	R$ 303,88	R$ 1.584,46	R$ 132,04	R$ 18.033,83
3	R$ 1.258,50	R$ 325,96	R$ 1.584,46	R$ 132,04	R$ 17.707,87
4	R$ 1.234,81	R$ 349,65	R$ 1.584,46	R$ 132,04	R$ 17.358,22
5	R$ 1.209,40	R$ 375,06	R$ 1.584,46	R$ 132,04	R$ 16.983,16
6	R$ 1.182,14	R$ 402,32	R$ 1.584,46	R$ 132,04	R$ 16.580,84
7	R$ 1.152,90	R$ 431,56	R$ 1.584,46	R$ 132,04	R$ 16.149,28
8	R$ 1.121,54	R$ 462,92	R$ 1.584,46	R$ 132,04	R$ 15.686,36
9	R$ 1.087,90	R$ 496,57	R$ 1.584,46	R$ 132,04	R$ 15.189,79
10	R$ 1.051,81	R$ 532,65	R$ 1.584,46	R$ 132,04	R$ 14.657,14
11	R$ 1.013,10	R$ 571,36	R$ 1.584,46	R$ 132,04	R$ 14.085,77
12	R$ 971,57	R$ 612,89	R$ 1.584,46	R$ 132,04	R$ 13.472,89
13	R$ 927,03	R$ 657,43	R$ 1.584,46	R$ 132,04	R$ 12.815,46
14	R$ 879,25	R$ 705,21	R$ 1.584,46	R$ 132,04	R$ 12.110,25
15	R$ 828,00	R$ 756,46	R$ 1.584,46	R$ 132,04	R$ 11.353,79
16	R$ 773,03	R$ 811,43	R$ 1.584,46	R$ 132,04	R$ 10.542,36
17	R$ 714,06	R$ 870,41	R$ 1.584,46	R$ 132,04	R$ 9.367,98
18	R$ 650,80	R$ 933,66	R$ 1.584,46	R$ 132,04	R$ 8.412,23
19	R$ 582,95	R$ 1.001,52	R$ 1.584,46	R$ 132,04	R$ 7.387,02
20	R$ 510,16	R$ 1.074,30	R$ 1.584,46	R$ 132,04	R$ 6.287,30
21	R$ 432,09	R$ 1.152,38	R$ 1.584,46	R$ 132,04	R$ 5.107,66
22	R$ 348,34	R$ 1.236,12	R$ 1.584,46	R$ 132,04	R$ 3.842,28
23	R$ 258,50	R$ 1.325,96	R$ 1.584,46	R$ 132,04	R$ 2.484,95
24	R$ 162,14	R$ 1.422,32	R$ 1.584,46	R$ 132,04	R$ 1.028,97
25	R$ 58,77	R$ 1.525,69	R$ 1.584,46	R$ 132,04	R$ 0,00

Table 3.26 - Loan simulation considering retail price for the PV system and DU investment

- **Retail price, reduced interest rate, DU investment**

At this point, the simulation includes the same reduced interest rate and DU investment proposed in the previous topics. This scenario simulates the impact on the investment supported by the low-income consumer. The monthly installments presented in Table 3.27 are useful for the finance planning of families.

These are the hypothetical loan characteristics:

- The cost of the system: R$ 18,621 ((€ 5,173). That value includes installation and 25 years of maintenance.
- Interest rate: fixed-rate 5.0% per year + TR (Referential Rate)
- TR: 1,5% per year
- Loan length: 25 years

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1.166,69 *€ 324.08*	R$ 316,21 *€ 87.84*	R$ 1.482,90 *€ 411.92*	R$ 123,58 *€ 34.33*	R$ 18.304,79 *€ 5,084.66*
2	R$ 1.146,14	R$ 336,77	R$ 1.482,90	R$ 123,58	R$ 17.968,02
3	R$ 1.124,25	R$ 358,66	R$ 1.482,90	R$ 123,58	R$ 17.609,37
4	R$ 1.100,93	R$ 381,97	R$ 1.482,90	R$ 123,58	R$ 17.227,40
5	R$ 1.076,11	R$ 406,80	R$ 1.482,90	R$ 123,58	R$ 16.820,60
6	R$ 1.049,66	R$ 433,24	R$ 1.482,90	R$ 123,58	R$ 16.387,36
7	R$ 1.021,50	R$ 461,40	R$ 1.482,90	R$ 123,58	R$ 15.925,96
8	R$ 991,51	R$ 491,39	R$ 1.482,90	R$ 123,58	R$ 15.434,58
9	R$ 959,57	R$ 523,33	R$ 1.482,90	R$ 123,58	R$ 14.911,25
10	R$ 925,56	R$ 557,35	R$ 1.482,90	R$ 123,58	R$ 14.353,90
11	R$ 889,33	R$ 593,57	R$ 1.482,90	R$ 123,58	R$ 13.760,33
12	R$ 850,75	R$ 632,16	R$ 1.482,90	R$ 123,58	R$ 13.128,17
13	R$ 809,66	R$ 673,25	R$ 1.482,90	R$ 123,58	R$ 12.454,92
14	R$ 765,89	R$ 717,01	R$ 1.482,90	R$ 123,58	R$ 11.737,92
15	R$ 719,29	R$ 763,61	R$ 1.482,90	R$ 123,58	R$ 10.974,30
16	R$ 669,65	R$ 813,25	R$ 1.482,90	R$ 123,58	R$ 10.161,06
17	R$ 616,79	R$ 866,11	R$ 1.482,90	R$ 123,58	R$ 8.993,91
18	R$ 560,50	R$ 922,41	R$ 1.482,90	R$ 123,58	R$ 8.051,94
19	R$ 500,54	R$ 982,36	R$ 1.482,90	R$ 123,58	R$ 7.048,74
20	R$ 436,69	R$ 1.046,22	R$ 1.482,90	R$ 123,58	R$ 5.980,33
21	R$ 368,68	R$ 1.114,22	R$ 1.482,90	R$ 123,58	R$ 4.842,47
22	R$ 296,26	R$ 1.186,64	R$ 1.482,90	R$ 123,58	R$ 3.630,66
23	R$ 219,13	R$ 1.263,78	R$ 1.482,90	R$ 123,58	R$ 2.340,07
24	R$ 136,98	R$ 1.345,92	R$ 1.482,90	R$ 123,58	R$ 965,60
25	R$ 49,50	R$ 1.433,41	R$ 1.482,90	R$ 123,58	R$ 0,00

Table 3.27 - Loan simulation considering retail price for the PV system, reduced interest, and DU investment

- **Wholesale price 20% smaller than retail, current interest rate**

The impact on non-technical losses may turn significant if the introduction of DG based on PV systems becomes massive in risky areas. Assuming a coordinate action between communities, DU and government, it is reasonable that the acquisition of a large number of systems could result in a significant reduction in the price of equipment and installation in the same region. Because of that, the next simulations consider that the retail price, including installation, presented early is reduced by 20% because the PV systems could be bought in the wholesale market, which use to offer cheaper prices. The maintenance is kept the same. The first results detailed in Table 3.28 consider current interest. The costs are as follows:

- The cost of the system: R$ 17,352 (€ 4,820). That value includes installation and 25 years of maintenance.
- Interest rate: fixed-rate 7.2675% per year
- Loan length: 25 years

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1.212,50 *€ 336.81*	R$ 263,98 *€ 73.33*	R$ 1.476,48 *€ 410.13*	R$ 123,04 *€ 34.18*	R$ 17.088,02 *€ 4,746,67*
2	R$ 1.193,31	R$ 283,17	R$ 1.476,48	R$ 123,04	R$ 16.804,85
3	R$ 1.172,73	R$ 303,75	R$ 1.476,48	R$ 123,04	R$ 16.501,10
4	R$ 1.150,66	R$ 325,82	R$ 1.476,48	R$ 123,04	R$ 16.175,28
5	R$ 1.126,98	R$ 349,50	R$ 1.476,48	R$ 123,04	R$ 15.825,77
6	R$ 1.101,58	R$ 374,90	R$ 1.476,48	R$ 123,04	R$ 15.450,87
7	R$ 1.074,33	R$ 402,15	R$ 1.476,48	R$ 123,04	R$ 15.048,72
8	R$ 1.045,11	R$ 431,37	R$ 1.476,48	R$ 123,04	R$ 14.617,35
9	R$ 1.013,76	R$ 462,72	R$ 1.476,48	R$ 123,04	R$ 14.154,62
10	R$ 980,13	R$ 496,35	R$ 1.476,48	R$ 123,04	R$ 13.658,27
11	R$ 944,06	R$ 532,43	R$ 1.476,48	R$ 123,04	R$ 13.125,84
12	R$ 905,36	R$ 571,12	R$ 1.476,48	R$ 123,04	R$ 12.554,73
13	R$ 863,86	R$ 612,63	R$ 1.476,48	R$ 123,04	R$ 11.942,10
14	R$ 819,33	R$ 657,15	R$ 1.476,48	R$ 123,04	R$ 11.284,95
15	R$ 771,58	R$ 704,91	R$ 1.476,48	R$ 123,04	R$ 10.580,04
16	R$ 720,35	R$ 756,14	R$ 1.476,48	R$ 123,04	R$ 9.823,91
17	R$ 665,39	R$ 811,09	R$ 1.476,48	R$ 123,04	R$ 8.729,56
18	R$ 606,45	R$ 870,03	R$ 1.476,48	R$ 123,04	R$ 7.838,94
19	R$ 543,22	R$ 933,26	R$ 1.476,48	R$ 123,04	R$ 6.883,60
20	R$ 475,39	R$ 1.001,09	R$ 1.476,48	R$ 123,04	R$ 5.858,82
21	R$ 402,64	R$ 1.073,84	R$ 1.476,48	R$ 123,04	R$ 4.759,57
22	R$ 324,60	R$ 1.151,88	R$ 1.476,48	R$ 123,04	R$ 3.580,44
23	R$ 240,89	R$ 1.235,60	R$ 1.476,48	R$ 123,04	R$ 2.315,60
24	R$ 151,09	R$ 1.325,39	R$ 1.476,48	R$ 123,04	R$ 958,85
25	R$ 54,77	R$ 1.421,72	R$ 1.476,48	R$ 123,04	R$ 0,00

Table 3.28 - Loan simulation considering wholesale price for the PV system, current interest rate

- **Wholesale price 20% smaller than retail, reduced interest rate**

This item assumes that consumer acquires the PV system is the wholesale market and finance it with the same subsidized interest rate explained in the simulation already detailed (fixed-rate 5.0% per year + TR). The results are summarized in Table 3.29. The simulation assumes the following costs:

- The cost of the system: R$ 17,352 (€ 4,280). That value includes installation and 25 years of maintenance.
- Interest rate: fixed-rate 5.0% per year + TR
- TR: 1,5% per year
- Loan length: 25 years

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1.087,18 *€ 301.99*	R$ 294,66 *€ 81.85*	R$ 1.381,84 *€ 383.84*	R$ 115,15 *€ 31.99*	R$ 17.057,34 *€ 4,738.15*
2	R$ 1.068,03	R$ 313,82	R$ 1.381,84	R$ 115,15	R$ 16.743,52
3	R$ 1.047,63	R$ 334,21	R$ 1.381,84	R$ 115,15	R$ 16.409,31
4	R$ 1.025,91	R$ 355,94	R$ 1.381,84	R$ 115,15	R$ 16.053,37
5	R$ 1.002,77	R$ 379,07	R$ 1.381,84	R$ 115,15	R$ 15.674,30
6	R$ 978,13	R$ 403,71	R$ 1.381,84	R$ 115,15	R$ 15.270,58
7	R$ 951,89	R$ 429,95	R$ 1.381,84	R$ 115,15	R$ 14.840,63
8	R$ 923,94	R$ 457,90	R$ 1.381,84	R$ 115,15	R$ 14.382,73
9	R$ 894,18	R$ 487,67	R$ 1.381,84	R$ 115,15	R$ 13.895,06
10	R$ 862,48	R$ 519,36	R$ 1.381,84	R$ 115,15	R$ 13.375,70
11	R$ 828,72	R$ 553,12	R$ 1.381,84	R$ 115,15	R$ 12.822,58
12	R$ 792,77	R$ 589,08	R$ 1.381,84	R$ 115,15	R$ 12.233,50
13	R$ 754,48	R$ 627,37	R$ 1.381,84	R$ 115,15	R$ 11.606,13
14	R$ 713,70	R$ 668,14	R$ 1.381,84	R$ 115,15	R$ 10.937,99
15	R$ 670,27	R$ 711,57	R$ 1.381,84	R$ 115,15	R$ 10.226,42
16	R$ 624,02	R$ 757,83	R$ 1.381,84	R$ 115,15	R$ 9.468,59
17	R$ 574,76	R$ 807,08	R$ 1.381,84	R$ 115,15	R$ 8.380,99
18	R$ 522,30	R$ 859,54	R$ 1.381,84	R$ 115,15	R$ 7.503,21
19	R$ 466,43	R$ 915,42	R$ 1.381,84	R$ 115,15	R$ 6.568,37
20	R$ 406,93	R$ 974,92	R$ 1.381,84	R$ 115,15	R$ 5.572,77
21	R$ 343,56	R$ 1.038,29	R$ 1.381,84	R$ 115,15	R$ 4.512,46
22	R$ 276,07	R$ 1.105,78	R$ 1.381,84	R$ 115,15	R$ 3.383,23
23	R$ 204,19	R$ 1.177,65	R$ 1.381,84	R$ 115,15	R$ 2.180,60
24	R$ 127,65	R$ 1.254,20	R$ 1.381,84	R$ 115,15	R$ 899,79
25	R$ 46,12	R$ 1.335,72	R$ 1.381,84	R$ 115,15	R$ 0,00

Table 3.29 - Loan simulation considering wholesale price for the PV system, reduced interest rate

- **Wholesale price 20% smaller than retail, current interest rate, DU investment**

This topic simulates the impact of participation of the DU on a small part of the total cost of the PV system. The DU can benefit from the massive insertion of DG in risky areas and may participate in the investment proposed. The simulated impact is a reduction of 10% on the final cost of the PV system and the results are shown in Table 3.30. These are the costs:

- The cost of the system: R$ 16,017 (€ 4,449). That value includes installation and 25 years of maintenance.
- Interest rate: fixed-rate 7.2675% per year
- Loan length: 25 years

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1.119,21 *€ 310.89*	R$ 243,67 *€ 67.69*	R$ 1.362,89 *€ 378.59*	R$ 113,57 *€ 31.55*	R$ 15.773,33 *€ 4,381.48*
2	R$ 1.101,50	R$ 261,38	R$ 1.362,89	R$ 113,57	R$ 15.511,94
3	R$ 1.082,51	R$ 280,38	R$ 1.362,89	R$ 113,57	R$ 15.231,56
4	R$ 1.062,13	R$ 300,76	R$ 1.362,89	R$ 113,57	R$ 14.930,81
5	R$ 1.040,27	R$ 322,61	R$ 1.362,89	R$ 113,57	R$ 14.608,20
6	R$ 1.016,83	R$ 346,06	R$ 1.362,89	R$ 113,57	R$ 14.262,14
7	R$ 991,68	R$ 371,21	R$ 1.362,89	R$ 113,57	R$ 13.890,93
8	R$ 964,70	R$ 398,19	R$ 1.362,89	R$ 113,57	R$ 13.492,74
9	R$ 935,76	R$ 427,12	R$ 1.362,89	R$ 113,57	R$ 13.065,62
10	R$ 904,72	R$ 458,17	R$ 1.362,89	R$ 113,57	R$ 12.607,45
11	R$ 871,42	R$ 491,46	R$ 1.362,89	R$ 113,57	R$ 12.115,99
12	R$ 835,71	R$ 527,18	R$ 1.362,89	R$ 113,57	R$ 11.588,81
13	R$ 797,39	R$ 565,49	R$ 1.362,89	R$ 113,57	R$ 11.023,32
14	R$ 756,30	R$ 606,59	R$ 1.362,89	R$ 113,57	R$ 10.416,73
15	R$ 712,21	R$ 650,67	R$ 1.362,89	R$ 113,57	R$ 9.766,05
16	R$ 664,93	R$ 697,96	R$ 1.362,89	R$ 113,57	R$ 9.068,09
17	R$ 614,20	R$ 748,69	R$ 1.362,89	R$ 113,57	R$ 8.057,94
18	R$ 559,79	R$ 803,10	R$ 1.362,89	R$ 113,57	R$ 7.235,84
19	R$ 501,43	R$ 861,46	R$ 1.362,89	R$ 113,57	R$ 6.354,00
20	R$ 438,82	R$ 924,07	R$ 1.362,89	R$ 113,57	R$ 5.408,07
21	R$ 371,66	R$ 991,22	R$ 1.362,89	R$ 113,57	R$ 4.393,39
22	R$ 299,63	R$ 1.063,26	R$ 1.362,89	R$ 113,57	R$ 3.304,97
23	R$ 222,35	R$ 1.140,53	R$ 1.362,89	R$ 113,57	R$ 2.137,45
24	R$ 139,46	R$ 1.223,42	R$ 1.362,89	R$ 113,57	R$ 885,08
25	R$ 50,55	R$ 1.312,34	R$ 1.362,89	R$ 113,57	R$ 0,00

Table 3.30 - Loan simulation considering wholesale price for the PV system, current interest rate, and DU investment

- **Wholesale price 20% smaller than retail, reduced interest rate, DU investment**

The results presented in Table 3.31 include the reduced interest rate and DU investment proposed in the last two topics. This scenario simulates the impact on the investment supported by the low-income consumer. The monthly installments presented are the share of the investment that would be paid by consumers. The simulation assumed the following costs:

- The cost of the system: R$ 16,017 (€ 4,449). That value includes installation and 25 years of maintenance.
- Interest rate: fixed-rate 5.0% per year + TR
- TR: 1,5% per year
- Loan length: 25 years

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 1.003,54 *€ 278.76*	R$ 271,99 *€ 75.55*	R$ 1.275,53 *€ 354.31*	R$ 106,29 *€ 29.53*	R$ 15.745,01 *€ 4,373.62*
2	R$ 985,86	R$ 289,67	R$ 1.275,53	R$ 106,29	R$ 15.455,34
3	R$ 967,03	R$ 308,50	R$ 1.275,53	R$ 106,29	R$ 15.146,84
4	R$ 946,98	R$ 328,55	R$ 1.275,53	R$ 106,29	R$ 14.818,28
5	R$ 925,62	R$ 349,91	R$ 1.275,53	R$ 106,29	R$ 14.468,37
6	R$ 902,88	R$ 372,65	R$ 1.275,53	R$ 106,29	R$ 14.095,72
7	R$ 878,65	R$ 396,88	R$ 1.275,53	R$ 106,29	R$ 13.698,84
8	R$ 852,86	R$ 422,67	R$ 1.275,53	R$ 106,29	R$ 13.276,17
9	R$ 825,38	R$ 450,15	R$ 1.275,53	R$ 106,29	R$ 12.826,03
10	R$ 796,12	R$ 479,41	R$ 1.275,53	R$ 106,29	R$ 12.346,62
11	R$ 764,96	R$ 510,57	R$ 1.275,53	R$ 106,29	R$ 11.836,05
12	R$ 731,78	R$ 543,75	R$ 1.275,53	R$ 106,29	R$ 11.292,30
13	R$ 696,43	R$ 579,10	R$ 1.275,53	R$ 106,29	R$ 10.713,20
14	R$ 658,79	R$ 616,74	R$ 1.275,53	R$ 106,29	R$ 10.096,46
15	R$ 618,70	R$ 656,83	R$ 1.275,53	R$ 106,29	R$ 9.439,63
16	R$ 576,01	R$ 699,52	R$ 1.275,53	R$ 106,29	R$ 8.740,11
17	R$ 530,54	R$ 744,99	R$ 1.275,53	R$ 106,29	R$ 7.736,18
18	R$ 482,11	R$ 793,41	R$ 1.275,53	R$ 106,29	R$ 6.925,94
19	R$ 430,54	R$ 844,99	R$ 1.275,53	R$ 106,29	R$ 6.063,03
20	R$ 375,62	R$ 899,91	R$ 1.275,53	R$ 106,29	R$ 5.144,03
21	R$ 317,12	R$ 958,40	R$ 1.275,53	R$ 106,29	R$ 4.165,29
22	R$ 254,83	R$ 1.020,70	R$ 1.275,53	R$ 106,29	R$ 3.122,94
23	R$ 188,48	R$ 1.087,05	R$ 1.275,53	R$ 106,29	R$ 2.012,83
24	R$ 117,82	R$ 1.157,70	R$ 1.275,53	R$ 106,29	R$ 830,57
25	R$ 42,57	R$ 1.232,96	R$ 1.275,53	R$ 106,29	R$ 0,00

Table 3.31 - Loan simulation considering wholesale price for the PV system, reduced interest rate, and DU investment

- **Wholesale price 30% smaller than retail, correction only by inflation, DU investment**

Finally, the last simulation is the most optimistic scenario presented in this study. The values presented in Table 3.32 are based on the assumption that the wholesale price for the PV system is 30% smaller than the retail cost, including the installation. Moreover, the government would offer a subsidized loan that is adjusted only by inflation, and the DU pays 10% of the cost of the of the PV system (including installation). The maintenance does not suffer any reduction and the following information summarizes the reference costs of the loan. The consumers support the monthly installments for 25 years.

- The cost of the system: R$ 14,115 (€ 3,921). That value includes installation and 25 years of maintenance.
- Inflation: 4.57% (IPCA)
- Loan length: 25 years

Year	Interest	Amortization	Total	Installments (Monthly)	Outstanding Balance
1	R$ 625,54 *€ 173.76*	R$ 313,72 *€ 87.14*	R$ 939,26 *€ 260.91*	R$ 78,27 *€ 21.74*	R$ 13.801,28 *€ 3,833.69*
2	R$ 611,20	R$ 328,05	R$ 939,26	R$ 78,27	R$ 13.473,23
3	R$ 596,21	R$ 343,05	R$ 939,26	R$ 78,27	R$ 13.130,18
4	R$ 580,53	R$ 358,72	R$ 939,26	R$ 78,27	R$ 12.771,46
5	R$ 564,14	R$ 375,12	R$ 939,26	R$ 78,27	R$ 12.396,34
6	R$ 547,00	R$ 392,26	R$ 939,26	R$ 78,27	R$ 12.004,09
7	R$ 529,07	R$ 410,19	R$ 939,26	R$ 78,27	R$ 11.593,90
8	R$ 510,33	R$ 428,93	R$ 939,26	R$ 78,27	R$ 11.164,97
9	R$ 490,72	R$ 448,53	R$ 939,26	R$ 78,27	R$ 10.716,44
10	R$ 470,23	R$ 469,03	R$ 939,26	R$ 78,27	R$ 10.247,40
11	R$ 448,79	R$ 490,47	R$ 939,26	R$ 78,27	R$ 9.756,94
12	R$ 426,38	R$ 512,88	R$ 939,26	R$ 78,27	R$ 9.244,06
13	R$ 402,94	R$ 536,32	R$ 939,26	R$ 78,27	R$ 8.707,74
14	R$ 378,43	R$ 560,83	R$ 939,26	R$ 78,27	R$ 8.146,91
15	R$ 352,80	R$ 586,46	R$ 939,26	R$ 78,27	R$ 7.560,45
16	R$ 326,00	R$ 613,26	R$ 939,26	R$ 78,27	R$ 6.947,19
17	R$ 297,97	R$ 641,29	R$ 939,26	R$ 78,27	R$ 6.085,70
18	R$ 268,67	R$ 670,59	R$ 939,26	R$ 78,27	R$ 5.405,04
19	R$ 238,02	R$ 701,24	R$ 939,26	R$ 78,27	R$ 4.693,28
20	R$ 205,97	R$ 733,29	R$ 939,26	R$ 78,27	R$ 3.948,99
21	R$ 172,46	R$ 766,80	R$ 939,26	R$ 78,27	R$ 3.170,69
22	R$ 137,42	R$ 801,84	R$ 939,26	R$ 78,27	R$ 2.356,81
23	R$ 100,77	R$ 838,48	R$ 939,26	R$ 78,27	R$ 1.505,75
24	R$ 62,46	R$ 876,80	R$ 939,26	R$ 78,27	R$ 615,79
25	R$ 22,39	R$ 916,87	R$ 939,26	R$ 78,27	R$ 0,00

Table 3.32 - Loan simulation considering wholesale price for the PV system, reduced interest rate, and DU investment

4. RESULTS AND DISCUSSION

This chapter presents the discussion about the information and results gathered in chapters 2 and 3. It debates about the insertion of distributed generation in areas with high levels of non-technical losses. That discussion focuses not only on the potential economic and technical benefits, but also on the alternatives to finance the projects to low-income citizens.

4.1. The use of distributed generation to promote the reduction non-technical losses

The information and results presented until now support the discussion presented in this item. The following questions guide the debate:

- Can distributed generation be considered an alternative to reduce non-technical losses in areas where the other methods are not effective?
- How to finance the insertion of DG for low-income consumers?
- Which other benefits can DG create if properly inserted in locations with lower socioeconomic status, besides the reduction of electricity commercial losses?

This study does not intend to give a final or exhaustive answer to those matters. The objective is to present some arguments to support the reader`s understanding of the potential benefits of the proposed solution and the aspects that may turn projects viable.

4.1.1 Reduction of non-technical losses

Belford Roxo

Table 4.1 provides the estimation of non-technical losses reduction in a specific location, the city of Belford Roxo in Rio de Janeiro State. Different levels of insertion implicate in higher or smaller levels of reduction of commercial losses, but the bottom row shows that the economic benefit in all the proposed scenarios is more than 2 times bigger than the cost to implement the distributed generation. The different proportions are calculated by dividing the non-technical losses avoided in 25 years by the total cost of the PV systems, including maintenance. As used before, it was considered the average energy tariff of R$ 0.527/kWh (€ 0.146/kWh). The effect of energy price change is not considered along the period.

The difference in the proportions of the last row is caused by the diverse discounts considered in the wholesale price of the PV systems included in each of the scenarios. Besides that, if the insertion of DG in areas with high commercial losses focuses on irregular consumers, each user that becomes a prosumer stops impacting on the energy tariff. The perverse effect of regular consumers that subsidize illegal energy supply is immediately reduced, independently of the number of PV systems installed. This fact may also reduce the price of energy for all the consumers in a specific concession area. Although relevant economic benefits can be noticed only with a significant reduction of non-technical losses, the inclusion of prosumers has long-term effect on the distribution system because the PV systems can generate electricity for 25 years with considerable reliability and do not use to need much maintenance.

The distributors may also reduce their financial losses if the current non-technical losses are above the regulatory limit imposed by ANEEL. In that case, the amount of energy over the limit is paid by the DU and directly affects its results. Moreover, the reduction of non-technical losses can also reduce the necessity of interventions and investment in the grid caused by illegal connections.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Non-Technical Losses LV Reduction (GWh)	311.778	233.833	155.889	62.356	25.486	158.607
City Non-Technical Losses LV Reduction (%)	100%	75.0%	50.0%	20.0%	8.2%	50.9%
Risky Areas Non-Technical Losses LV Reduction (%)	12.1%	9.0%	6.0%	2.4%	1.0%	6.1%
Concession Area Non-Technical Losses LV Reduction (%)	5.4%	4.1%	2.7%	1.1%	0.4%	2.8%
Number of Required Systems	106,920	80,190	53,460	21,384	8,740	54,392
25 years of Net Economic Benefit x R$ 1,000 (x € 1,000)	2,430,849 *675,236*	1,756,218 *487,838*	1,170,812 *325,226*	450,480 *125,133*	176,826 *49,118*	1,191,230 *330,897*
25-Years Economic-Benefit / 25-Years Total Cost	2.45	2.33	2.33	2.21	2.11	2.33

Table 4.1 - Benefits of DG insertion in different scenarios in a specific location

Scenario 5, for example, supposes a reduction of non-technical losses of 8.2% in the area of Belford Roxo. The amount of losses avoided by the introduction of DG would represent 1% of all low-voltage commercial losses in risky areas and 0.4% in all the concession area of the DU. That amount could generate a net economic benefit of more than R$ 176 million in 25 years, around € 49 million (the increase in energy price is not included). That benefit already considers the cost of installing and maintaining the systems for 25 years. The installed capacity of 22,374 kW, provided by 8,740 PV systems installed on the roof of residences, would provide the equivalent energy.

If the reduction achieves 20%, bringing the current level of non-technical losses assumed in the simulations from 73.4% to 53.4%, R$ 450 million (~ € 125 million) in losses would be avoided. Assuming the total consumption in the concession area to be stable along 25 years, the reduction of commercial losses would represent 2.4% lower levels in risky areas and 1.1% of the whole low-voltage consumption of LIGHT S.A. The economic benefit increases until the unlikely limit of around R$ 2.4 billion (~ € 667 million) if the non-technical losses are eliminated.

The hypothetical benefit generated by the reduction of commercial losses in a city with around 3% of the consumers of the DU is relevant. It brings a first impression about the potential of DG to provide gains to low-voltage consumers and companies, in particular, the generation based on the significant solar radiation available in the country. Further discussion will be held along this chapter.

Risky regions of the concession area

In a similar way to the results of Belford Roxo, Table 4.2 shows the simulations for all of the risky regions, which represent almost 45% of all low-voltage non-technical losses in the concession area. The figures gain a much higher scale, as expected when the universe of analysis is an illegal supply of more than 2,585 GWh per year.

The study aims to contribute to evaluate the benefits that DG can offer to low-income citizens. In the case of the concession area taken as a reference, the risky areas represent a significant contribution to the commercial losses (almost 45% of the total) and the major part of the population of these areas live with low earnings. The simulations focus on that share of losses and assume that the rest of the non-technical losses could be reduced by other methods already mentioned in this study.

	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Non-Technical Losses LV Reduction (GWh)	2585.795	1292.897	517.159	258.579	129.290	232.908
Risky Area Non-Technical Losses LV Reduction (%)	100%	50.0%	20.0%	10.0%	5.0%	9.0%
Concession Area Non-Technical Losses LV Reduction (%)	44.9%	22.5%	9.0%	4.5%	2.2%	4.0%
25 years of Net Economic Benefit x R$ 1,000 (x € 1,000)	20,900,777 *5,805,771*	10,080,388 *2,800,108*	4,032,155 *1,120,043*	1,942,077 *539,466*	971,039 *269,733*	1,749,272 *485,909*
25-Years Economic-Benefit / 25-Years Total Cost	2.59	2.45	2.45	2.33	2.33	2.33
Number of Required Systems	886,761	443,380	177,352	88,676	44,338	79,873

Table 4.2 - Benefits of DG insertion in different scenarios in risky regions of the concession area

Taking into account the high socioeconomic complexity of the concession area and its historically high level of commercial losses, Scenario 7 is unlikely to happen and it is presented to establish the maximum limit of economic benefit. The total elimination of losses in risky areas would avoid the irregular supply of more than 2,585 GWh per year and generate almost R$ 21 billion in 25 years (~ € 5.83 billion). Moreover, scenarios 8 and 9 are presented as a reference to the potential economic benefit that DG could generate and require the installation of more than 100,000 residential PV systems.

Scenario 10 simulates a reduction of 10% in the losses of risky areas, which represents a significant reduction of 4.5% in all the non-technical losses of the DU. The reduction requires an investment of R$ 1.11 billion (around € 308 million) to install the PV systems. On the other hand, the net economic benefit (which already discounts the costs of installation and maintenance for 25 years) would achieve almost R$ 2 billion (~ € 556 million). This amount would generate a reduction in the average energy tariff.

Scenario 11 represents approximately half of the impact because the simulation considers almost all directly proportional variables. Even a 5% reduction in risky areas could generate almost R$ 1 billion (€ 278 million) of benefit in 25 years.

Finally, Scenario 12 simulates an impact particularly interesting from the point of view or the DU. Non-technical losses above the limit of 36.06%, determined by ANEEL, are paid by the DU because the amount subsidized by regular consumers is limited. Because of that, the company is interested in respecting the Regulator to avoid financial losses. In the case of reducing the current commercial losses from 39.63% to 36.06%, the contribution of risky areas, which represents around 45% of the commercial losses, would require an investment of R$ 999.8 million (~ € 278 million) in the installation of PV systems. Although the investment is significant, the DU could avoid losses of almost R$ 1.75 billion (~ € 486 million) in 25 years. The recovered energy in 25 years represents more than 2 times the required investment. The spending in other methods to reduce commercial losses in the rest of the concession area is not accounted in this study.

Figure 4.1 shows in light blue the available data about non-technical losses in the concession area of LIGHT. The lines of the graph beginning in June 2015 are rough projections of non-technical losses reduction depending on the total amount invested in purchasing and installing PV systems in consumers that currently are illegal consumers. The costs are the ones assumed in Scenarios 9 to 12 (maintenance not included). They consider that the total amount of consumption and commercial losses do not increase over the years. Each line projects values of non-technical losses that could be reached if the investments are repeated every year until June 2021. The level of commercial losses would vary from 18.26% (Scenario 9) to 34.29% (Scenario 11) in the end of the projected period.

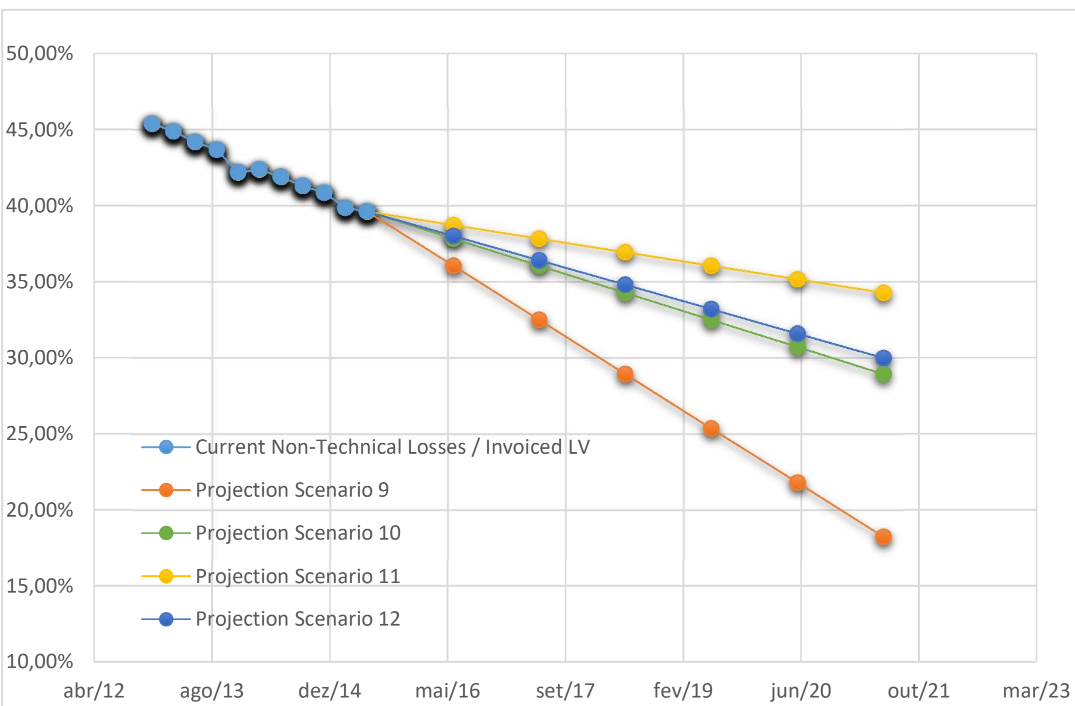

Figure 4.1 - Projections of commercial losses reduction depending on different Scenarios

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The results show that distributed generation may be considered an alternative to reduce non-technical losses, especially in areas where other methods are not effective. The insertion of DG can generate benefits that are much bigger than the initial investment in the long term. Besides that, if an irregular consumer becomes a “prosumer” it is likely that he or she would not connect irregularly again, at least during the period that the PV system is supplying all his or her needs.

The traditional methods usually applied to avoid irregular consumption are focused on avoiding the theft of energy. They may be effective in many situations, but low-income citizens are highly sensitive to the socioeconomic changes. If family earnings are reduced because of an economic crisis or unemployment, for example, the irregular connections may raise again in areas where existing methods for reduction commercial losses were already applied. In the case of distributed generation, in theory, even if the families stop paying the loan used to buy the PV systems, the energy used by them keeps being generated and the DU does not need to buy energy from another generator to supply them (this fact needs a legal analysis that is not considered by this research).

The risky areas are a challenge for the operation teams of distributor companies and for the combat energy theft. It is a highly complex social issue for the Brazilian society, the support of governmental institutions, including law enforcement, is essential, and it would be necessary also to make the insertion of DG possible. However, the installation of PV systems has some characteristics that may increase the acceptance by the population. The creation of prosumers give the users a new role in the power system and may turn the citizens aware of the contribution that PV systems generate to the communities. The communities could even organize cooperatives to promote the efficiency division of the energy among the members. If the impact of the systems in the families’ budget is smaller than the energy bill and other potential benefits are clear to the consumers, the acceptance can be higher than other methods that aim to avoid theft.

Technical and managerial methods can be seen by the population just as ways to make disconnection easier without any direct benefit for the consumers [43]. It is reasonable to look for a market in which everyone consumes energy legally. Social campaigns have helped to show that energy theft is a crime in Brazil and illegal connections cause damage. Despite of all the effort already done using the traditional methods, even if they include new technological solutions, the non-technical losses are still quite high in certain locations of Brazil. It requires continuous efforts from companies and the Government in order to tackle the problem. LIGHT itself has made significant progress in certain locations to reduce non-technical losses, with initiatives like the “Área Perda Zero (APZ)” (Zero-Loss Area) that focus on areas with high indexes of theft and defaults, but the total commercial losses keep being significant.

The initial investment to install many PV systems may become a barrier because it requires a huge amount of money. Considering that, loans are required to make feasible that consumers and distributors invest in DG. The discussion about the financing aspects is held in the next topic of this study.

4.1.2 Financing aspects

The spread of distributed generation depends on the offer of affordable loans. In the specific case of systems with photovoltaic technology, the initial investment represents the major part of the costs. When the analysis considers only the market share of low-income citizens, the viable possibilities of financing families are very narrow.

The item 3.2.4 of this document presents alternatives to finance distributed generation in low-income communities. The massive development of PV systems requires a huge investment and it is assumed that the main beneficiaries (consumers) would support the major part of it. The fixed monthly installments would substitute the energy bill. If the consumers increase the consumption above the limit originally planned to size the system, they would pay the additional consumed energy.

The average residential consumption of 243 kWh per month (see Table 3.17 for more details) generates an energy bill[20] of R$ 159.87 per month (~ € 40). If low-income consumers fulfill some requirements defined in the law[21], they pay a cheaper bill because they can benefit from the Electrical Energy Social Tariff (“Tarifa Social de Energia Elétrica”). In this case, the consumer would pay R$ 115.12 per month (~ € 32). The discount depends on the amount consumed and the tariff is cumulatively calculated according to Table 4.3.

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[20] Energy bill calculated using the energy bill simulator offered by LIGHT S.A. on the internet. Simulador de Conta – Light. Consulted on April 2017. Available at: http://www.light.com.br/para-residencias/Simuladores/conta.aspx

[21] Brazilian laws that regulate the Electrical Energy Social Tariff (“Tarifa Social de Energia Elétrica”): Lei nº 12.212, de 20 de janeiro de 2010 e pelo Decreto nº 7.583, de 13 de outubro de 2011

Monthly Consumption Portion (MCP)	Discount
MCP <= 30 kWh	65%
30 kWh < MCP <= 100 kWh	40%
100 kWh < MCP <= 220 kWh	10%
220 kWh < MCP	0%

Table 4.3 - Electrical Energy Social Tariff discounts according to the portion of energy[20]

The average monthly energy bills, with and without the reduction provided by the Social Tariff, called *social bill* from now on, are the references to evaluate the simulated loans. The following discussion compares the energy bill with the monthly installments presented in topic 3.2.4. Each hypothetical loan simulation has a different cost impact to the consumer. It is necessary to register that the discount rate of Brazil is historically high and influences the interests offered in the market.

<u>Retail price</u>

The first loan presented in this study considers the retail price for the PV system and a loan available to residential consumers in Brazil. The high-interest rate and the five-years-length loan generate installments with high value. The low-income consumers would need to pay R$ 437.15 (~ € 121) every month for five years. That value represents approximately 20% of the monthly average *per capita* wage (R$ 2,249 / € 625), it is almost three times bigger than the average monthly bill and near four times more expensive than the social bill. After the loan is paid, the consumer would keep spending around R$ 160 (€ 44.4) per year of maintenance. This cost is too heavy for the low-income families and could be even heavier if the monthly earnings are smaller than the one considered in this study.

After that, two simulations based on interests available for small businesses and small rural producers, which are not currently available for residences, result in monthly installments of R$ 240.23 (€ 66.73) for ten years and R$ 143.09 (€ 39.75) for 20 years, respectively. In both cases, the users would need to spend R$ 160 (€ 44.4) per year of maintenance after the loan finishes. The first one generate quotas 50% higher than the average energy bill and affects families` budget. The last case presents an interest rate much lower than the one usually available for a natural person and a longer loan period. Because of that, the consumers would pay 10% less than the regular energy bill, but beneficiaries of the social tariff would pay almost 25% more than the expected energy bill for 20 years. The fixed installments represent around 6% of the earnings of families in Belford Roxo and could protect consumers from future energy raises. This simulation presents a result that some families can realize as money savings, but just for those without social bills.

The effects of a reduced interest rate and DU investment over the loan, if analyzed separately, generated similar results. The installments of R$ 137.31 (€ 38.14) and R$ 132.04 (€ 36.68), respectively, would be paid for 25 years and already include maintenance. If both reductions are considered in the retail price of the PV system, the installments are reduced to R$ 123.58 (€ 34.33), close to the average social bill and more than 20% lower the regular simulated bill. The effect of both reductions has the potential of attracting a broader range of consumers, including the ones who pay the social tariff.

Wholesale price

The retail price of the PV systems is suitable for individual acquisitions. As already shown, lower interests and DU support for part of the cost may encourage consumers to become prosumers. However, it is reasonable to consider that massive insertion of DG in areas with high levels of non-technical losses would require a wide planning. The effectiveness of the plan would probably require actions joining DU, government, and communities. In this case, the acquisition of many systems at the same time for lower prices, usually found in the wholesale market, and many consumers would benefit from cheaper costs of equipment and installation. Considering that possibility, the following discussion considers the simulations for PV systems, including installation, bought for 20% less than the assumed retail price, in other words, the cost would reduce from R$ 16,690 (€ 4,636) to R$ 13,352 (€ 3,709). The total maintenance does not vary.

The first calculation considers a current interest rate available for small rural producers and small businesses. The discount considered in the price of the PV system allowed monthly installments of R$ 123.04 (€ 24.18), very similar to the lowest value found for systems bought by the retail price and already viable for a significant number of low-income consumers.

Lower interest rates and DU investment reduce from 6% to 8% the previous installments, respectively. When both reductions are included in the simulation, the cost for the user is significantly affected. The installments decrease from R$ 123.04 (€ 34.18) to R$ 106.29 (€ 29.53). This quota represents less than 5% of the monthly *per capita* wage of the city of Belford Roxo and 11.3% of the minimum monthly wage in Brazil (R$ 937 / € 260.28)[22]. Moreover, it is almost 8% less than the social tariff for the same consumption.

Finally, in a hypothetical condition that includes a reduction of 30% over the PV system retail price, a heavily subsidized interest rate, and DU investment, monthly installments could be reduced to R$ 78.27 (€ 21.74). This simulation exemplifies an optimist result that depends on factors that are far from the current conditions available in the Brazilian market. However, it shows that are various possibilities that can reduce the cost of PV systems to low-income consumers.

4.1.3 Final considerations

The last scenario, related to the reduction of non-technical losses eliminates 1.6% of the total LV electricity irregularly supplied in the concession area, which means a reduction of the current index from 39.63% to 38.03%. This would require the installation of 31,657 PV systems. The magnitude of that amount can be compared to the current situation of DG in Brazil. In April 2017, the installed capacity of distributed generation achieved 106,782.84 kW in Brazil and it is divided as shown in Table 4.4.

Consumer Type	Number of Consumers	Installed Power (kW)
Commercial	1,492	39,963.96
Public Lightning	6	7152
Industrial	211	22,653,66
Public Sector	83	3,345.80
Residential	7,743	32,216.89
Rural	195	8,003.39
Public Services	26	527.62
TOTAL	9,756	106.782.84

Table 4.4 - Consumers with distributed generation in Brazil[23]

[22] Brazilian law that regulates the minimum monthly wage. Lei nº 13.152, de 29/7/2015. Available at: http://www.planalto.gov.br/ccivil_03/_ato2015-2018/2015/lei/l13152.htm

[23] Data about DG in Brazil. ANEEL - Unidades Consumidoras com Geração Distribuída. Available at: http://www2.aneel.gov.br/scg/gd/GD_Classe.asp

There are only 7,743 residential systems of DG in Brazil, which are not exclusively based on photovoltaic systems, and Scenario 12 requires four times that amount of systems. The total only increases in the other scenarios. Nevertheless, the development of DG in Brazil is recent, the first specific regulation was created in 2012 and amended in 2015. The number of prosumers increased around 400% in 2016 and the Brazilian Government created a program called ProGD to develop distributed generation, especially based on PV, that aims to generate investments of R$ 100 billion (~ € 28 billion) [24] until 2030. The Ministry of Mines and Energy (MME) installed a PV plant over the roof of its building in the capital of Brazil, Brasilia, at the end of 2016 to promote the solution.

The range of monthly installments calculated from R$ 123.58 (€ 34.33) and R$ 437.15 (€ 121.43) for the retail price of the PV system, and between R$ 78.27 (€ 21.74) and R$ 123.04 (€ 34.18) for the wholesale market, clarifies that the current residential loans available to the acquisition of this kind of systems are not affordable for low-income citizens. The loan conditions are one of the main barriers to the DG sector in Brazil today. However, the financing results also show that there are feasible alternatives that, if deeply analyzed and negotiated, can promote the reduction of non-technical losses by the development of DG. There is more than one simulation that provides installments that would make electricity represent less than 10% of household expenditures, which represents an affordability benchmark [44]. Besides that, the regulations may also improve the attractiveness of DG to low-income citizens, allowing them to sell the energy they generate for prices higher than they buy for example, as shown in the case study of topic 2.3.2. The Brazilian regulations require that distributors spend 0.5% of their net incomes in energy efficiency projects, which means around R$ 500 million (~ € 139 million) in investments per year in the country. Part of this value could finance DG and reduce technical losses.

[24] ProGD - Programa de Desenvolvimento da Geração Distribuída de Energia Elétrica Available at: http://www.mme.gov.br/web/guest/pagina-inicial/outras-noticas/-/asset_publisher/32hLrOzMKwWb/content/programa-de-geracao-distribuida-preve-movimentar-r-100-bi-em-investimentos-ate-20300

The development of DG to reduce non-technical may also contribute to the power system and to the society in different ways. The following list presents examples of additional benefits, some of them already mentioned in the study:

- In theory, even if the families stop paying the loan used to buy the PV systems, the energy used by them keeps being generated and the DU does not need to buy energy from another generator to supply them. The application of this hypothesis would need legal treatment, which is not evaluated by this study.
- The duration and frequency of supply interruptions can be reduced because the number of illegal connections diminishes. This fact improves the quality of the service for the consumers and reduces costs of the DU.
- It can avoid or postpone the construction of long transmission lines that connect distant big power plants to the loads. These lines have a high environmental impact and are difficult to be approved by environmental agencies.
- It can contribute to diversify the energy matrix with renewable resources and increase the reliability of the power system, especially during drought periods. The current environmental restrictions to the creation of hydraulic power plants with big dams have changed the characteristics of new projects. Because of that, it is expected that generation expansion in Brazil during the next decades, which is currently highly dependent on hydraulic power plants, will be based on renewable resources that maintain the supply during drought periods.
- If DG is affordable for low-income classes, they are not forced to buy more expensive electricity provided by the DU and can avoid energy poverty. The current market conditions in Brazil make DG reachable only for upper classes that can benefit from lower energy prices provided by DG. In the long-term, this scenario could make energy cheaper for richer consumers, and more expensive for low-income citizens because they would support increasing costs of energy supplied by DUs [8].
- The insertion of DG may contribute to reduce the visual pollution usually caused in regions with a great number of illegal connections.

- Potential local job and business creation related to the maintenance of the generation systems.
- The massive insertion of DG in a specific location with a high level of commercial losses could contribute to make citizens of the community and the rest of the population aware of the benefits of the project. This fact could accelerate the accession of new consumers and reduce in electricity misuse.
- The creation of energy cooperatives, already allowed by the current regulation, contributes to the establishment of intercommunity co-ordination and social entities related to the generation of energy. It also may increase the confidence of new consumers to become prosumers. The benefits of collective generation can be shared among all the members of the cooperatives [43].

The technical potential to reduce non-technical losses and generate long-term benefits, and the possibility to make financing of DG viable even in low-income communities, reinforce a positive answer to the first question proposed at the beginning of this chapter. Distributed generation can be considered an alternative to reduce non-technical losses in areas where the other methods are not effective. It is possible to create conditions to transform illegal consumers into regular prosumers and the discussion presented by financing may contribute to make DG affordable for low-income consumers (second question). Finally, the socioeconomic improvements briefly mentioned along this study, as in the case studies, exemplify some of other benefits that DG can create if properly inserted in locations with lower socioeconomic status.

5. BUDGET

Chapters 3 and 4 present the cost forecast to implement the projects, the simulations about loans to finance equipment and maintenance, and the potential benefits generated by the projects.

The budget to develop this study is concentrated especially on hours of work of the author from the start of this idea until the construction of this document. Laptop, software license, and news subscription complete the list of costs.

5.1. Labor cost

Table 5.1 details the labor cost of the study.

Item	Wage per hour	Hours	Total
Theme definition	€ 20	80	€ 1,600
Research	€ 20	500	€ 10,000
Writing	€ 20	360	€ 7,200
TOTAL	-	940	**€ 18,800**

Table 5.1 - Labor cost

5.2. Material cost

Table 5.2 presents the cost of material used to develop the study. The budget considers that amortization period for laptop and software lasts three years. The study took six months to be developed.

Item	Cost per item	Number of items	Amortized cost
Laptop (ASUS Zenbook®)	€ 600	1	€ 100
Microsoft Office®	€ 80	1	€ 13
News subscription per month	€ 20	6	€ 120
TOTAL	-	8	**€ 233**

Table 5.2 - Material cost

5.3. Total budget

Table 5.3 summarizes the total budget of the study.

Item	Cost
Labor cost	€ 18,800
Material cost	€ 233
TOTAL	**€ 19,033**

Table 5.3 - Total budget of the study

6. ENVIRONMENTAL IMPACT

This chapter describes how the impact of the insertion of distributed energy resources (DER) affects the environment, in particular, the residential photovoltaic systems. Positive and negative changes that the project could generate are crucial to evaluate its viability.

The operation of a PV system is considered a zero-emission electricity generation. Besides that, its Life-Cycle Analysis (LCA), which evaluates the impact of a product from cradle to grave, also indicates that the emissions are much smaller than the emissions from conventional power plants, in particular, those based on fossil fuel. Its life cycle is also safer than conventional energy sources, a fact that benefits people working in activities related to photovoltaics [45].

Another positive effect of the distributed generation based on PV is the reduction of greenhouse-gas (GHG) emissions. This study presents several scenarios to estimate the reduction of non-technical losses using PV systems. Table 6.1 and Table 6.2 present the avoided emissions of some gases, including non-methane volatile organic compounds (NMVOC), and carbon dioxide equivalent (CO_2eq) for each of scenarios detailed in topic 3.2.3. The estimation of avoided emissions is based on the conventional electricity generation of Brazil in 2016[25].

Belford Roxo

Emissions	Tones (t) of Emissions per GWh	Scenario 1 (t)	Scenario 2 (t)	Scenario 3 (t)	Scenario 4 (t)	Scenario 5 (t)	Scenario 6 (t)
CO_2	79.3182	24,729.64	18,547.23	12,364.82	4,945.93	2,021.50	12,580.44
CO	0.0638	19.89	14.92	9.94	3.98	1.63	10.12
CH_4	0.0036	1.13	0.85	0.56	0.23	0.09	0.57
NOx	0.3517	109.64	82.23	54.82	21.93	8.96	55.78
N_2O	0.0010	0.33	0.25	0.16	0.07	0.03	0.17
NMVOC	0.0034	1.05	0.79	0.53	0.21	0.09	0.54
CO_2eq	79.7194	24,854.71	18,641.03	12,427.35	4,970.94	2,031.72	12,644.07

Table 6.1 - Avoided GHG emissions by PV systems insertion in different Scenarios - Belford Roxo

[25] Daily updates about the composition of the Brazilian energy matrix and GHG emissions. SEEG Monitor Elétrico. Available at: http://monitoreletrico.seeg.eco.br/

Risky regions of the concession area

Emissions	Tones (t) of Emissions per GWh	Scenario 7 (t)	Scenario 8 (t)	Scenario 9 (t)	Scenario 10 (t)	Scenario 11 (t)	Scenario 12 (t)
CO_2	79.3182	205,100.64	102,550.32	41,020.13	20,510.06	10,255.03	18,473.87
CO	0.0638	164.96	82.48	32.99	16.50	8.25	14.86
CH_4	0.0036	9.35	4.67	1.87	0.93	0.47	0.84
NOx	0.3517	909.32	454.66	181.86	90.93	45.47	81.90
N_2O	0.0010	2.71	1.36	0.54	0.27	0.14	0.24
NMVOC	0.0034	8.74	4.37	1.75	0.87	0.44	0.79
CO_2eq	79.7194	206,137.95	103,068.98	41,227.59	20,613.80	10,306.90	18,567.30

Table 6.2 - HG emissions by PV systems insertion in different Scenarios - DU concession area

Depending on the scenario, the insertion of DER in Belford Roxo could avoid emissions between 2,031.72 and 24,854.71 tons of CO_2eq per year. In the case of the risky areas, the values vary from 10,306.90 and 206,137.98 tons of CO_2eq per year. The tables also detail the reduced emissions of CO_2 (carbon dioxide), CO (carbon monoxide), CH_4 (methane), NOx (nitrogen oxides), N_2O (nitrous oxide) and NMVOC (*non-methane volatile organic compounds)* for each scenario. These figures confirm the positive impact of PV systems on the environment.

Table 6.3 details the amount of electricity generated by source in 2014, 2015 and 2016. In comparison to the previous two years, the participation of thermal by fossil fuels has reduced significantly in 2016. In 2014 and 2015, the generation by fossil fuels was more than 50% bigger than in 2016. Mostly because of that, emissions reached 119.88 tons of CO_2eq/GWh in 2015 and 131.02 tons of CO_2eq/GWh in 2015, the highest levels since 2009. The lack of rain in the country compared to previous years was the main cause of that phenomenon. The estimation of avoided emissions would be even higher if considered the conventional generation in 2014 and 2015.

Source	Electricity Generation 2016 (GWh)	Electricity Generation 2015 (GWh)	Electricity Generation 2014 (GWh)
Hydraulics	407,244.7	381,785.9	392,193.0
Thermal by fossil fuel	69,003.3	107,593.1	114,437.7
Eolic	30,262.0	20,808.1	9,439.8
Nuclear	15,763.2	14,733.2	15,378.5
Thermal by renewable source	2,480.6	2,275.1	1,711.8
Other	12,500.2	10,409.1	7,570.6
TOTAL	537,253.9	537,604.5	540,731.3

Table 6.3 - Electricity generation by source in Brazil - 2016, 2015 and 2014

Moreover, the installation of PV systems on the roof of houses and apartments generate other positive and negative effects:

- This study considers only the installation of small-scale systems over the roof of residences that do not require land use.

- The installation of PV panels may degrade the architectonic characteristics of houses and buildings. The projects must consider that aspect to avoid visual pollution. On the other hand, the introduction of PV systems may reduce the bad visual aspect of illegal connections to the grid, as seen in Figure 6.1.

Figure 6.1 – Irregular connections in Rio de Janeiro State. Adapted from O GLOBO[26]

- The proper maintenance of PV panels requires water use. Depending on the weather characteristics of the location, the amount of water may become relevant. This fact may affect the environment and raise the owners` water bill.

- If many PV systems are installed at the same time in a specific region, the presence of service vehicles and installation teams may temporally disturb neighbors.

[26] News about energy theft. O GLOBO. Available at: http://oglobo.globo.com/economia/tarifa-especial-da-light-tera-desconto-de-70-10708139

7. CONCLUSION AND FURTHER RESEARCH

7.1. Conclusions

The study has presented a contribution to evaluate the benefits that distributed generation can create for low-income citizens. First, it has summarized general economic benefits that are found in the literature and it has detailed the impacts generated by case studies in different countries for low-income users. After that, the study has focused on the technical benefits created by DG and it has developed a case study about the financial impact that electricity non-technical losses generate in Brazil. It has also proposed a method to reduce these losses by the insertion of DG in low-income communities, which can provide economic and technical benefits. It includes a discussion about conditions regarding projects financing.

The research about economic benefits showed that the introduction of DG is responsible for some positive effects to low-income consumers.

- The installation of DG generates earnings to low-income communities and improve their socioeconomic conditions. It depends on the regulation of the location.
- It contributes to the creation of cooperatives and social entities related to the generation of energy. The economic benefits can be shared between the users and improve the infrastructure.
- It creates temporary and permanent jobs since the installation of the project.
- The reliability and quality of supply provided by DG can be higher than the service provided by distribution utilities. This fact benefits small business and may contribute to increase the number of clients. Moreover, it can be an important backup during interruptions of supply from the electricity grid.
- Consumers have access to cheaper energy.
- Reduction of accidents and air-pollution caused by fossil fuels used in households.

Regarding the technical benefits, the developed case study shows that the financial impact of non-technical losses in Brazil is relevant and it has not improved over the last ten years. Moreover, it indicated that the distributed generation could be considered an alternative solution to reduce these losses and generate other technical and economic benefits in low-income communities, which are detailed in Chapter 4.

- The introduction of DG in areas with high levels of commercial losses can be a more effective way of reducing losses than the traditional methods. It can also reduce the chances of a former irregular consumer relapse on the same practice in the case of socioeconomic instabilities. Once the users generate their own energy, they are less susceptible to steeling it.
- The current illegal users can be transformed in “prosumers” and reduce the electricity bills for the regular consumers and distributors that currently subsidize the illegal supply.
- The quality of the supply may improve and reduce the maintenance costs of the distribution utilities. If number of illegal connections is reduced, the frequency and the duration of supply interruptions can be reduced.

The massive insertion of DG to reduce commercial losses in low-income communities, including risky areas, depends on loans that are affordable to that population. Government, distributors and society should work together in integrated actions to the make the proposed solution feasible.

7.2. Suggestions for Further Research

The study presented scenarios of non-technical losses reduction and their respective economic impact. Among other assumptions, the calculations, assumed the average residential capacity of generation using photovoltaic systems, the average electricity consumption, and the average non-technical losses in a specific location of Brazil. It would be interesting to evaluate the results using actual data from residences of a low-income location, which could be provided by a distribution company and verified *in loco*. It would be also interesting to evaluate the effect of the development DG in the quality of the supply of low-income areas, which could have current high level of non-technical losses and/or be difficult to access by maintenance teams.

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