UNIVERSIDADE FEDERAL DO PARANÁ

ADRIANO CARDON CASTRO

ANALYSIS OF ENERGY AND SUSTAINABILITY IMPACTS OF ELECTRIC VEHICLES ON THE ISLAND FERNANDO DE NORONHA

CURITIBA

2021

ADRIANO CARDON CASTRO

ANALYSIS OF ENERGY AND SUSTAINABILITY IMPACTS OF ELECTRIC VEHICLES ON THE ISLAND FERNANDO DE NORONHA

Monografia apresentada no Curso de Especialização do Departamento de Engenharia Elétrica da Universidade Federal do Paraná como requisito parcial para obtenção do título de Especialista em Eficiência Energética e Geração Distribuída.

Orientador: Prof. Dr. Alexandre Rasi Aoki
Co-orientadora: M.Sc. Thaís Marzalek Blasi

CURITIBA
2021

MINISTÉRIO DA EDUCAÇÃO
SETOR DE TECNOLOGIA
UNIVERSIDADE FEDERAL DO PARANÁ
PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO
CURSO DE PÓS-GRADUAÇÃO EFICIÊNCIA ENERGÉTICA E GERAÇÃO DISTRIBUÍDA - 40001016117E1

TERMO DE APROVAÇÃO

Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação EFICIÊNCIA ENERGÉTICA E GERAÇÃO DISTRIBUÍDA da Universidade Federal do Paraná foram convocados para realizar a arguição da Monografia de Especialização de ADRIANO CARDON CASTRO intitulada: ANALYSIS OF ENERGY AND SUSTAINABILITY IMPACTS OF ELECTRIC VEHICLES ON THE ISLAND FERNANDO DE NORONHA, que após terem inquirido o aluno e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

A outorga do título de especialista está sujeita à homologação pelo colegiado, ao atendimento de todas as indicações e correções solicitadas pela banca e ao pleno atendimento das demandas regimentais do Programa de Pós-Graduação.

Curitiba, 28 de Setembro de 2021.

Alexandre Rasi Aoki
Presidente da Banca Examinadora

Prof. Dr. Alexandre Rasi Aoki
PROFESSOR DO DEPTO DE ENG. ELÉTRICA
Matrícula UFPR 200437

Prof. Dr Rogers Demonti
Servidor Docente do Depto. de Engenharia Elétrica
Matrícula: UFPR 201875

Rogers Demonti
Avaliador Interno (UNIVERSIDADE FEDERAL DO PARANÁ)

Prof. André A. Mariano, Ph.D.
Depto. Engenharia Elétrica - UFPR
Mat.: 202366 / 1847807

André Augusto Mariano
Avaliador Interno (UNIVERSIDADE FEDERAL DO PARANÁ)

“I never lose. I either win or learn”

Nelson Mandela

ACKNOWLEDGMENT

To my wife Adriana and my son Gianluca for their patience to listen to my worries and to help me in the tough moments.

To my parents, Ana Maria and Aldo, for their love, assistance, and encouraging words all over my career.

To Prof. Dr. Alexandre Rasi Aoki, M.Sc. Thaís Marzalek Blasi, and Victor Lunet Alvares de Azevedo for the rich debates and several online meetings during this project.

To my colleagues in Renault Brazil and Renault France, for sharing their knowledge and contribution during several projects, especially Eric Guillon and Silvia Barcik with whom I have worked since 2015 in EV's world. Many thanks to all of you.

RESUMO

O uso eficiente de energia e a redução das emissões causadas por gases poluentes passaram a ser a agenda de sustentabilidade mundial entre governos, indústria e sociedade. O Acordo de Paris estabelecido em 2015 colocou em prática ações para diminuir a temperatura global e o Brasil se comprometeu a reduzir as emissões de gases de efeito estufa em 37% abaixo dos níveis de 2005 até 2025. Como o transporte e a geração de eletricidade emitem dois terços do CO_2 global, é crucial desenvolver novos sistemas sustentáveis de mobilidade para fazer frente a essas metas ambientais. A interação de veículos eletrificados e geração de energia usando fontes renováveis constitui uma área interessante para limitar a pegada de carbono, considerando uma abordagem poço-à-roda (*well-to-wheel*). Na ilha de Fernando de Noronha, reconhecida pela UNESCO como Patrimônio Mundial da Humanidade, o programa Noronha Carbono Zero proíbe novos veículos a combustão em 2022 e estabelece a proibição total até 2030. O objetivo deste estudo é realizar uma avaliação de mobilidade e a integração de geração de energia fóssil e solar com veículos elétricos a bateria com base no despacho da geração de energia, suas consequências no balanço energético, o custo total de propriedade e o impacto ambiental. Este trabalho compreende três fases: a primeira consiste em verificar os dados atuais de mobilidade como quilometragem anual, emissão de gases e consumo de energia, para avaliar a geração de energia elétrica, distribuição na infraestrutura da rede, consumo de energia e balanço energético. A segunda fase estuda o uso de veículos elétricos e gerenciamento de carga. A terceira fase inclui um roteiro de simulação para a inserção progressiva do veículo elétrico na Ilha de Fernando de Noronha com foco no balanço de emissões, geração de energia e custo total de propriedade. O *roadmap* proposto confirma que a substituição do veículo de combustão interna pelo elétrico é economicamente viável pela consequente expansão da geração de energia solar para 3,7 m^2 para cada veículo elétrico inserido na Ilha de Fernando de Noronha, o que representa um investimento de R$ 3850 para cada veículo e economiza 310 litros de Diesel por ano. Recursos energéticos como sistema de armazenamento de energia por bateria e planta de energia fóssil tornam-se necessárias para garantir a segurança e cumprir com os padrões de qualidade de energia.

Palavras-chave: Noronha Zero Carbono, Sistema de Energia Renovável, Mobilidade Sustentável, Custo Total de Propriedade, Análise Well-to-Wheel

ABSTRACT

Efficient use of energy and reduction of emissions caused by polluting gases became the world's sustainability agenda among Governments, industry, and society. The Paris Agreement established in 2015 put in place actions to decrease global temperature and Brazil committed to reducing greenhouse gas emissions by 37% below 2005 levels until 2025. As transport and electricity generation emits two-thirds of global CO_2, it is crucial to develop new sustainable mobility modalities to cope with these environmental targets. The interaction of electrified vehicles and energy generation using renewable sources constitutes an interesting area to limit carbon footprint considering a Well-to-Wheel approach. In the island of Fernando de Noronha, recognized by UNESCO as a World Heritage Site, the Noronha Zero Carbon program prohibits new combustion vehicles in 2022 and sets a complete ban by 2030. The purpose of this study is to perform a mobility assessment and the integration of fossil and solar energy generation with BEV based on energy generation dispatch, its consequences to energy balance, the total cost of ownership, and environmental impact. This work comprehends three phases: the first phase consists of verifying current mobility data as annual mileage, gas emission, and energy consumption, to evaluate electrical energy generation, distribution in grid infrastructure, power consumption, and energy balance. The second phase consists of studying electric vehicle usage, charging management, and cycling. The third phase includes a simulation for the progressive insertion of the electric vehicle in Fernando de Noronha Island focusing on emission balance, energy generation, and total cost of ownership. The proposed roadmap confirms that internal combustion vehicle replacement by electrical is economically feasible by consequent solar energy generation expansion to 3.7 m^2 for each electric vehicle added to Fernando de Noronha Island, this represents an investment of R$3,850 for each vehicle and it saves 310 liters of Diesel per year. Energy resources such as battery energy storage systems and fossil energy plants become necessary to respect safety and power quality standards.

Keywords: Noronha Zero carbon, Renewable Energy System, Sustainable Mobility, Total Cost of Ownership, Well-to-Wheel Analysis.

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF ABBREVIATIONS

AC	Alternating Current
ANEEL	Brazilian Electricity Regulatory Agency
ANFAVEA	National Association of Motor Vehicle Manufacturers
BEV	Battery Electric Vehicle
CO_2	Carbon Dioxide
CO_2-eq/km	Carbon Dioxide equivalent per kilometer
CONAMA	National Environnent Commission
DC	Direct Current
EPA	Environment Protection Agency
EPE	Brazilian Energy Research Office
EPRI	Electric Power Research Institute
EU	European Union
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GDP	Gross Product Domestic
GHG	Green House Gas
HEV	Hybrid Electric Vehicle
IBAMA	Brazilian Institute of Environment and Natural Resources.
ICE	Internal Combustion Engine
IPI	Industrialized Product Tax
kW	kilowatt
kWh	kilowatt-hour
LCA	Life Cycle Assessment
LFP	Lithium Iron Phosphate
NEDC	New European Driving Cycle
OECD	Organization for Economic Co-Operation and Development
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle
PV	Photovoltaic
R&D	Research & Development
SAE	Society of Automotive Engineers
SOC	State of Charge

TTW	Tank to Wheel
UC	Consumer Unit
UVAR	Urban Vehicle Access Restriction
V2G	Vehicle to Grid
WHO	World Health Organization
WTW	Well-to-Wheel

LIST OF SYMBOLS

d	Distance of the trip
E	Energy
Pcharge	Power drawn from the charging station
Q	Battery’s nominal capacity
SOC0	State of the charge at the beginning of the trip
t	Time

SUMMARY

1 INTRODUCTION

Annual global carbon dioxide (CO_2) emissions reached 43 gigatons in 2019, doubling over the past 50 years, and concentration levels in the atmosphere exceeded the 400 parts of million thresholds in 2016, a level that catastrophic impact on the environment is imminent (TESLA, 2019).

The efficient generation, distribution, and usage of electric power and transport have become major players in the world's sustainability agenda, as they are responsible for over two-thirds of CO_2 global emissions. The remaining third is mainly associated with the industry and building sectors (IEA, 2020a).

Governments, societies, and industries have established policies, incentives, and laws targeting a reduction of Greenhouse gases (GHG) emissions. In energy generation, despite improvements in renewable penetration and power plant efficiency, the world average carbon intensity of electricity generation remained flat mainly because coal-fired plants increased in Asia.

In the transport sector, to control air pollution in cities and avoid reaching dangerous health limits, European cities have implemented circulation restriction zones (UVAR – Urban Vehicle Access Restriction). Depending on local policy and air quality standards, vehicle circulation is limited to electrified vehicles (hybrid electric vehicles – HEV or plug-in hybrid electric vehicles - PHEV) or only Zero Emissions vehicles (battery-powered electric vehicles - BEV or fuel cells electric vehicles - FCEV). Another strategy to reduce air pollution is the circulation limitations during specific workdays in a week as implemented by the government in cities such as São Paulo (Brazil), Bogota (Colombia), and Mexico DF (Mexico).

Complementary to emission legislation, the United States, Brazil, Korea, Japan, China, and the European Community enforce programs to reduce vehicle energy consumption on the Corporate Average Fleet Economy (CAFE). Vehicle design, and performance evolve, embedding new features, lightweight material, low friction parts, and more recently toward partial or full-electric powertrain. In Europe, maximum fuel consumption in New European Drive Cycle (NEDC) standard cycle decreased from 130 gCO_2/km (5,6 liters of petrol/100km) in 2015 to 95 gCO_2/km (4,1 liter of petrol/100km) in 2021, an improvement of 27% (IEA, 2019).

Regulation (EU) 2019/631 sets new European fleet-wide CO_2 emission targets as a percentage from 2021, resulting 15% reduction from 2025 on and a 37.5%

reduction from 2030 on. One economically viable alternative to respect these targets is by increasing EV mix as they correspond to zero gCO_2/km.

Despite recent progress toward zero-emission mobility and BEV, global electric energy has been mainly generated by centralized non-renewable power plants (gas, oil, nuclear, coal), which results in the emission of carbon dioxide, ranging from 320 $kgCO_2$/kWh in Europe to 750 $kgCO_2$/kWh in China (CLIMATE ACTION TRACKER, 2020).

Actions in the electricity sector have a high priority as it directly enables the successful decarbonization of all other sectors moving from fossil source to electricity where possible.

1.1 CONTEXT

In 2001, UNESCO declared Fernando de Noronha Island in the Atlantic Ocean as a World Heritage. The island covers an area of 21 km^2 and is divided between the Fernando de Noronha Marine National Park and the Fernando de Noronha Environmental Protection Area.

With 3,000 inhabitants, the local economy is based on tourism. To conquer sustainable growth and protect flora, fauna, and marine life, the Island Administration incentives public actions to eliminate plastic bottles, reduce water and energy consumption supported by educational programs.

In January 2020, the ordinary law 16810/20 of Pernambuco State (PERNAMBUCO, 2020) determined that new entries of combustion vehicles in Fernando de Noronha are prohibited from August 2022 and combustion vehicles circulation is prohibited from August 2030 (Noronha Zero Carbon Program). The Island became the first place in Brazil to have a mobility policy focused on environment preservation by restricting fossil fuel fleet increase and replacing by BEV .

However, with an energy matrix relying primarily on Diesel fuel burned in generators to supply energy to the distribution network, a deeper analysis of the impacts of energy sourcing, transportation, and usage is necessary.

Electric energy on the island is sourced and managed by the power utility Companhia Elétrica de Pernambuco (CELPE). The generation system comprehends a thermal plant, named Tubarão, composed of five Diesel generators which consume

5.4 million liters of Diesel per year and dispatch 19.2 GWh/year (90% of electricity demand) (CELPE, 2019).

In addition, there are two solar plants named Noronha I and Noronha II, with 400 kW and 550 kW respectively, totalizing a generation of 1.37 GWh/year (10% of electricity demand). Recently a lithium-ion battery storage system of 1020 kWh was installed to reduce the intermittency effect of solar generation to the grid and to optimize the Diesel generation efficiency (NEOENERGIA, 2021) (MARINHO, 2019).

Questions from residents, media, and environmental organizations emerge about the impacts on the supply of electricity for BEV if emission reductions would be achievable, if the necessary investments would be available within the established deadlines, and if the environmental impacts would be positives.

1.2 OBJECTIVES

Considering the integration of mobility and electricity, this project brings elements to understand fundamentals issues and provides answers related to overall energy efficiency comparing BEV and ICE vehicles, and the main goal is to propose a roadmap focused on the achievement of sustainable Zero Carbon emissions in Fernando de Noronha Island.

Therefore, the specific objectives are:

- Assess vehicle fleet composition on Fernando de Noronha Island. The analysis will not include aerial, maritime nor agricultural modalities, since circulation restriction in Law 16810/20 excluded them.
- Analyze vehicle fleet gas emissions and fuel consumption, referencing a database supplied by public Government sources.
- Evaluate the energy demand and generation on the Island in terms of renewable and non-renewable. The generation system expansion with renewable sources as photovoltaic systems deserves a detailed study, as this remains a viable energy source to replace non-renewable matrix energy.
- Analysis of BEV usage, charging modalities, battery characteristics, and network impact.
- Propose a roadmap for the progressive adoption of BEV in Fernando de Noronha Island focusing on Well-to-Wheel (WTW) analysis, the total cost of ownership, and infrastructure investments.

1.3 JUSTIFICATIVE

There are more than 10,000 inhabited islands around the world and an estimated 750 million islanders. Most of this population relies on Diesel generators for their electricity production and spends a considerable percentage of their gross domestic product (GDP) on the import of fuels.

Renewable energy generation and management in isolated regions are growing steadily as declining costs and increasing performance is reached. Solar photovoltaic, electricity storage and control systems have become standard for these applications in developed and undeveloped countries (KEMPENER et al., 2015).

As the transport sector emits 24% of global CO_2, zero vehicle emissions mobility makes sense in most renewable energy system generation as this offsets Carbon footprint in the WTW analysis.

Considering the annual constant solar irradiation and low latitude, Fernando de Noronha Island has a geographical location that enables the deployment of solar panels, while it reduces the fuel consumption of Diesel generators.

This study integrates these two sectors, renewable energy generation, and mobility, to deploy an approach that combines technical and economic constraints and limitations in a feasible roadmap.

Expansion to the further application as small neighborhoods and cities is a near possibility, which opens opportunities for new businesses and technologies to support the adoption of renewable energy in a cost-effective approach for sustainable mobility.

1.4 STRUCTURE OF THE MONOGRAPHY

Five chapters divide this study, in addition to the introduction and conclusion. Chapter 2 introduces general aspects of sustainability, energy, and emission on a global basis. Chapter 3 describes electric vehicle insertion in the Global market, Energy Generation, and CO_2 impact. Chapter 4 presents a literature review from technical papers, from International Energy Association, Climate Watch publications, among others. Chapter 5 describes the application case in Fernando de Noronha, considering Geo-economics, Energy matrix, Noronha Zero Carbon program, and environmental legislation. Chapter 6 develops the methodology for BEV fleet increase and its impact on Energy, Emission, and economical benefits of mobility, and conclusion.

2 SUSTAINABILITY AND EMISSIONS

Sustainability means meeting one's own needs without compromising the ability of future generations to meet their own needs. Sustainability is not just environmental or ecological aspects of the atmosphere and development. It needs to include economic sustainability like availability of resources to communities to maintain their independence and meet their needs, and social sustainability as human rights and necessities are attainable by all people, who have access to resources to keep their families, communities healthy, and secure.

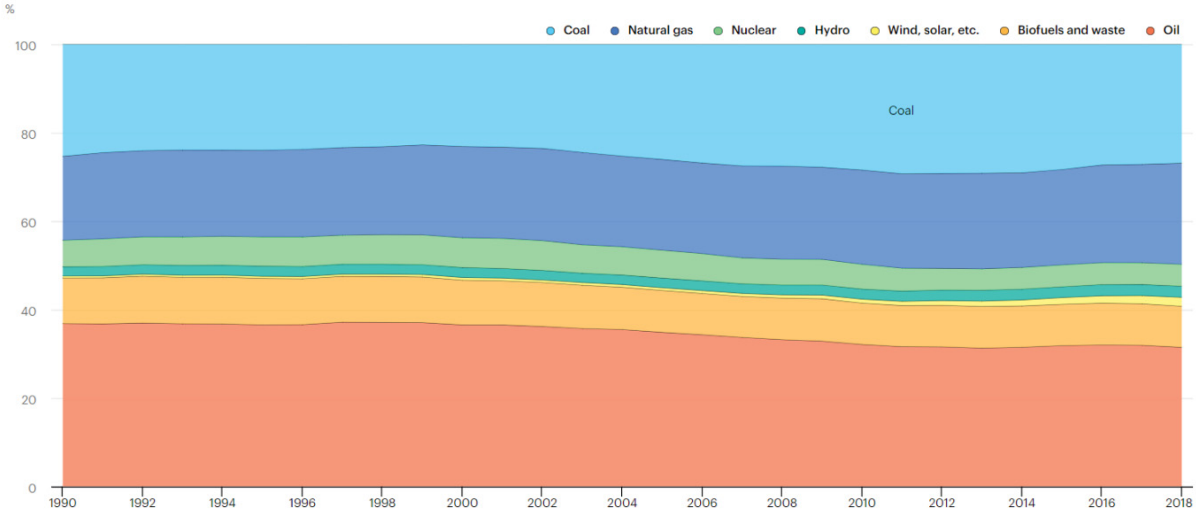
According to World Health Organization (WHO), between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year, from malnutrition, diseases, and heat stress. Reducing emissions of GHG through better transport, food, and energy-use choices can result in improved health, particularly through reduced air pollution (WHO, 2021).

Air pollution levels remain dangerously high in many parts of the world. WHO declares that nine out of ten people breathe air containing high levels of pollutants and WHO estimates that around seven million people die every year from exposure to polluted air.

According to the United States Environmental Protection Agency (EPA), observed climate change since the mid-20th century is a result of GHG from human activities. They are built up in the atmosphere and warm the climate, leading to changes to the atmosphere, on land, and in the oceans and they stay ten to hundreds of years after being released, with warming effects persisting for a long time. Worldwide, net emissions of GHG (Carbon Dioxide CO_2, Methane CH_4, Nitrous Oxide N_2 and Fluorinated gases F-gas) from human activities increased by 35 percent from 1990 to 2010. Emissions of carbon dioxide, which count for about three-fourths of total emissions, increased by 42 percent over this period.

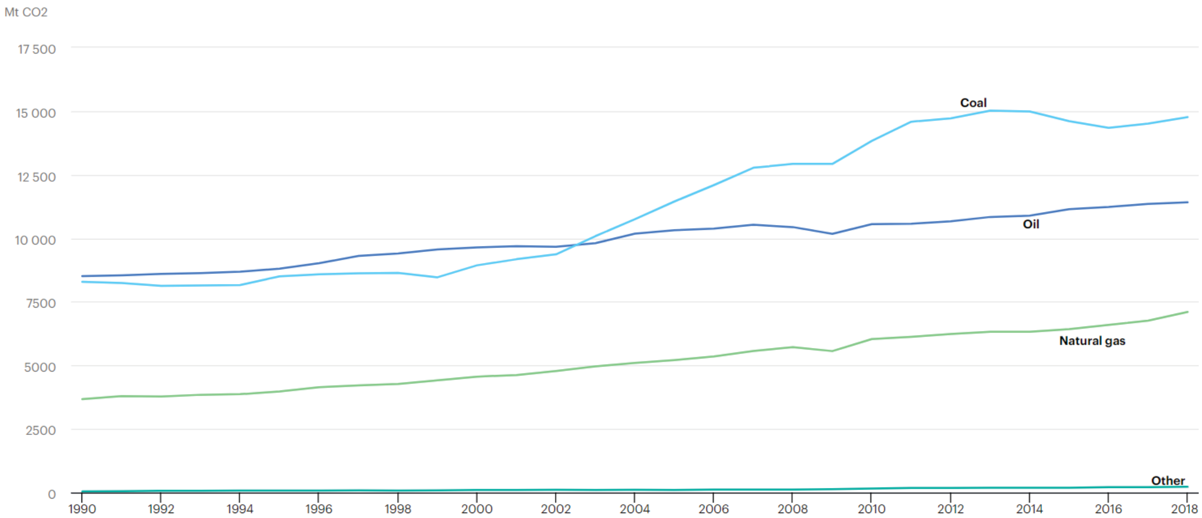
IEA (2020d) reports that in 2018 world energy amounted to 14.2 Gigatons of oil equivalent (oil 31.6%, natural gas 22.8%, coal 26.9% - Figure 1), with China's share of 22.5% and OECD Countries share of 37.5%. In the same period, global CO_2 emissions reached a historical high of 33.5 GtCO_2, driven by growth in population and economic activity, and were largely driven by non-OECD countries, led by China and India. Power generation, together with transport, is responsible for over two-thirds of total emissions in 2018 while the remaining third was mainly associated with the industry and building sectors. Figure 2 represents this growth in CO_2 emissions.

FIGURE 1 - TOTAL ENERGY SUPPLY BY SOURCE IN THE WORLD FROM 1990 – 2018.



SOURCE: IEA (2020d).

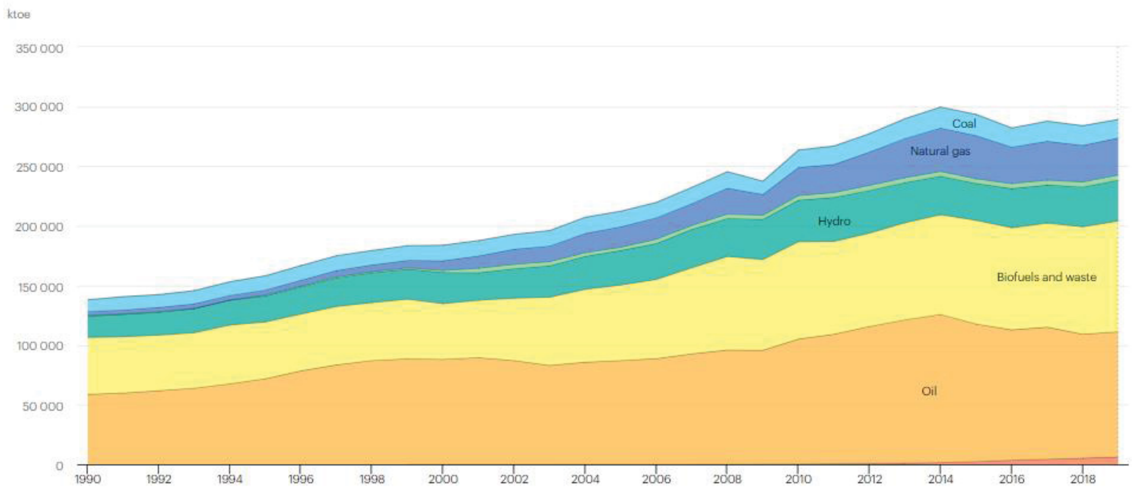
FIGURE 2 - CO_2 EMISSIONS BY ENERGY SOURCE IN WORLD FROM 1990 TO 2018



SOURCE: IEA (2020d).

IEA (2020e) states that between 1974 and 2018, world gross electricity production increased from 6,298 TWh to 26,730 TWh, an average annual growth rate of 3.3%. In terms of capacity, between 2010 and 2018, the growth rate in OECD countries was 1.9% and the majority (91.0%) of the increase in capacity was driven by growth in solar (+26.1%) and wind (+11.0%) as OECD countries accelerated their investments in renewable energy generating infrastructure. In 2019, generation from total combustible fuels summed 57.1% of total OECD gross electricity production; nuclear plants: 18.0%; hydroelectric plants: 13.2%; wind: 7.6%; solar: 3.3%; and geothermal, tidal and other plants: 0.8%. In 2018, World electricity final consumption reached 22,315 TWh, 4.0% above 2017.

FIGURE 3 - ELECTRICITY GENERATION BY SOURCE, WORLD 1990 - 2019



SOURCE: IEA (2021b)

Soares et al. (2020) report that in the period between 2001 and 2018, the Brazilian Gross Domestic Product increased at an average rate of 2.3% per year, accumulating an increase of 50%. The internal energy supply grew at the same pace as the economy (2.3% per year). During 2010 and 2013, because of a social government program to promote the reduction of inequality associated with improvements in the conditions to access to credit, income increased. It contributed to possession and use of household appliances in Brazilian homes, energy consumption grew at an average annual rate of 5.1% in this period, with GDP growing at a rate of 4.1%. In the last five years, (2014-2018) Internal Energy Supply curve detached from GDP. This movement indicates an increase in energy intensity caused by the increased participation of energy-intensive segments in the industrial sector, combined with a period of an economic downturn.

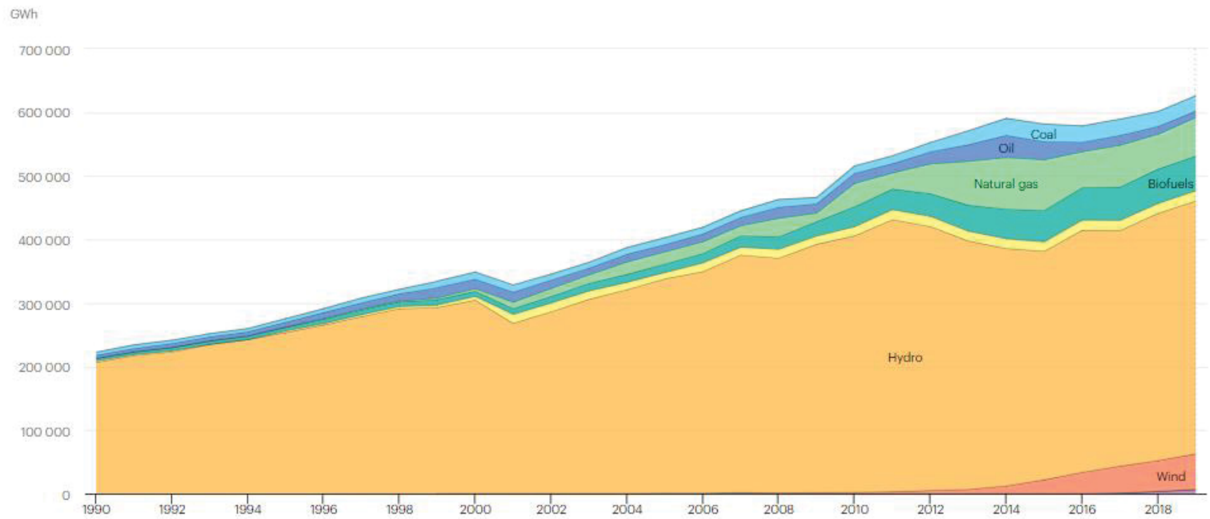
CLIMATELINKS (2019) reports that Brazil's total GHG emissions in 2014 were 1,357 million metric tons of carbon dioxide equivalent ($MtCO_2e$), totaling 2.78% of global GHG emissions. In Brazil, 37.4 percent of GHG emissions come from the energy sector, followed by agriculture 32.6%, land-use change and forestry 22.6%, industrial processes 4.2%, and waste sectors 3.4% relative to GHG emissions.

According to IEA (2021), total primary energy demand has doubled in Brazil since 1990, led by strong growth in electricity consumption and demand for transport fuels on the back of robust economic growth, as shown in figure 4 and figure 5. Large hydropower plants are responsible for around 80% of electricity generation, giving the electricity system a great deal of operational flexibility. Reliance on other sources for power generation is growing, notably natural gas, wind, and bioenergy. Large offshore oil and gas discoveries have confirmed Brazil's status as one of the world's foremost oil and gas provinces.

According to the Brazilian Electricity Regulatory Agency (ANEEL), Brazil reached 173,564 MW of energy in 2020, shared in 60% of hydropower plants, 9.1% from wind power plants, biomass 8.4%, natural gas 8.2%, oil, and coal 5.0%, and centralized photovoltaic solar of 1.6% (ABSOLAR, 2020).

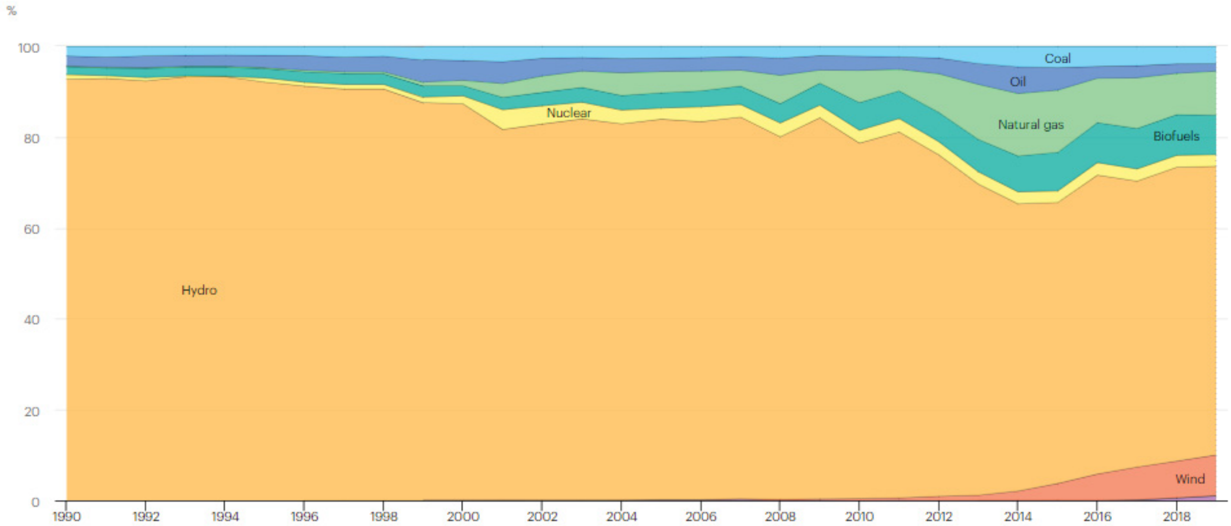
Photovoltaic energy plants grew 152% in 2020 compared to 2019, which positions Brazil in 16th global ranking with 4.5 GW. China leads with 204.5 GW installed, followed by Europe Union 137 GW, United States 75.9 GW, Japan 63 GW, and Germany 49.2 GW (MASSON et al., 2020).

FIGURE 4 - ELECTRICITY GENERATION IN GWh BY SOURCE, BRAZIL 1990 - 2019



SOURCE: IEA (2021b)

FIGURE 5 - ELECTRICITY GENERATION MIX EVOLUTION BY SOURCE, BRAZIL 1990 - 2019



SOURCE: IEA (2021b)

3 ELECTRIC VEHICLES AND POWER GENERATION

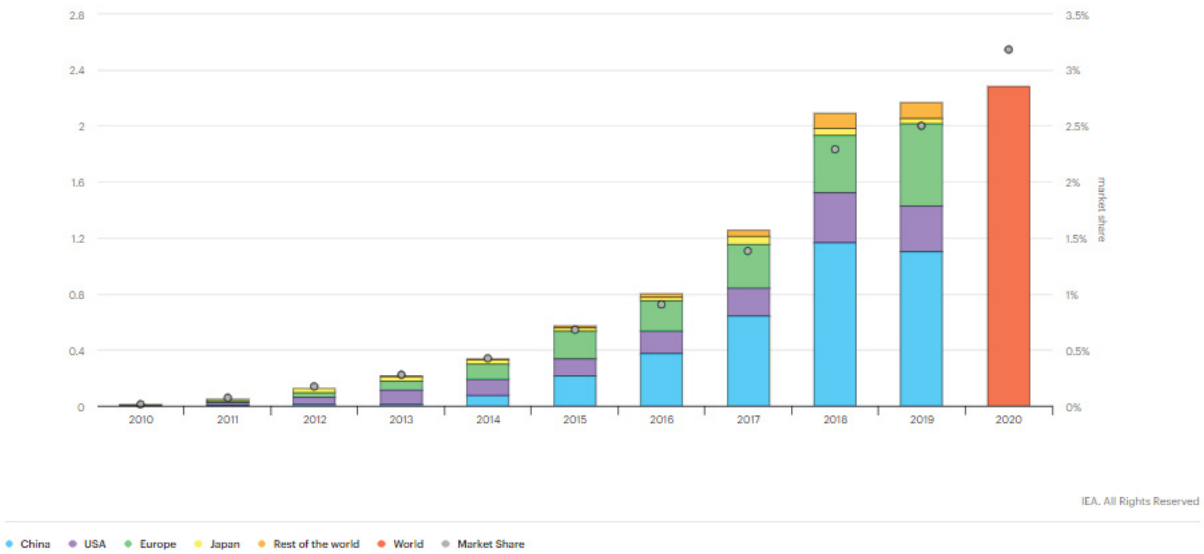
3.1 ELECTRIC VEHICLE GLOBAL MARKET

In the context of generalized efforts towards greener uses of energy, massive transport electrification is an important driver for both GHG emissions and air pollution reduction, and several countries take steps in this direction.

To reduce adoption barriers, some governments address the increase BEV adoption by reducing the upfront cost of EVs relative to conventional vehicles and by promoting the availability of charging infrastructure. Energy consumption reduction programs are enforced and tailored by reducing taxes or incentives for electrified vehicles over the years.

Until 2019, the world in-use fleet accounts for 7.2 million BEV, concentrated in China (47%), Europe (25%), and the United States (20%), with an annual average increase of 60% from 2014 to 2019 as shown in figure 6. This represents less than 1% of the in-use fleet worldwide. IEA (2021c) forecasts 50 million BEV by 2025 and 140 million by 2030, corresponding to annual average growth of close to 30%.

FIGURE 6 - GLOBAL ELECTRIC CAR STOCK, 2010 - 2020



SOURCE: IEA (2021c)

The EV adoption in each market is a consequence of the geographic aspects, the energy mix, and electricity generation, the purchasing power of end-consumers, mobility characteristics, incentives program, variety of offered products, and local production among other issues.

The adoption of BEV in operation globally in 2019, according to IEA (2020g) avoided the consumption of almost 0.6 million barrels of oil products per day. In the same year, the electricity generation to supply the global BEV fleet emitted 51 Mt CO_2-eq, about half the amount that would have been emitted from an equivalent fleet of internal combustion engine vehicles.

3.2 ELECTRIC VEHICLES AND ELECTRICAL NETWORK INTEGRATION

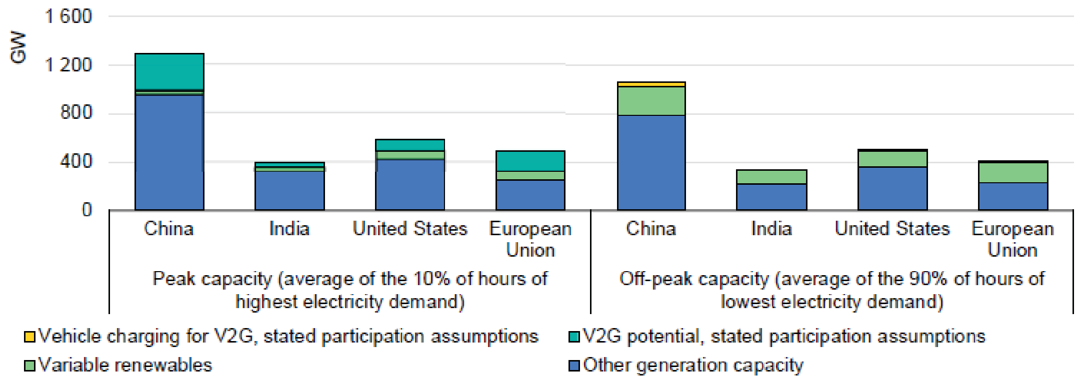
Balancing electricity demand and supply is key to ensure the integration of renewables-based energy generation and the electrification of multiple end-use sectors. Managing BEV charging patterns is necessary to encourage charging at periods of low electricity demand or high renewables-based electricity generation. Energy generation in peak hours is more expensive than in low demand and, with growing numbers of BEV in the future, unmanaged charging must be avoided.

A range of charging management systems is available to reduce BEV charging at peak system demand, so this can postpone the need to upgrade for generation, transmission, and distribution assets. System control can promote off-peak charging at night through programming, alternating with in response to real-time price signals from utilities (V1G – Vehicle to Grid, non-bidirectional) to exploit synergies with variable renewable electricity generation.

More complex charging systems integrate EV batteries to provide energy to the grid under the control of a complex architecture (V2G Vehicle-to-Grid bidirectional charging, and V2H Vehicle-to-Home). The V2x full potential exploitation depends on the availability of vehicles to participate in such services at suitable times, consumer acceptance and routines, and the ability for participants to generate revenues, as well as other technical constraints related to battery life.

It is estimated that 5% of the total BEV capacity in 2030 could be made available for vehicle-to-grid applications during peak times (16,000 GWh in 2030) and this will contribute to offset lower renewable electricity generation during peaks as well as the increase of capacity needed to meet peak demand. Vehicle-to-grid services could unlock up to 600 GW of flexible capacity distributed across the main BEV in 2030 and moderate intermittency of variable renewables during peak demand, as shown in figure 7 (IEA, 2020g).

FIGURE 7 - VEHICLE-TO-GRID POTENTIALS AND VARIABLE RENEWABLE CAPACITY RELATIVE TO TOTAL CAPACITY GENERATION REQUIREMENTS FORECASTED 2030



SOURCE: IEA (2020g)

To exploit the full potential of dynamic controlled charging (V1G) and vehicle-to-grid services (V2G) and the synergies of variable renewable generation, the whole energy sector regulatory framework needs a transformation and new regulatory framework.

The flexible BEV integration is not on track for power systems to accommodate the distributed loads that BEV represents in a coordinated way and on a large scale. Regulatory framework and business models must adapt flexible services to reward BEV owners and to contribute to the power system stability on a significant scale.

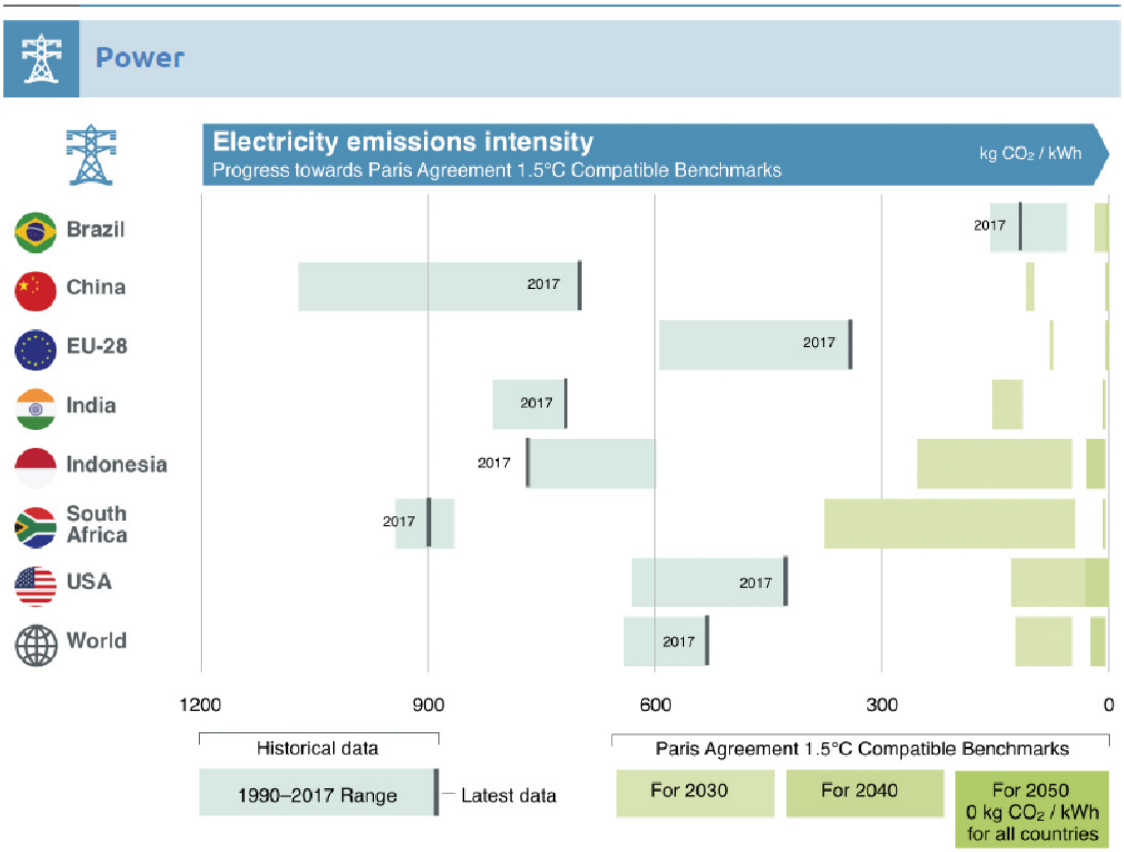
One example of regulatory barriers is Brazilian Regulation 819, 06/19 in article 10 (ANEEL, 2019) declares “The injection of electric energy into the distribution network from vehicles is prohibited as well as participation in the Electric Energy Compensation System. This does not apply to the bidirectional flow restricted to the same consumer unit”. This hinders potential business exploitation by the trading of BEV energy injected into the grid in peak hours and further re-charging to the vehicle. Legislation needs to be updated to incorporate all the innovations in progress in the electric sector and encourage more consumers and investors to be self-sustainable. (ALMEIDA, 2017).

3.3 ELECTRIC VEHICLE AND EMISSION

WTW emission comprises Well-to-Tank (WTT - upstream) and Tank-to-Wheel (TTW - downstream) emissions. In the case of oil, WTT emissions include those incurred from oil extraction, refining, and distribution. For biofuels, they include the emissions that come from growing the biofuels' feedstock, transforming it into biofuel, and transporting it to the fuel pump. For electricity, WTT comprises the emissions incurred in generating the electricity, including line losses as in charging the vehicle. TTW emissions come from the leakage of hydrocarbons in vehicle tanks and fuel combustion. Therefore, TTW emissions are zero for electric and fuel cell electric cars.

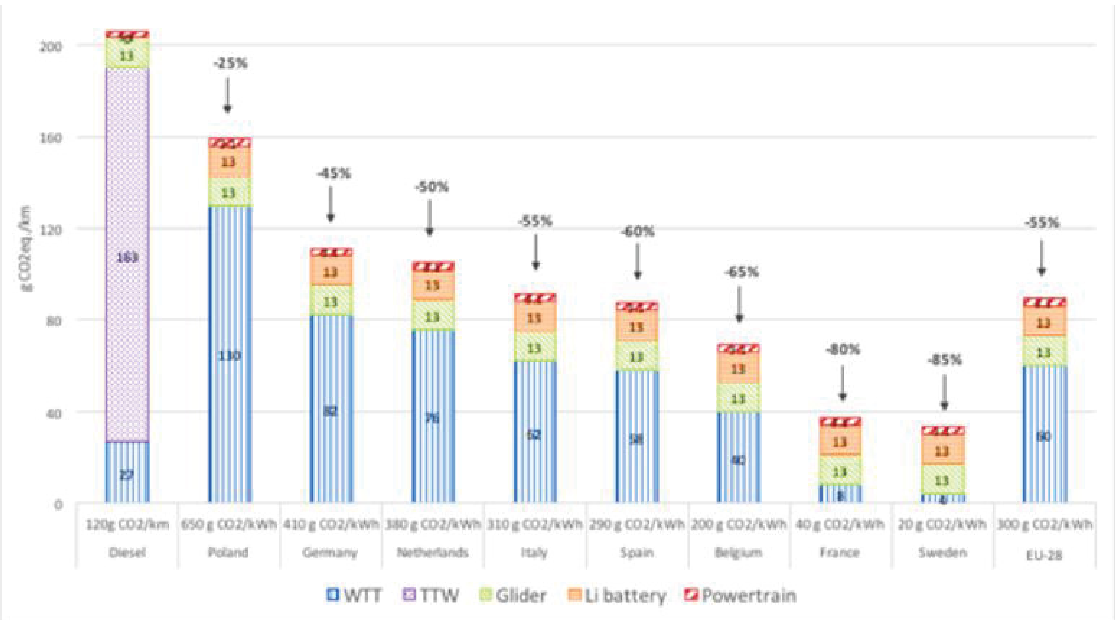
On a WTW basis, in 2018 a medium-size BEV that is representative of global average energy intensity had the lowest specific WTW GHG emissions among the powertrains evaluated, at around 95 g CO_2-eq/km. The average BEV emits about 60% less g CO_2-eq/km than gasoline ICE vehicles and 40% less than conventional hybrid cars. However, due to the large variability in the carbon intensity of electricity generation in electricity systems and across countries, the GHG mitigation potential of BEV can vary considerably, depending on the power system that serves to charge demand, as shown in Figure 8. BEV has nearly zero WTW GHG emissions in Norway and Iceland reflecting their low-carbon power generation, while they may have even higher specific emissions than gasoline internal combustion engines in similar size segments in countries that still rely primarily on coal as a source for electricity generation, as shown in Figure 9.

FIGURE 8 - ELECTRICITY EMISSIONS INTENSITY



SOURCE: CLIMATE ACTION TRACKER (2017)

FIGURE 9 - INFLUENCE OF NATIONAL ELECTRICITY MATRIX IN CLIMATE CHANGE



SOURCE: TRANSPORT & ENVIRONMENT (2017)

3.4 ELECTRIC VEHICLES IN BRAZIL

Brazilian National Association of Motor Vehicle Manufacturers (ANFAVEA), registers the total in-use vehicle fleet in Brazil as 45 million units with an average of 10 years old. In 2020, total sales comprehended 2,054 thousand units, of those 1,954 thousand units of passenger cars and 89 thousand light commercial vehicles (ANFAVEA, 2020).

As an emerging market with electrified vehicles, HEV and BEV summed for 19.7 thousand units in 2020, representing a +66% increase compared to 2019. This represents 1% of the market share in 2020 sales. Toyota 75% and Volvo 15% dominated HEV sales. Renault (20%), Jaguar (18%), Audi (18%), and Nissan (15%) dominated BEV's total sales of 1 thousand units.

As a mass-production BEV is not foreseen in a short time in Brazil, the market is supplied by imported models, and no importation tax is applied (passenger car or light vehicle) since 2015.

On customer-based price, federal, state, and municipal level a series of taxes apply, which hampers the competitiveness of BEV compared to internal combustion engine vehicles. Current taxes and percentages are:

1. IPI - (*Imposto de Produto Industrializado* - Industrialized Product Tax): from 7% to 18%
2. COFINS (*Contribuição para Financiamento da Seguridade Social* - Contribution to Social Security Financing): 9.60%
3. PIS (*Contribuição para os Programas de Integração Social* - Contribution to Social Integration Program): 2%
4. ICMS (*Imposto sobre Operações Relativas à Circulação de Mercadorias e Serviços* - Tax on Operations Related to Circulation of Goods and Services): 12%

For the in-use taxes, BEV owners pay IPVA (annual Motor Vehicle Property Tax), depending on which state the car is registered. The BEV annual tax can vary from 4% to full exemption as shown in table 1. Table 2 presents the Brazilian tax policy for HEV, PHEV, and BEV.

TABLE 1- IPVA LEGISLATION FOR EV

Local	Incentive	Description
States	**IPVA**	100% Exemption : PI, MA, CE, SE, RS, DF, RN, PE, PR
Mato Grosso do Sul	**IPVA**	reduction up to 70% for EV
Rio de Janeiro	**IPVA**	Reduction (HEV 1.5%, EV 0.5%)
São Paulo	**IPVA**	50% reduction (MSRP <R$150,000)

SOURCE: AUTHOR (2021)

TABLE 2 - IPI LEGISLATION FOR EV

POWERTRAIN	ENERGY EFFICIENCY (EE)	MASS IN RUNNING ORDER (MRO)	RATE	Tax min Flex -3%, ROTA -2%
	MJ/km	kg	%	%
HEV PHEV	EE ≤ 1,10	MRO ≤1400	9	4
		MRO >1400 & ≤ 1700	10	5
		MRO > 1700	11	6
	1,10 < EE ≤ 1,68	MRO ≤1400	12	7
		MRO >1400 and ≤1700	13	8
		MRO > 1700	15	10
	EE >1,68	MRO ≤1400	17	12
		MRO >1400 ≤1700	19	14
		MRO > 1700	20	15
BEV	EE ≤ 0,66	MRO ≤1400	7	5
		MRO >1400 and ≤1700	8	6
		MRO > 1700	9	7
	0,66 < EE ≤1,35	MRO ≤ 1400	10	8
		MRO > 1400 and ≤1700	12	10
		MRO > 1700	14	12
	EE >1,35	MRO ≤ 1400	14	12
		MRO >1400 and ≤1700	16	14
		MRO > 1700	18	14

SOURCE: AUTHOR (2021)

Cities promote EV expansion by offering in-use benefits, as Curitiba gives exemption on public parking, and São Paulo allows the circulation of EV during circulation restriction in “rush-hour” as shown in table 3.

TABLE 3 - LOCAL INCENTIVES FOR EV

Local	Incentive	Description
Curitiba	Parking	Free public parking for EV
	Infra-structure	Regulate and authorize Charger installation
São Paulo	Circulation restriction	Exemption for EV and HEV

SOURCE: AUTHOR (2021)

As Brazil ratified in 2016 the "Paris Agreement", the Country commits to reduce GHG by 37% below 2005 levels until 2025. By 2030, these rates are expected to be 43% lower.

To foster improvement in the fuel efficiency of combustion vehicles and strengthen Brazilian industry competitiveness, the government established the INOVAR-AUTO program in 2012 and ROTA 2030 (BRASIL, 2020) program in 2018. The Automotive companies engaged in these programs are obliged to invest in the development of new technologies, intensify local production, and comply with corporate fuel economy targets.

The new mandatory Energy Efficiency targets for 2022 represents -11% energy consumption reduction compared to 2018 limits. To achieve these targets, the automotive industry needs to introduce new technologies such as mild and full-electrification, low resistance tires, low friction materials, improved aerodynamics, and mass reduction. These additional costs require an economical balance calculated by the IPI tax-saving mechanism, as INOVAR-Auto Program. The trade-off to invest in new technologies and confirm the economical return is very complex.

One of the most economical strategies to comply with ROTA 2030 by 2022 and future 2026 regulation is by selling a larger number of BEV, as already seen in equivalent programs in China and Europe. BEV profits from low energy consumption in the homologation cycle, relatively heavy mass which influences favorably minimal compliance corporate limits, and they benefit from a multiplier factor for each vehicle sold (super-credit) for the calculation in the OEM fleet average.

3.5 ELECTRIC VEHICLE CHARGERS

To optimize system cost and deliver the most appropriate rate of power, the Society of Automotive Engineers (SAE) and Electric Power Research Institute (EPRI) categorize EV charging levels as AC Level-1, AC Level-2, and DC fast charging or Level-3 charging.

Level 1 charging utilizes a 120V AC outlet, capable of supplying power in the range of 1.4 to 1.9 kW. It is commonly used as a private home charger for its low price and no additional infrastructure requirements since it utilizes a normal household electrical outlet (KHAN et al., 2018).

Level 2 charging uses a single-phase, bi-phase, or tri-phase 127 - 240V AC outlet, having a current-carrying capacity of 40 A for private systems and a three-phase 400 V AC connection having a current-carrying capacity of 80 A for public installations. Level 2 charging can provide power at 3.4 to 43 kW.

Level 3 charging or DC fast charging, consists of an off-board AC to DC converter, supplied by a three-phase circuit ranging from 208 to 600 V, with a carrying capacity of up to 200 A. Fast charging offers to charge up to a level of 80% in about 10 to 15 min depending on EV battery type and size. This level of charging is mainly used in public installations, primarily because of its high cost, estimated between US$ 50,000 and US$ 160,000 (KHAN et al., 2018).

EV charging stations can also be classified based on the direction of power flow, being either unidirectional or bidirectional. An EV charger with a unidirectional topology uses a diode rectifier and a unidirectional DC-DC converter for charging control. The unidirectional charger is easy to control because of its less complexity, since the power flow from the main power grid to the charger and in the sequence to the vehicle. It minimizes battery degradation and has fewer interconnection issues compared to bidirectional types. A bidirectional EV charger has a bidirectional grid-connected AC-DC converter and a bidirectional DC-DC converter. This kind of charger can operate in either charging or discharging mode, which enables EVs to provide various ancillary services to the grid in a V2G application. Although the frequent cycling of the discharging power back to the grid can degrade the EV battery lifetime.

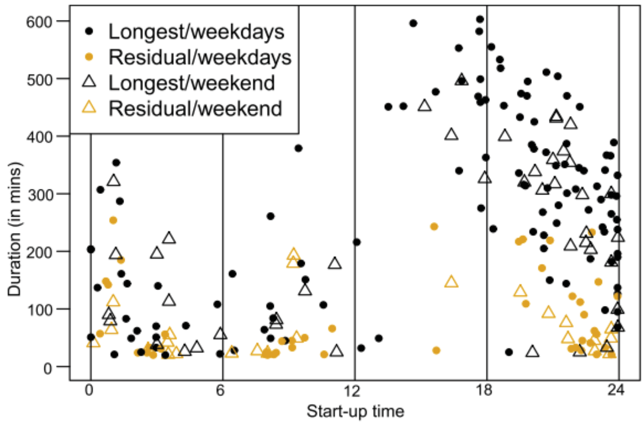
The time required to charge the EV is solely dependent on the vehicle's battery capacity, the current state of charge, and the maximum power provided by the charging station. Equation 1 shows the time required to charge the vehicle.

$$t = \frac{Q * (1 - SOC)}{P_{charge}} \tag{1}$$

Where Q is the battery's nominal capacity, SOC is the state of charge, and P_{charge} is the power drawn from the charging station.

Most of the privates own Level 1 and 2 slow chargers. They accounted for 6.5 million out of the total 7.3 million chargers in 2019 (IEA, 2020g). Because of the considerable amount of time required by a level 1 or 2 chargers to fully recharge a modern EV, most charging is done overnight, when the vehicle is not in use and electricity prices are lower. From Gerossier, Girard, and Kariniotakis (2019), it was found that about half of the EV owners charged during the night and in the early morning, between 6 PM and 6 AM, with cycles tending to last longer when started earlier in the night. The second most frequent time of recharge was found to be in the evening, presumably when people come back from work, with around 20% of the charging events. Figure 10 presents the charging start time and duration for individual EVs throughout the year.

FIGURE 10 - CHARGING START TIME AND DURATION FOR EVs FOR ONE YEAR



SOURCE: GEROSSIER; GIRARD; KARINIOTAKIS (2019).

3.5.1 ENERGY CHARGING FOR ELECTRIC VEHICLES

Lithium-Ion (Li-Ion) batteries are the most common battery type in modern BEV, mainly due to their high energy density and increased power per mass of the battery unit, allowing the development of batteries with reduced weight and dimensions at competitive prices. A Li-Ion battery can be modeled in terms of its terminal voltage, open-circuit voltage, internal resistance, discharge current, and state-of-charge. This model can be applied for discharge as well as for charge (TREMBLAY; DESSAINT, 2009).

The condition of the battery capacity to supply energy to a BEV is given by its state of charge SOC, which can be defined as shown in Equation 2.

$$SOC = SOC_0 - \frac{d * E}{Q_{nom}} \tag{2}$$

Where: SOC_0 is the original SOC at the departure, d is the trip distance, E is the electricity and Q_{nom} is the nominal capacity of the battery (LIN et al., 2019).

3.5.2 CHARGING INFRASTRUCTURE

In terms of public and private infrastructure of charging in Brazil, government and private companies have worked to foster a distinct approach to this new business. From the government side, ANEEL R&D programs rule the development areas to which electric companies should invest and allocate their compulsory quota of 0.5% of revenues. In 2020, ANEEL signed R$616 Million for the development of infrastructure for BEV (ANEEL, 2020b). Energy companies such as EDP, CELPE, COPEL, and CPFL have implemented fast and ultra-fast chargers in highways and public stations since then. Premium vehicle brands such as Audi, BMW, Porsche, and Volvo implement a medium to an ultra-fast charger in recent years to follow their customer in their experience with BEV.

National infrastructure for charging counts around 500 charging points with 34 fast-charging (Chademo, CCS, Power output above 50 kW). The site Plugshare (https://www.plugshare.com/) provides the location and characteristics of these charging points.

3.6 ELECTRICAL SYSTEMS

Hybrid Energy Systems are the combination of different renewable resources such as wind, sun, biomass, hydraulic micro turbines, and fossil fuels (usually Diesel generators) to provide electricity.

This integration of renewable energy into hybrid systems saves fossil fuels, as this is the most expensive link in the chain and the Diesel generator remains as a backup. A hybrid system can be connected to the network (on-grid), independent to the network with a distribution system (off-grid), and independent to the network without a distribution system and with direct load supply (off-grid with direct supply) (SILVEIRA et al., 2013).

The on-grid system relies on the network if the hybrid system does not work, minimizing power cuts and quality. For the off-grid configurations, either they can supply one or more scattered loads as well as be used to charge batteries in energy storage systems.

A micro grid or mini-grid is a system that generates electricity, and possibly heat, to serve a nearby load and its main characteristic is its availability to that load. This grid is usually formed by one or more power generation systems combined with different storage technologies to regulate energy flow and allow the possibility to operate disconnected from the main grid. A solar system connected to batteries for an isolated village, a wind system in conjunction with Diesel for an island, or a system connected to the grid and connected to a gas micro turbine to generate electricity and heat for a factory, are examples of the mini and micro grid.

3.7 PHOTOVOLTAIC SOLAR PLANTS

The three main technologies to generate energy by solar sourcing are photovoltaic, thermo-solar, and thermoelectric solar. Photovoltaic systems directly transform solar energy into electrical energy. The photovoltaic cell is the basic component of the system and consists of semiconductor material that converts solar irradiation into electricity in direct current.

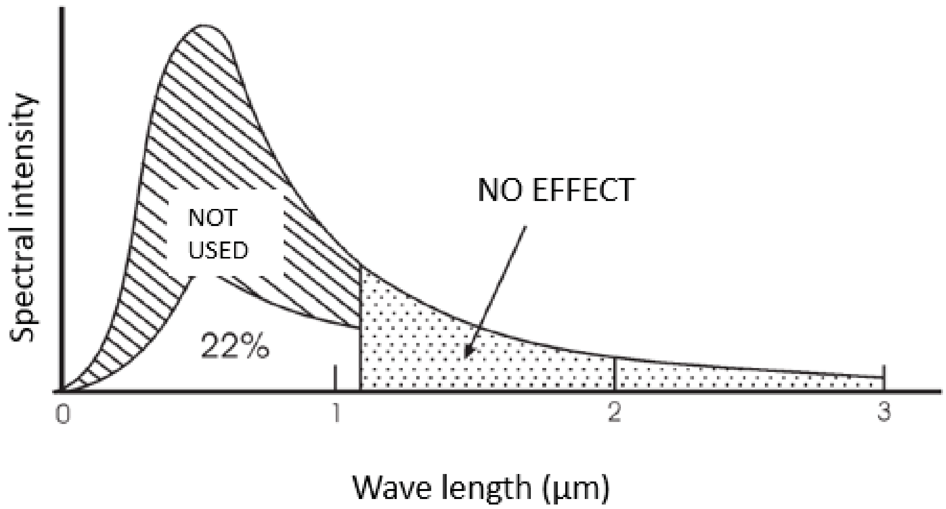
In general, the photovoltaic effect is the creation of an electric current after solar exposure to the photovoltaic module. A photovoltaic cell works by absorbing photons, which are energy elements present in sunlight. The photon, in turn, releases electrons that flow through cells, generating electrical energy.

Each cell has a glass cover, an anti-reflective layer, a frontal contact, which allows electrons to enter a circuit, a conductor that allows electrons to complete the circuit, and, finally, layers of semiconductors.

When joining several cells, we have a solar panel that generates the photovoltaic effect. Alexandre-Edmond Becquerel observed this phenomenon first in 1839. Becquerel exposed an electrolytic cell (composed of silver chloride in an acidic solution connected with platinum electrodes) to sunlight, producing a certain voltage and electric current. The discovery that certain types of materials react to sunlight was a fundamental basis for modern solar technology.

The question remains what the limiting factors in this process are to convert light energy into electricity. The first limiter is the spectrum of its radiation, as shown in Figure 11. It spreads over a wide range and only the portion with a length of a wave less than 1μm can excite electrons in silicon cells.

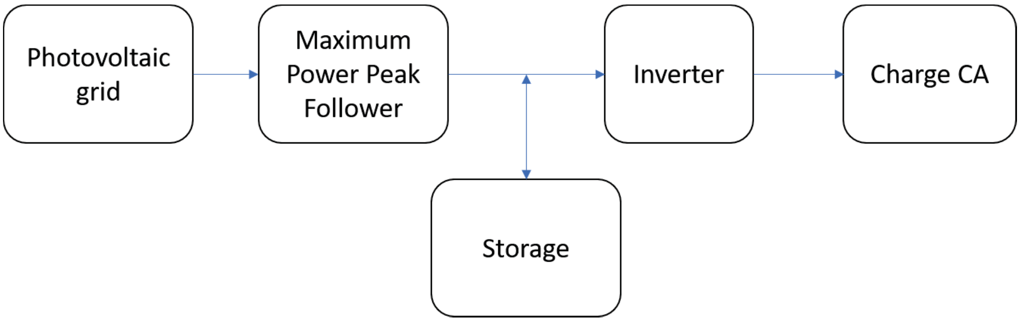
FIGURE 11 - ENERGY CONVERSION FOR A SILICON CELL



SOURCE: CRESESB (2004)

The photovoltaic plant consists of photovoltaic panels combined in arrays; voltage inverters to transform direct voltage into alternate voltage, and could also present battery storage, as shown in Figure 12.

FIGURE 12 - CHARGING SYSTEM WITH STORAGE AND SOLAR PANELS



SOURCE: AUTHOR (2021)

Another factor is that each photon can only excite one electron. Therefore, for photons with energy higher than the energy of the gap, there will be an excess of energy that will be converted into heat. Finally, even for excited electrons, there is a likelihood that they will not be collected and will not contribute to the current. Photovoltaic cell manufacturing technology tries to reduce the latter to the maximum. For silicon cells, the theoretical limit for converting solar radiation to electricity is 27% (CRESESB, 2004).

The most common panel construction in the market is crystalline silicon panels, which can be mono or multi-crystalline and represent approximately 90% of the annual market and their conversion efficiency varies from 15% to 20%. Multi crystalline silicon is less expensive but the conversion ratio ranges only 14%.

3.8 BASELINE CO2 EMISSION AND ENERGY CONSUMPTION

To present a baseline of CO_2 emission and energy consumption, this study examines the Brazilian Vehicle Labelling program (INMETRO, 2020).

This program allows consumers to compare the energy efficiency of vehicles from the same category for conscious choice and provides information about the fuel consumption of light vehicles sold in Brazil. These reference values are obtained from consumption measurements made in the laboratory, according to the NBR 7024 standards. For this purpose, Brazilian standard fuels and pre-established driving cycles are used in Standardized laboratory measurements and they are the ideal way to measure energy consumption, regardless of the laboratory used. They allow models to be tested in standardized and controlled conditions, ensuring that measurements can be repeated under the same conditions and used in a uniform comparison between different vehicle models, within the same category.

However, under real conditions of use of the vehicle, several factors influence the consumption perceived by the driver, which may vary considerably in terms of those obtained in laboratory measurements under standard conditions. To approximate the reference values to those perceived by drivers in their actual use, maintaining the relative comparison between vehicles, INMETRO decided to adopt adjustment factors for the 2010 Program, such as the evolution of this theme in the United States of America conducted by the Environmental Protection Agency (EPA).

It is worth emphasizing that fuel consumption varies from driver to driver, for a wide variety of reasons, such as the way of driving, the conditions weather, traffic patterns, use of accessories (especially air conditioning), the loads imposed on the vehicle, the type and pressure of the tires, the type of soil, the state maintenance and how to measure the amount of fuel consumed.

When different drivers drive the same vehicle, they obtain consumption differently according to the variations of the conditions indicated above; in such a way that there is a “perfect method”, that ensures accurate measurement of energy consumption fuel in the real world for all consumers. With an estimate, there will always be consumers who will get better or worse results in their cases, private individuals.

Therefore, the essential thing is to measure vehicle consumption in standardized and repetitive conditions, always the same for all models, to allow a fair comparison in relative terms, as the laboratory tests allow, adjusting them to values that approach statistically those of the real world. The adjustment factors now adopted were developed by the Brazilian Protection Agency from thousands of real data and indicate that 90% of users achieve results within about 20% of consumption declared.

These factors ought to contemplate more real conditions of use of the vehicles, which are also observed in Brazil today, for example: driving styles more aggressive, more congested traffic, greater speed on the roads, greater use of air conditioning, etc. The values measured in laboratory tests under conditions standardized by NBR 7024 will continue to be used for comparing and classifying efficient vehicles in each category, strictly followed by international standards and international vehicle driving standards for measuring consumption. The lack of maintenance, unbalanced tires, aggressive driving with sudden acceleration and braking, very congested traffic, high speed, inappropriate fuel, weather conditions or conditions adverse side effects, excess weight, etc. can cause a significant increase in consumption of fuel, including up to more than 20%.

Brazilian Environmental Agency (IBAMA) established on CONAMA (1986) (the National Council for the Environment), the resolution 18/1986 with the general objectives:

- Reduce the emission levels of pollutants by motor vehicles to meet the Air Quality Standards, especially in urban centers;
- Promote national technological development, both in automotive engineering, as in methods and equipment for testing and measuring the emission of pollutants;
- Create inspection and maintenance programs for motor vehicles in use
- Promote the population's awareness of the issue of air pollution by motor vehicles;
- Establish conditions for evaluating the results achieved;
- Promote the improvement of the technical characteristics of liquid fuels, made available to the national fleet of motor vehicles, aiming at the reduction of polluting emissions to the atmosphere.

To reduce and control atmospheric contamination and noise emission from mobile sources, CONAMA created the Air Pollution Control Programs by Motor Vehicles: PROCONVE (cars, motor vehicles and agricultural) and PROMOT (motorcycles and similar) establishing deadlines, maximum emission limits, and establishing technological requirements for national and imported motor vehicles. In 2018, CONAMA published Resolutions 490 (CONAMA, 2018a) and 492 (CONAMA, 2018b), which bring new phases of PROCONVE L7, L8, and P8 from 2022. The new L7 phase will bring a significant reduction in fuel vapors that are lost in the atmosphere, while the P8 phase should significantly reduce the emission of nitrogen oxides. These two actions complement each other and should help to reduce the formation of oxidation compounds in the atmosphere of large urban centers, especially ozone gas.

The new L8 phase from 2025 brings a methodological change for approval in the licensing processes, which will cease to be per vehicle model and will change to the corporate average, requiring that the vehicles sold by a company present an average emission that meets progressively more restrictive limits. Thus, it induces the production of zero-emission vehicles (such as electric), which compensate to produce vehicles that are more emitters.

In ideal combustion, all the fuel burned should become CO_2. It is not considered a pollutant because it does not harm the human organism, but it is a GHG. Hence, the concern with the quantity of its emission, as its generated volume is shown to be very large to the other pollutants.

Thus, engine engineers agreed to measure the pollutant emission level of a vehicle in grams of carbon dioxide per kilometer run, which notation is CO_2/km.

In the real world, combustion is never complete, and other, much more harmful pollutants come from the operation of engines, such as carbon monoxide (CO), hydrocarbons (HC), and nitrous oxide (NO_x).

The above gases, products of incomplete combustion, cause serious damage to health and the environment, which is why the approval authorities and manufacturers consider that their emission should be zero. The most efficient way to reduce the emission of these residues is to improve the technology of catalysts since the mere reduction of fuel consumption does not necessarily imply its mitigation.

In turn, CO_2 is shown to be a natural product of engine operation, but efforts are always made to improve energy efficiency. To assess whether the result is being achieved, engineers pursue the reduction of CO_2 emissions, an indication of reduced fuel consumption. It proves to be the main indicator of improvement in the use of the calorific power of the fuel.

This study integrates the Brazilian Labelling Program and CONAMA regulation to present a baseline for simulation and forecast it until 2030, considering CO_2 emission regulated for ROTA 2030.

3.9 FINAL CONSIDERATION

Brazil ratified its commitment to reduce its GHG emissions by 37% below 2005 levels in 2025 and by 43% below 2005 levels in 2030. Brazil has determined to increase the share of sustainable biofuels to 18%, zero illegal deforestation in the Brazilian Amazon, restore 12 million hectares of forests, enhance sustainable native forest management, achieve 45% renewables in the energy mix and achieve 10% electricity efficiency gains.

Brazil’s energy sector is among the world’s least carbon-intensive, with almost 45% of primary energy and 85% of electricity coming from renewable sources, mostly large hydropower plants (80%) and other sources of power generation have been growing, such as natural gas, wind, bioenergy, and solar.

The deployment of BEV in Brazil is still in the very early stage due to several aspects such as missing infrastructure for charging in domestic, commercial places, and highways, BEV high price of acquisition, as consumer doubts about battery lifetime and recycling. On the other hand, BEV has the potential to reduce the transport CO_2 emission, reduce the air and noise pollution in high population density cities and take the benefit of low carbon intensity energy footprint in Brazil.

The transition toward cleaner and more sustainable energies is set by Federal Brazilian programs as PROCONVE (emission and evaporation) and ROTA 2030 (energy efficiency) and this induces the automotive manufactures to deploy electrified vehicles (HEV, PHEV, BEV) in the market to comply to Regulation limits.

4 LITERATURE REVIEW

4.1 SEARCH OF BIBLIOGRAPHIC PORTFOLIO

The development of the literature review is based on author research on subjects with the keywords mentioned in table 4, defined on the problem to be analyzed and the method to be applied, being these the axis of keywords definition.

TABLE 4 - KEYWORDS DEFINITION

Axis	Problem		Method
Keywords	Electric Vehicles		Total Cost of Ownership
	Energy	Generation	

SOURCE: AUTHOR (2021)

To enlarge the literature review, the author searched for complementary technical papers from sources as the International Council on Large Electric Systems (CIGRE), Energy and Mobility Forums (Society of Automotive Engineers-SAE), International Conference, Universities, R&D Centers, International Agencies, and Industries Press Reports.

Table 5 presents the total amount of articles.

TABLE 5 - RESULTS OF QUERIES

Articles	**Initial Results**
Selected for consulting	112 articles
Selected for analysis	89 articles
Selected for project review	15 articles

SOURCE: AUTHOR (2021).

The option to enlarge the search for materials, using not only Publish or Perish software or Google Scholar results, allowed finding materials that contributed for in-depth analysis of industrial and services knowledge coupled with legislation review in similar cases.

4.2 LITERATURA ANALYSIS

The literature review started by looking at the last press reviews of automotive companies as General Motors, BWM, BYD, Renault, and Tesla. For the electricity sector, the research focused on the last publication of ANEEL, CIGRE, International Forums, and technical papers related to the keywords. For the energy and electrical sector, the International Energy Agency offers a vast collection of publications covering World and Country- specific subjects, including EV Outlook. To complete the academic research, the research focused on keywords in table 5, attending to the most relevant and abstracts and conclusions.

TESLA Inc., founded in 2003 in California, has developed and sold only BEV since then. Tesla's mission is to "accelerate the world's transition to sustainable energy". In the second annual Impact Report published in 2019, Tesla disclosed facts related to their products, manufacturing, and environmental impacts and depicted it from lifecycle analysis. Tesla reported the vehicle and battery production carbon footprint and energy consumption, how Tesla integrated renewable energy usage in their factories and how Tesla worked to minimize their environmental impacts in the supply chain (TESLA, 2019).

As Tesla manufactures battery storage systems and solar panels, Tesla delivers an entire sustainable energy ecosystem together with the BEV for home consumers, enabling the exploitation of micro grid potentials for low-energy consumers. Tesla has an end-to-end value chain, from research, design, manufacturing, distribution, selling, and servicing and they have cost-effectively managed the required infrastructure while becoming less reliant on it and reaching the maximum energy performance from the complete energy system. According to the TESLA (2019) report, 4 billion miles traveled by sold Tesla Model 3 have served to compare to internal combustion engine vehicles. A premium sedan, the model year 2019 consumes 23.6 MPG (miles per gallon) which translates to 420 grams of CO_2 per mile by including upstream activities as extraction, refining, and shipment of oil and remains constant throughout its life cycle. On the other side, considering the total lifecycle of 12,000 miles over 17 years, a Tesla Model3 consumes 180 grams of CO_2 per mile using a U.S. national energy generation mix. As electricity generation is becoming renewable, this emission could decrease consequently and reach 100 grams of CO_2 per mile if energy is generated by solar-powered. The dynamic highlights how BEV on the road today will become cleaner as they age and how critical "greening" the grid will be to achieve reduced transportation emissions.

Lopes et al. (2013) address a comprehensive integration of EV into the electric grid, evaluating all the possible effects of the introduction of EV that are directly relevant to the future development of the power systems. The report covers a wide variety of topics as BEV key drivers and deployment scenarios, regulatory frameworks and agents of the electric power system, steady-state and dynamic behavior impacts of EV introduction in the electric grid, integration of renewable energy, management, and control system for scale deployment of BEV, effects of the BEV into electricity markets, tariff and charging modes of operation including Vehicle-to-Grid.

While the integration of a moderate mix of BEVs does not affect the distribution grids, their broad adoption would most likely create some problems in grid operation and management. Considering BEV as a simple uncontrollable load that consumes a large amount of power, it is necessary to foresee major congestion problems in already heavily loaded grids, low voltage problems, peak load, energy losses increase, large voltage drops, and load imbalances between phases in low voltage grids.

Two different approaches exist to accommodate the forecasted increasing BEV penetration and reduce the negative impacts on energy quality, power, and operation cost. The first is to reinforce the existing infrastructures and plan new networks to handle the EV integration, which will require high investments in the network grid, including generation and distribution. The second is to develop and implement enhanced charging management strategies in the distribution networks, capable of controlling EV charging according to the grid's needs and their owners' requirements. This approach provides elasticity to these new loads, allowing the management structure to optimize according to congestion levels or voltage problems. The synergy among EV users, grid operators, and service suppliers would allow a massive insertion of EV into distribution networks while avoiding expenditures in equipment reinforcements.

BEV has a broader impact than environmental as this creates value with additional business opportunities within the energy sector and mobility. Energy providers can develop intelligent management of the grid during charging; battery second life can create new storage units to micro grids, energy metering, and billing systems including charging point operation and maintenance. Vargas et al. (2020), presents initiatives in Brazil for the product-service system (PSS) which refers to this entire new value chain. Policies with an environmental background as PROCONVE, ROTA 2030 (BRASIL, 2020), and RENOVABIO display the legislation incremental enforcement to adopt more stringent emission standards, more technological equipment to decrease the energy consumption, and the expansion of biofuels in the energy matrix.

Tejeda et al. (2020) evaluate the challenge to cope with the future energy demand needed for large-scale BEV insertion. The potential benefits associated with different types of smart charging (from simple time-of-use tariffs to dynamic control signals with V2G injection) are analyzed in three demand scenarios: from lower to a higher share of smart charging and V2G penetration up to 20%. The analyses were carried out using a large-scale model of the European electricity system including interconnectors at hourly resolution. It emphasizes the customer behavior changes since the cost of electric mobility can be controlled by developing charging flexibility. The authors highlight that BEV offers an advantage for the carbon footprint over combustion vehicles: reducing emissions during the use phase compensates for the carbon impact during the batteries manufacturing phase. These studies thus show that due to the low carbon content of the electricity mix in France, electrification of vehicles offers an advantage for the carbon footprint, as soon as a vehicle covers 50,000 kilometers throughout its lifetime, a level far lower than the average use of a vehicle in France (200,000 km).

In Europe, the regulatory standards to reduce CO_2 emission oblige the deployment of more efficient internal combustion engine cars and higher shares of BEV. According to Thiel et al. (2016), to comply with this standard, BEV would sharply increase between 2020 and 2030 at a rate above 12.5%, reaching shares of 30% in 2030 and it pushes the car Tank-to-Wheel emissions below 70 gCO_2/km without additional system costs. The study took into consideration the flexibility of the charging system to use load shifting and V2G and increased renewable energy sources. It concluded that regulating CO_2 emission from cars has effective CO_2 mitigation since it can promote renewable sources without significant cost increase and positive impacts on the European energy security.

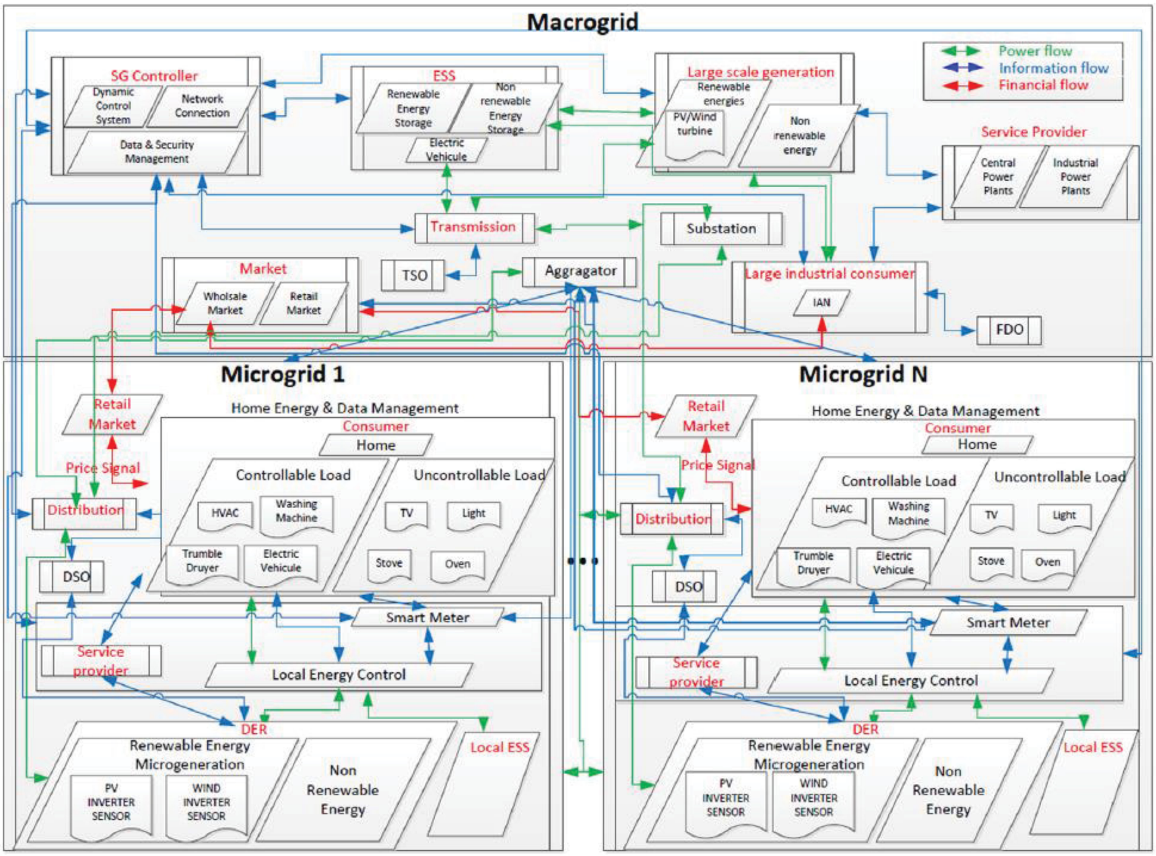
In the transport sector, Brazil benefits from the local production of ethanol, which can be used in internal engine combustion vehicles as hydrated ethanol, or anhydrous ethanol blended with gasoline. On the other hand, the increasing insertion of BEV would benefit from Brazilian energy generation based on a high mix of renewable energy. A Life Cycle Assessment (LCA) study by Choma, Ugaya (2017), compares both approaches focused on the in-use phase, including energy consumption, whereas attributional data were used for the vehicle production stage. The BEV is better for abiotic depletion, global warming, and ozone layer depletion. This study highlights the need to implement residential tariff differentiation to stimulate the off-peak charging and the promotion of vehicles for daily commuting which require a smaller battery and give an improved vehicle energetic efficiency.

Electricity Generation in an isolated grid relies on a non-intermittent source to prevent any energy shortage and reliability for the population and in some cases, a second renewable source serves as an alternative to reduce energy consumption and air pollution. Kempener et al. (2015) report that microgrids are particularly relevant for island states and it is estimated that there are more than 10,000 inhabited islands around the world and an estimated 750 million islanders. Many of them rely on Diesel generators for their electricity production and spend a considerable percentage of their gross domestic product (GDP) on the import of fuels. In most cases, renewables are already a cost-effective replacement for these Diesel generators, creating an important market for off-grid renewable energy systems. This paper analyzes the status of off-grid renewable energy systems, explaining each type of grid category (from 5 kW to 100,000 kW) provides a global overview of available data organized by country and statistical resources. Finally, this paper remarks on the urgent need to improve the statistical basis for off-grid systems which would help to improve the technology deployment, cost reduction for renewable energy generation, and electricity storage technologies.

By assessing the sustainability (economic, social, and environmental criteria), of the energy system approach, Barros et al. (2015) state that small-scale renewable energy systems are preferable to the large-scale ones, with small solar photovoltaic systems rank first, followed by micro-hydro, micro-wind, biomass, large-scale wind, landfill gas, large-scale hydro and energy from waste. Considering their contribution to sustainable developments, the solar-thermal ranked as first (index Sustainability Index = 0.8), followed by wind (onshore) (0.76), photovoltaic (0.69), small hydro (0.61), natural gas (0.57), nuclear (0.40), biomass (0.39), oil (0.31), coal (0.29) and lignite (0.29).

Coupling renewable energy systems with different generation characteristics and equipping the power systems with the battery storage systems requires a smooth transition from the conventional power system to the smart grid, with innovative controls such as Artificial Intelligence and Machine learning. Worighi et al. (2019) propose a smart grid consisting of the main grid and multiple embedded micro grids, integrating solar power generation units, battery energy storage systems with the proposed grid architecture, as shown in figure 13.

FIGURE 13 - PROPOSED SMART GRID ARCHITECTURE



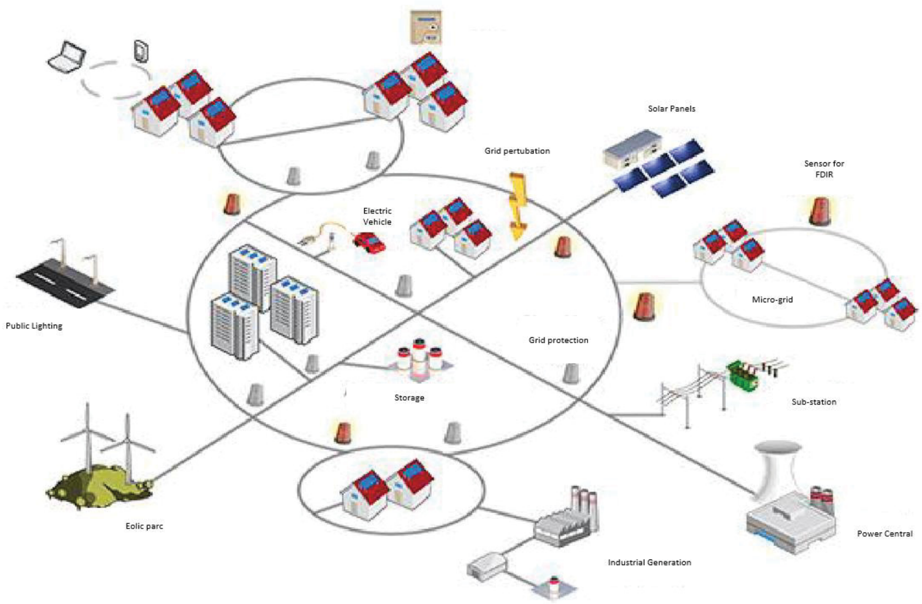
SOURCE: WORIGHI ET AL (2019)

The virtualization of the proposed grid architecture addresses issues related to Photovoltaic (PV) penetration, back feeding, and irregularity of supply. The simulation results show the effect of Renewable Energy (RE) integration into the grid and highlight the role of batteries that maintain the stability of the system in different weather conditions to reduce and control the fluctuation of distributed generations.

The photovoltaic generation is reaching significant participation in electrical energy generation, causing perturbations due to its intermittence. Almeida (2017) proposes the integration of photovoltaic power with a forecasting tool in the isolated power system of Fernando de Noronha. The effects of a high photovoltaic penetration are seen in the performance of Diesel energy generation, reaching an efficiency level below the minimum regulated by ANEEL legislation. The authors claim a national Regulatory review, expose the benefit of the dispersed photovoltaic system which dampers energy fluctuation, analyze the interaction with a storage system for primary regulation for Diesel operation, and highlight the inverter ability to manage active and reactive power flow to the grid.

Silveira et al. (2013) present a feasibility study by using simulation software HOMER with a different arrangement of photovoltaic panels, wind generators, energy converters, and storage systems, as shown in figure 14. Power demand increase caused by the hypothetical replacement of the entire vehicular fleet powered by internal combustion engines by BEV was studied. Renewable energy mix could potentially reach 67% of total energy supply, saving 6 million USD of operational cost, 70% of GHG reduction, and 2 million tons of CO_2 from internal engine combustion would be suppressed. This research presented in 2013 revealed an interesting approach based in partnership with KWO (Kraftwerke Oberhasli AG) and ITAIPU (Bi-national Hydro-Electric Energy Plant) applying the smart electric grid architecture of energy systems (generation, transmission, and distribution), communication technologies, and information systems, to reduce costs, improve efficiency, and minimizing environmental impact.

FIGURE 14 - GRID ELEMENTS



SOURCE: SILVEIRA ET AL. -adapted (2013)

An economical synthesis of installation and run-in cost of hybrid systems including energy storage revealed the optimized balance of renewable energy insertion and concluded that a mix of 67% of renewable energy with Eolic plant is the optimized operational and economic scenario.

The replacement of 868 existing internal combustion engine vehicles by BEV would increase 8.7% of the total energy production of 43 MWh/day, which represented additional 167 thousand liters of Diesel per year corresponding to 500 tons of CO_2 emission. However, considering the WTW approach, the author appointed a potential saving of 1400 tons of CO_2 when using 100% BEV.

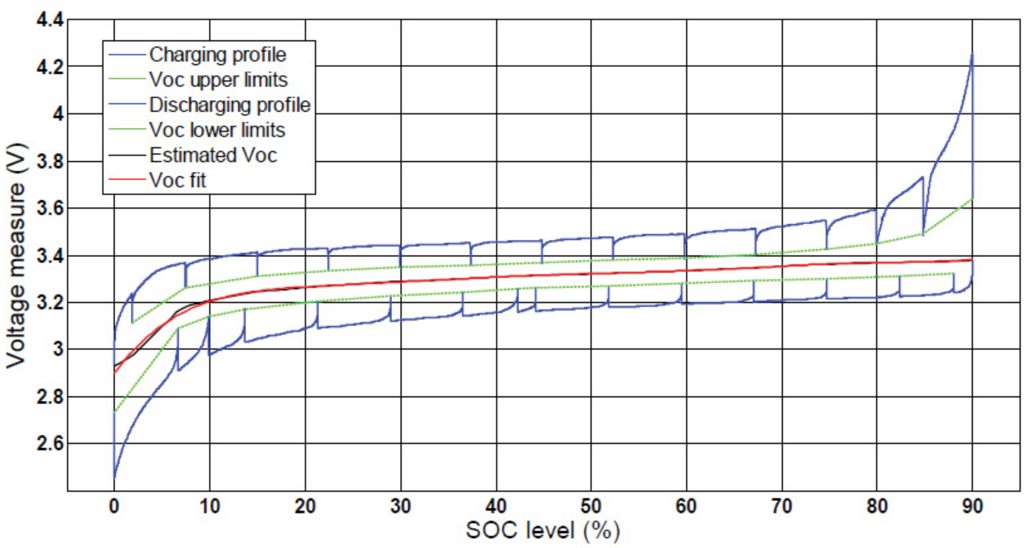
As energy generation in isolated islands is heavily dependent on Diesel fuel, this has a consequently elevated carbon footprint and high operational cost. As studied by Jakhrani et al. (2012), Diesel engines release many hazardous air contaminants and GHG including particulate matter (Diesel soot and aerosols), carbon monoxide, carbon dioxide, and oxides of nitrogen. Particulate matter is a large elemental of organic carbon soot, coated by gaseous organic substances such as formaldehyde and polycyclic aromatic hydrocarbons (PAHs) which are highly toxic. As a matter of simplification, emissions are resumed to CO_2 and the consumption of one-liter Diesel emits around 2.7 kg of CO_2. To obtain the maximum power from each kg of fuel, the Diesel generator must run closer to 70% to 80% of its rated power design and consumes between 0.32 and 0.53 liters/ kWh at its rated power, and the selected Diesel generator should be close to the load demand.

Transport & Environment (2020), claims that a BEV in Europe emits, on average, almost 3 times less CO_2 than the equivalent petrol/ Diesel cars, considering the carbon footprint of battery production, in-use energy production, electricity losses, specific country grid characteristics, and recycling. In the worst-case scenario, a BEV with a battery produced in China and driven in Poland still emits 22% less CO_2 than Diesel and 28% less than petrol. In addition, in the best-case scenario, a BEV with a battery produced in Sweden and driven in Sweden can emit 80% less CO_2 than Diesel and 81% less than petrol. BEV will reduce CO_2 emissions four-fold by 2030 thanks to an EU grid relying more and more on renewables.

Although charging a BEV from the customer's perspective is easy to manipulate and requires a few seconds, it comprehends a sophisticated management system to control all internal parameters such as battery cell voltage and temperature, maximal current depending on grid network characteristics. Simulation results show that BEV charging generates different demand profiles into the grid, depending on the applied charging option. Moreover, a linear region for the control of BEV chargers is identified in the range of 20-90% state-of-charge (SOC).

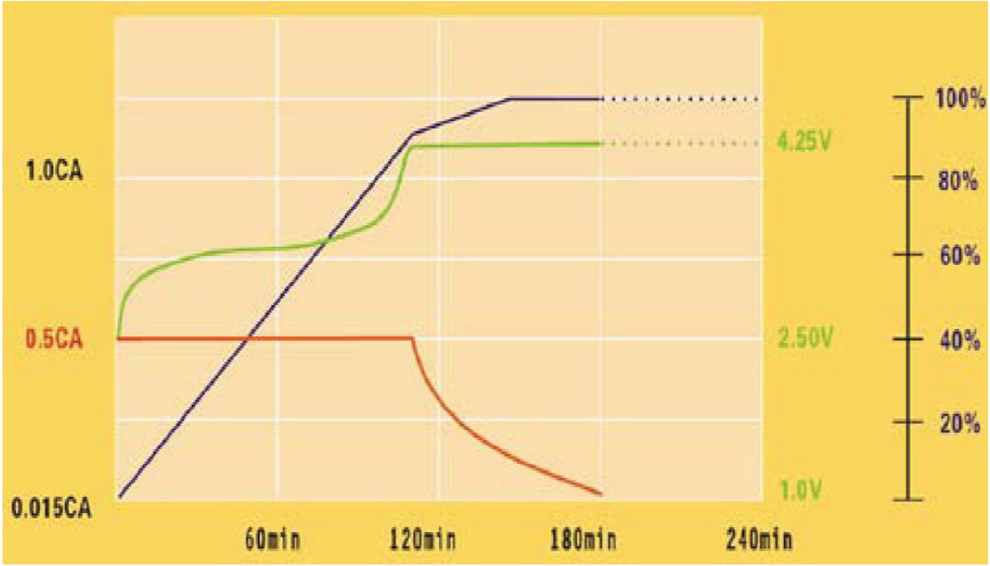
Marra et al. (2012) demonstrated how the charging process of a BEV must be intelligently controlled, to cope with renewable power fluctuations, electricity price, and local grid constraints. The modeling of the demand profile of a BEV is performed, addressing typical aspects of different BEV charger options, the battery parameters are extracted, and the battery manufacturer curves are reproduced without the need for sophisticated tools. Simulation results show that the demand profile due to BEV charging can have different characteristics based on the two charging options implemented by the charger. BEV has a preferable SOC usage window. Experimental charging/discharging tests performed on a single LFP battery cell demonstrate a relatively flat voltage profile up to about 80% SOC, while an exponential voltage increase from 80 to 90%, as shown in figure 15 and figure 16. Based on the findings of simulations and tests, it is determined that both charging current and power are controllable until a SOC level of about 90%. P_{ac} states for power on-grid side and P_{dc} states for Power on the battery side, as shown in figure 17.

FIGURE 15 - VALIDATION OF VOLTAGE PROFILE OF A LI-ION EV BATTERY WITH CHARGE/ DISCHARGE CURRENT OF 0.5C



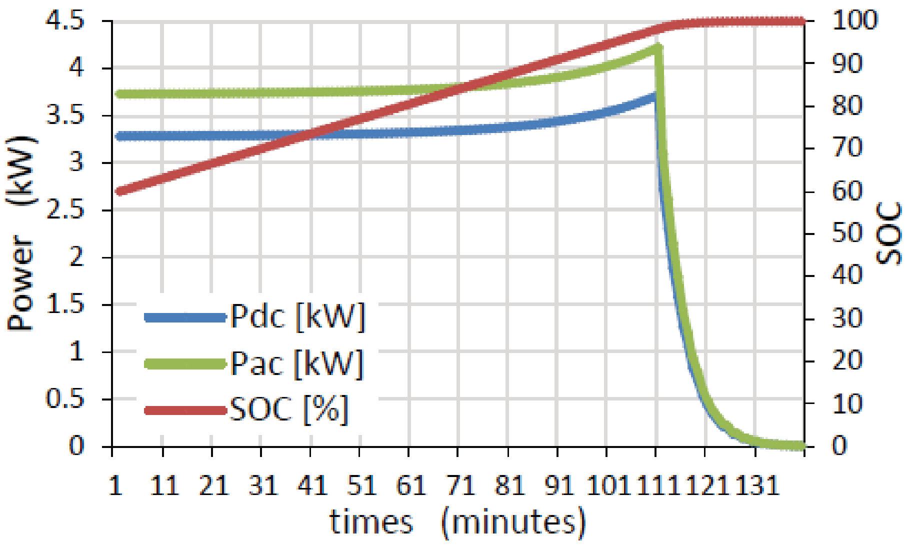
SOURCE: MARRA ET AL. (2012)

FIGURE 16 - TYPICAL CHARGING PROFILES FOR AN EV LI-ION BATTERY



SOURCE: MARRA ET AL. (2012)

FIGURE 17 - SIMULATION OF DEMAND PROFILE OF EV CHARGING WITH CC-CV OPTION, CHARGER EFFICIENCY η = 0.88, SOC = 60%. PDC, PAC, AND SOC PROFILES



SOURCE: MARRA ET AL. (2012)

ANEEL rules the regulatory framework of the electrical sector in Brazil. ANEEL has implemented laws to foster electric mobility since 2010. The main principle followed by ANEEL is to not create barriers and monopolies. According to normative resolution 819/2018 (ANEEL, 2018), the first regulation on recharging BEV, reduces uncertainty for those investing in the development of the recharging infrastructure. Any interested party can carry out, including for commercial exploitation at freely negotiated prices, the so-called public recharge. At its discretion, the local distributor may install charging stations in its operating area for the public recharging of BEV. In article 10, the normative states that Injection of electrical energy into the distribution network from vehicles is prohibited as participation in the Electricity Compensation System referred to in Normative Resolution No. 482, of April 17, 2012 (ANEEL, 2012). The provision in the caput does not apply to the bidirectional flow restricted to the same consumer unit. This is a controversial subject, as this does not allow a smart grid operation that could optimize the flow of energy while reducing the cost of ownership if the customer's choice is to sell energy at peak hours and buy it when energy costs less.

4.3 FINAL CONSIDERATIONS

The integration of BEV and electricity generation is a topic mentioned by researchers and international agencies worldwide. The reduction of CO_2 emission, responsible for GHG and the increase of Earth's temperature, demands a holistic and cross-boundaries action plan engaged by the government, industries, and services sectors.

Studies focus on the Life Cycle Assessment, the energy generation matrix, and the incorporation of new measuring techniques to size the efficiency and products derived from the transition from combustion engines to BEV. Several reports mention the integration of renewable energy sources such as biogas, solar panels, Eolic plants, and battery storage systems as a key element to reduce carbon footprint.

Kempener et al. (2015) mention remote location and solar panels as a perfect match to integrate into a smart island program and consequently reduce the economic dependency on Diesel fuel sources. The investment needed to enlarge the solar plant adoption is decreasing yearly as the worldwide volume of production is growing.

The fast rate of BEV adoption demands that the utility services are ready to manage this extra demand and plan beforehand the necessary system integration. CIGRE paper depicts the whole system interfaces and agents, exploring the new player's role and business creation for small-dedicated companies to large energy distributors.

BEV charging, and grid stability are addressed by smart charging. Substations and distribution transformers can quickly overload when no charging restrictions are applied, especially when charged during peak demand times. A charging strategy can mitigate this effect, moving loads to the valleys of the demand curve, thus not stressing furthermore the distribution grid, and permitting a higher BEV insertion percentage. It is advantageous to the grid the utilizing distributed generation resources with the vehicle chargers, increasing the overall reliability of the distribution system.

Authors explore Fernando de Noronha case while proposing the exploitation of renewable sources, BEV, and modification of Electricity Regulation toward the new era of distributed generation and grid evolution

Table 6 presents an overview of the papers described above, comparing their contributions with those of the proposed study.

TABLE 6 - REVIEW OF CURRENT LITERATURE

	PROPOSED STUDY	TESLA (2019)	LOPES ET AL. (2011)	BARROS ET AL. (2015)	KEMPENER ET AL. (2015)	ALMEIDA (2017)	SILVEIRA ET AL. (2013)	JAKHRANI ET AL. (2012)	TEJEDA ET AL. (2020)	CHOMA; UGAYA (2017)	THIEL ET AL. (2016)	WORIGHI ET AL. (2019)	VARGAS ET AL. (2020)	TRANSPORT & ENVIRONMENT (2020)	MARRA ET AL. (2012)	ANEEL (2018)
LIFE CYCLE ASSESSMENT	■	■	■					■		■	■		■	■		
RENEWABLE ENERGY	■	■	■	■	■	■	■		■	■	■	■		■		
ELECTRIC VEHICLE ADOPTION	■		■				■	■		■	■	■	■	■	■	
SMART ISLAND	■		■			■	■					■				
DISTRIBUTED GENERATION	■		■	■	■	■	■	■	■	■		■			■	
PBEV, ROTA 2030	■												■			
ELECTRICITY REGULATION	■												■			■

SOURCE: AUTHOR (2021).

5 APPLICATION CASE

In 2001, UNESCO declared Fernando de Noronha Island as a World Heritage Site (ICMBio, 2001). The island covers an area of 21 km^2 divided between the Fernando de Noronha Marine National Park and the Fernando de Noronha Environmental Protection Area, as shown in Figure 18.

With 3,000 inhabitants, tourism is the main economic activity and the number of visitors is increasing year over year. In 2019, 106,130 visitors spend on average five days on the island. This temporary population is not concentrated only in summer breaks but all over the year.

FIGURE 18 - FERNANDO DE NORONHA ARCHIPEL

SOURCE: ARCGIS (2021)

The Island administration is engaged to assure sustainable growth, to protect flora, fauna, and marine life. Public policies interdict the circulation of plastic bottles and promote sustainability education to reduce water and energy consumption.

In January 2020, the Governor of Pernambuco through law 16,810/20 (PERNAMBUCO, 2020) determined that new entries of vehicles that emit CO_2 (as those powered by gasoline, ethanol, or Diesel fuels) in Fernando de Noronha are prohibited from August 2022. This law exempts boats, airplanes, tractors used for building, and airport services. A second phase prohibits any vehicle circulation and permanence that emits CO_2 from August 2030. The Island became the first city in Brazil to determine a mobility policy focused on environment preservation by restricting fossil fuel fleet increases and replacing them with BEV in ten years. The term established will be extended by up to five years, if, at the time of the estimated date, there is not enough technological development to guarantee the supply of clean energy in the State of Fernando de Noronha.

5.1 ENERGY GENERATION IN FERNANDO DE NORONHA

The energy generation for the increasing number of consumer units (fixed and temporary users and potentially for BEV) in Fernando de Noronha must encompass the developments in technologies for renewable energy and energy efficiency. Electric Utility, End-users, and Government must share the benefits of introducing new technologies.

From the electric utility's view, the increase of renewable sources in the energy matrix must seek the lowest financial cost for electricity service without compromising safety standards or failing end users' expectations for reliability and customer service. From the End-user, this program must guarantee an affordable electricity service that allows all users to pay for at least a basic supply while preserving the economic growth of local activities. This requires a new framework of policy, legislation, and regulation as the current framework, based mainly on non-renewable sources, lacks the flexibility to integrate new options.

As of the date of the promulgation of law 16,810/20, a detailed plan of energy matrix transition to renewable sources was not followed, questions from residents, specialized media, the economic sector, and environmental organizations have emerged about the impacts on the supply of electricity, affordability of new mobility program and emission reduction effect.

As Fernando de Noronha's energy generation matrix relies primarily on Diesel-powered generators to supply energy to the resident population and tourists, a deeper analysis of the impacts of energy sourcing, transportation, and usage is necessary. Electric energy on the island is sourced and managed by the power utility Companhia Elétrica de Pernambuco (CELPE). Their generation system comprehends a thermal plant, named Tubarão, composed of five Diesel generators with an installed generation capacity of 4,978 MW. Three generators have a rated power of 1.28 MW, one has a rated power of 1.12 MW and a fifth generator operates as a system backup and has 1.12 MW of rated power, which consumes 5.4 million liters of Diesel per year in 5 generators groups and dispatches 19,2 GWh/year (91% of demand). Table 7 displays the yearly records from 2015 to September 2019. This study considers 2020’s energy generation information based on CELPE's official declaration to ANEEL.

TABLE 7 - THERMOELECTRIC GENERATION

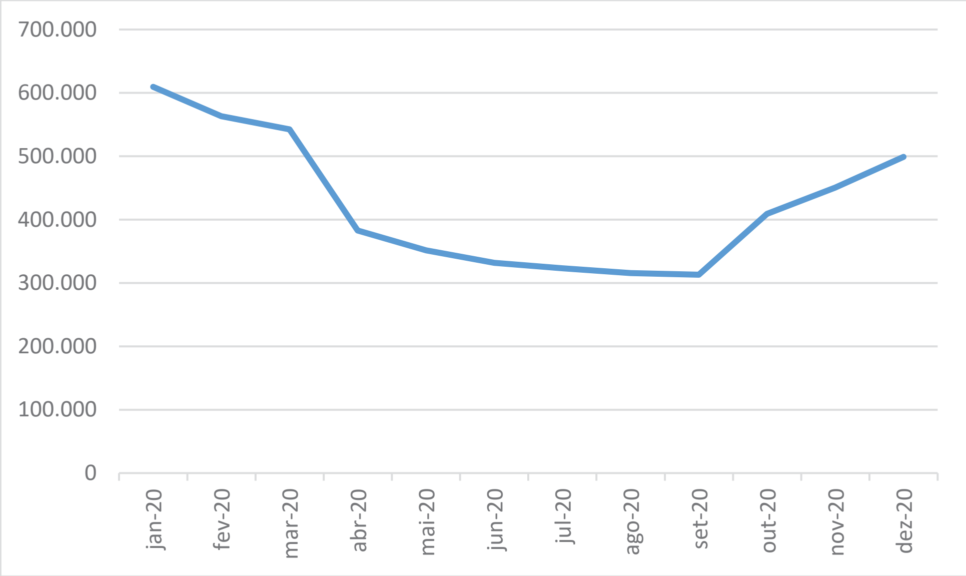
	Fuel Consumption	Energy Generation	Power Demand	
Year	Liters	GWh	MW max	MW average
2015	4,503,000	15,865	2.841	1,811
2016	4,761,000	16,827	3.031	1.916
2017	5,339,800	18,180	3.261	2.070
2018	5,378,385	19,253	3,852	2.197
2019* (sept)	4,461,531	16,068	3,720	2.454

SOURCE: CELPE (2019)

Fossils fuels are brought by maritime transport for Tubarão Power Plant and registered by CELPE on Electric Energy Trading Chamber (from Portuguese “Câmara de Comercialização de Energia Elétrica”) as Financial Statement of the Fuel Consumption Account (from Portuguese “Demonstrativo Financeiro da Conta de Consumo de Combustíveis (CCC)”), established by Normative Resolution no. 801 from December 19th, 2017 (ANEEL, 2017).

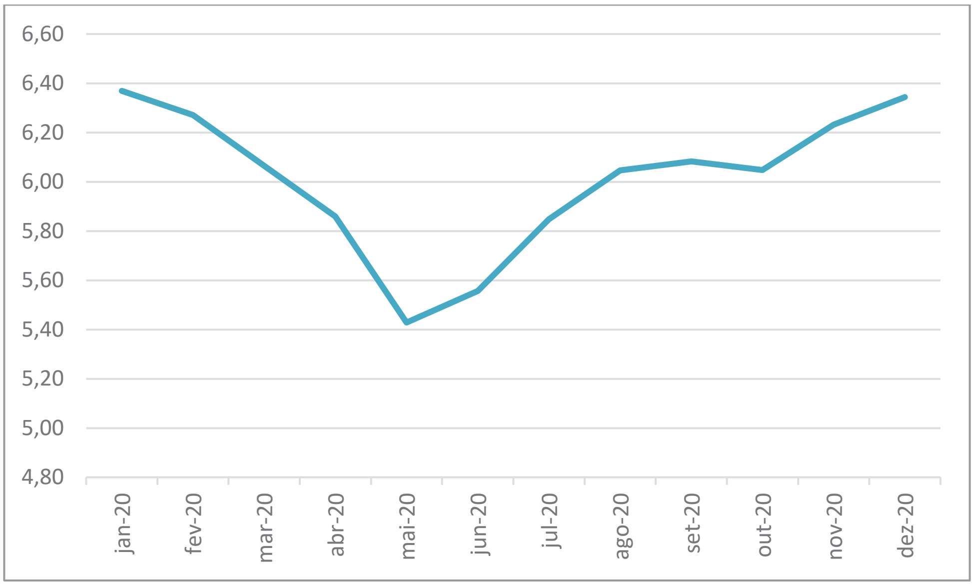
Figure 19 shows the number of liters of Diesel fuel used by the Tubarão Thermoelectric Plant in 2020 and Figure 20 presents the corresponding unit cost per Liter of Diesel.

FIGURE 19 - FUEL CONSUMPTION IN LITERS FOR ELECTRICITY GENERATION IN 2020



SOURCE: AUTHOR (2021)

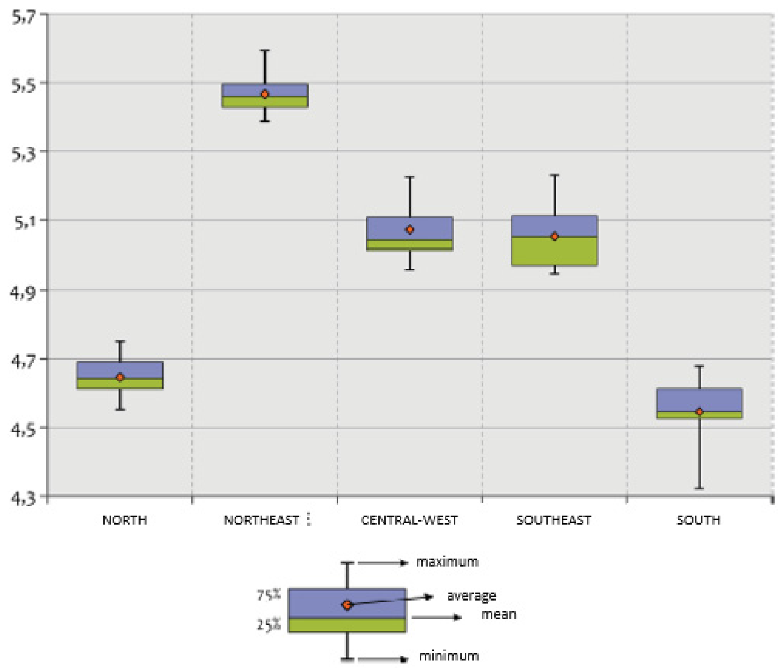
FIGURE 20 - FUEL COST IN R$ FOR ELECTRICITY GENERATION IN 2020



SOURCE: AUTHOR (2021)

Concerning renewable electricity generation, Fernando de Noronha is located 3 degrees south of the Ecuador line and has two solar plants with an installed power of 400 kWp and 550 kWp, generating 1,400 MWh/year (CELPE, 2019). According to INPE (National Institute for Space Research), the solar irradiation average equals 5.5 kWh/m^{2}day, relatively one of the highest irradiation levels in Brazil as shown in Figure 21.

FIGURE 21 - YEARLY VARIANCE FOR HORIZONTAL SOLAR IRRADIANCE (2005 to 2015)



SOURCE: INPE (2017)

Both solar power plants were built in areas ceded by the government, the first in the Air Force Command, and the second on a rainwater catchment plate belonging to the local government. In the case of the latter, it accumulates the function of generating energy and capturing rainwater, which passes underneath the photovoltaic modules on a sloping plate in an area of 8,000 square meters. Noronha I Solar Plant I has an area of 5,000 square meters, as shown in Figures 22 and 23.

FIGURE 22 - NORONHA I SOLAR PLANT

SOURCE: CELPE (2019)

FIGURE 23 - NORONHA II SOLAR PLANT

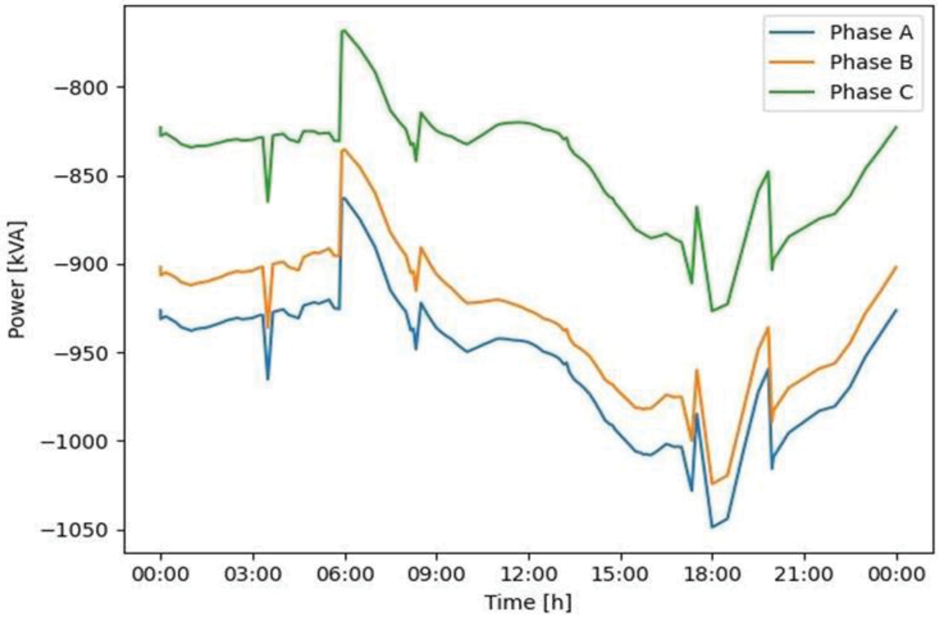
SOURCE: CELPE (2019)

Fuels for transport and maritime in the island are delivered by one unique gas station with prices of R$7.82/ liter for gasoline and R$6.46/ liter for Diesel as of March 2021 (MARINHO, 2021).

Energy storage is composed of two lithium-ion battery systems, each with a rated power of 280 kW and a nominal capacity of 510 kWh (total 1020 kWh) and they support the island grid.

The island’s substation is composed of the main transformer with a power rating of 6 MVA, a secondary transformer of 45 kVA, and a capacitor bank for power factor regulation. Figure 24 represents a typical output power profile from the substation.

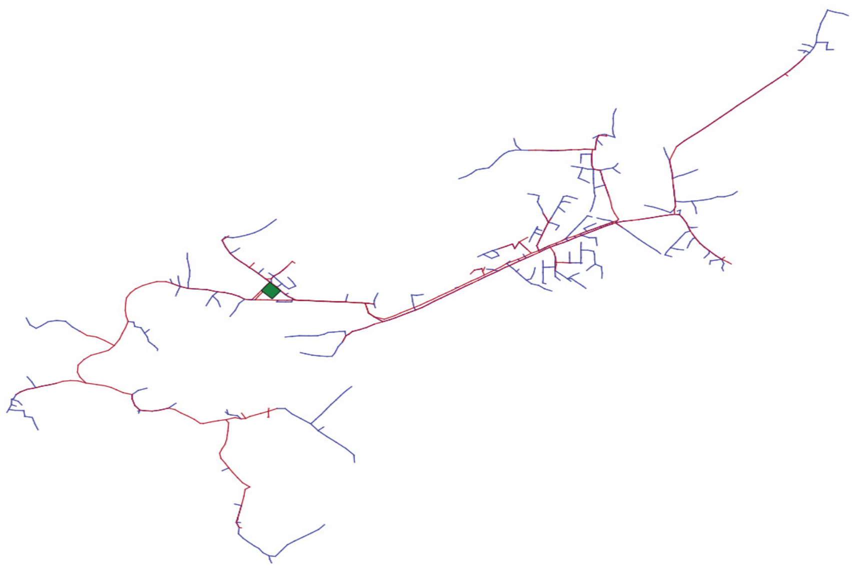
FIGURE 24 - SUBSTATION POWER OUTPUT



SOURCE: AZEVEDO (2021).

Three feeders are derived from the substation, FEN 01, 02, and 03. Figure 25 presents a georeferenced single-line diagram of the power system described above. Green squares represent the substation, red lines represent the medium voltage lines and blue lines represent the low voltage line.

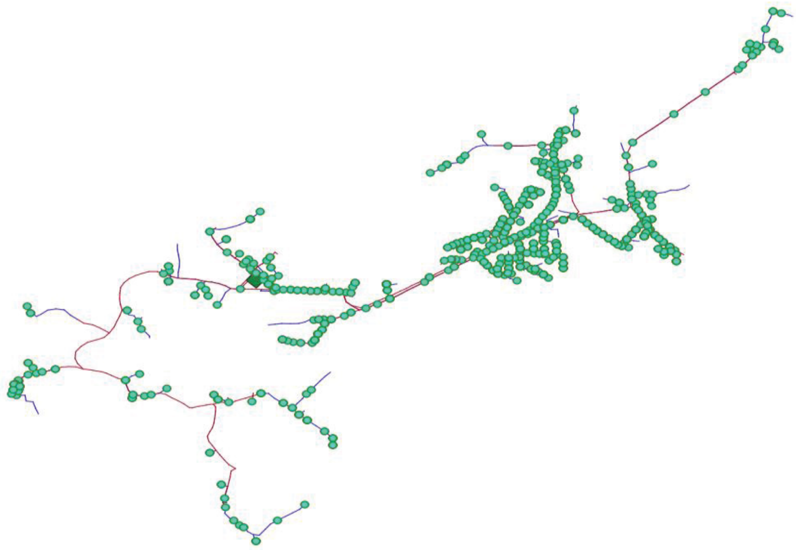
FIGURE 25 - FERNANDO DE NORONHA GEOREFERENCED POWER SYSTEM



SOURCE: LACTEC (2016).

The distribution system operates at a primary voltage of 13.8 kV, and a secondary voltage of 380/220 V. There are 35 distribution transformers along the grid. Some consumers are connected to the primary voltage of 13.8 kV (medium voltage consumers), but most of the loads are connected to the low voltage grid, 380/220 V. Figure 26 displays the location of these consumers as green dots.

FIGURE 26 - LOCATION OF LOW VOLTAGE CONSUMERS

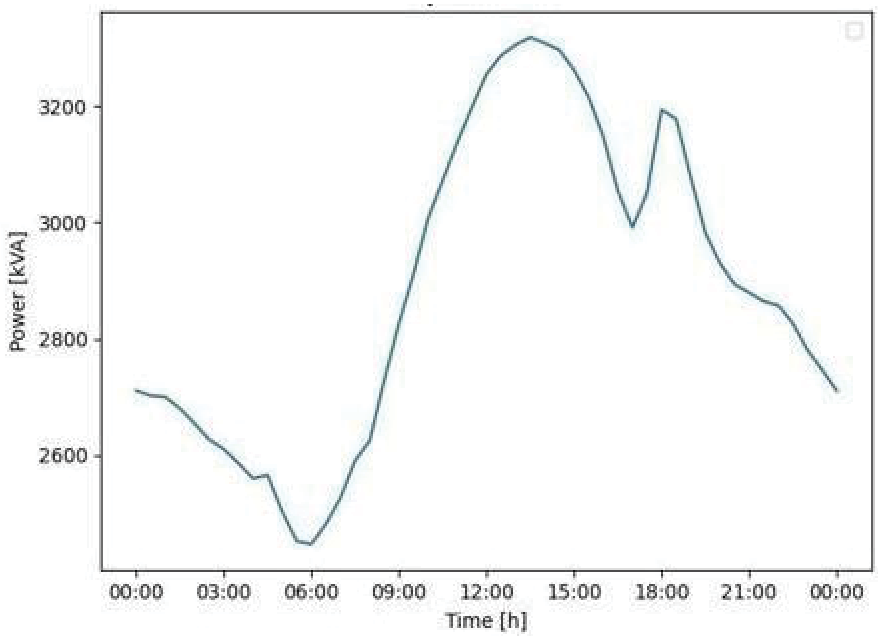


SOURCE: LACTEC (2016).

The load profile of the power system exhibits the typical behavior presented in Figure 27, being this profile, a result of measurements made on the island's power system.

The peak demand time reaches its limits during the afternoon. That phenomenon is common in Brazil's power grid, mainly due to high temperatures during the afternoon, which induce a mass use of air conditioning systems.

FIGURE 27 - SYSTEM LOAD PROFILE



SOURCE: AZEVEDO (2021)

Based on the report from LACTEC, a detailed analysis of electricity consumers' typology was carried out targeting to define detailed power impacts (capacity constraints) on the grid during charging periods.

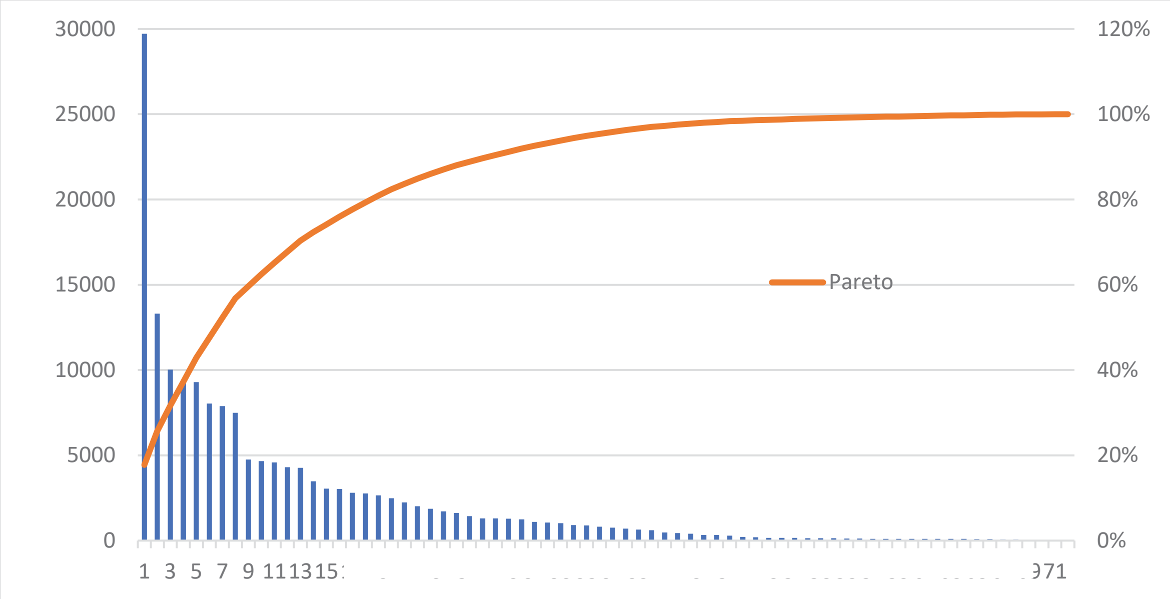
Based on these records, the energy consumption amounts to 216,279 MWh/year with the Industrial sector 112,514 MWh/year (52 % from total), Services 44,793 MWh (21%), commercial as 26,714 MWh/year, inland as 21,927 MWh (10%), followed by residential 10,330 MWh/year (5 % from total). Figure 28 shows in the Commercial sector, 20 units consume approximately 80% of total electrical energy, and table 8 shows the equivalent energy generation with photovoltaic panels.

TABLE 8 - ENERGY CONSUMPTION BY UC

Consumer Unit	Energy Consumption	Equivalent PV panels
	MWh/month	Quantities
UC 1	29.7	602
UC 2	13.3	270
UC 3	10.0	207
UC 4	9.3	193

SOURCE: AUTHOR (2021)

FIGURE 28 - MONTHLY ENERGY CONSUMPTION (IN kWh) BY UNIT CONSUMERS (UC) AND ACCUMULATED



SOURCE: AUTHOR (2021)

5.2 MOBILITY PANORAMA IN FERNANDO DE NORONHA

According to the DENATRAN database, 1,388 vehicles are registered in Fernando de Noronha, 702 are classified as automobile (51%), 568 are classified as two-or-three wheels (41%), 49 are classified as a trailer (4%), 36 are classified as light commercial vehicles (3%) as shown in table 9. The remaining 33 units are spread as Bus, Truck, Sidecar, and others (DENATRAN, 2021).

TABLE 9 - FLEET COMPOSITION

SEGMENT	TOTAL	Share in total Fleet
AUTOMOBILE	702	51%
MOTORCYCLE	568	41%
TRAILER	49	4%
LCV	36	3%
BUS	13	1%
TRUCK	12	1%
NOT IDENTIFIED	7	1%
TOTAL	1388	

SOURCE: DENATRAN (2021)

The total number of 702 automobiles is split among 354 leisure vehicles (Buggy), 147 passenger vehicles, 113 light commercial Pick-ups, 40 hard-work utility vehicles, 35 Sport-utility vehicles, seven small picks, and six medium pick-ups as shown in table 10.

TABLE 10 - AUTOMOBILE FLEET COMPOSITION

SEGMENT	SUB-SEGMENT	UNITS
AUTOMOBILE	BUGGY	354
	JEEP	40
	MEDIUM PICK-UP	6
	VEHICLE	147
	PICK-UP	113
	SMALL PICK-UP	7
	SUV	35
TOTAL		702
BUS	PEOPLE MOVER	13
LCV	PEOPLE MOVER	11
	VAN	25
TOTAL LCV		36

SOURCE: DENATRAN (2021)

As of January 2020, there are 18 BEVs as shown in table 11.

TABLE 11 - ELECTRIC VEHICLE FLEET

SEGMENT	SUB-SEGMENT	UNITS
AUTOMOBILE	IEV40	3
LCV	KANGOO	15
TOTAL		18

SOURCE: DENATRAN (2021)

Because of local amenities and tourist's interest, leisure vehicles (buggy) account for an expressive 50% of the automobile fleet. These are non-homologated vehicles, using engines adapted from mass production vehicles. More than 54% of these vehicles are in operation for more than 21 years as shown in table 12.

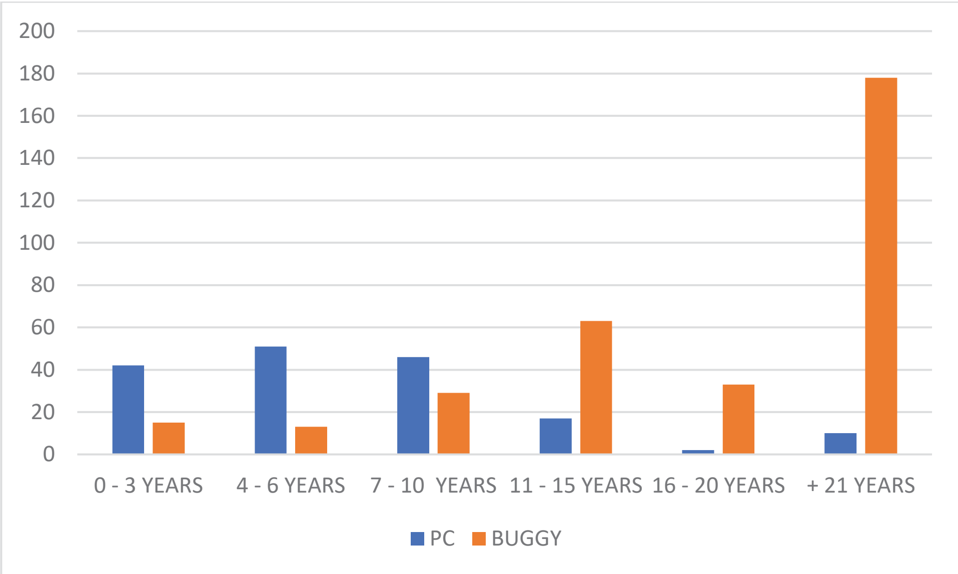
TABLE 12 - BUGGY FLEET - YEARS OF USAGE

In-Use Age	Passenger Cars	Leisure Vehicles (Buggy)
	147	354
0 - 3 years	25%	5%
4 - 6 years	30%	4%
7 - 10 years	27%	9%
11 - 15 years	10%	19%
16 - 20 years	1%	10%
+ 21 years	6%	54%

SOURCE: DENATRAN (2021)

Figure 29 and Table 13 show the total units in accumulated numbers of years in Fernando de Noronha for passenger cars and buggies. Buggy's fleet age is in the +21 years range while passenger cars are less than 10 years.

FIGURE 29 - FLEET IN-USE AGE



SOURCE: DENATRAN (2021)

TABLE 13 - FLEET - IN-USE AGE

In-Use Age	Quantity	Mix	From	To
0 - 3 years	205	15%	2021	2018
4 - 5 years	218	16%	2017	2015
6 - 10 years	254	18%	2014	2011
11 - 15 years	201	14%	2010	2006
16 - 20 years	190	14%	2005	2000
+ 21 years	320	23%	1999	
	1388			

SOURCE: DENATRAN (2021)

This study analyzed the homologated 147 passenger vehicles, their CO_2 emission, and energy fuel consumption from the regulatory official database (INMETRO, 2020) which enables a detailed and traceable correspondence. The modeling of non-homologated vehicles incurs in non-accurate simulations and many assumptions that may not correspond to real figures.

The circulation of vehicles in Fernando de Noronha is observed in paved roads and non-paved roads distributed along the main highway (BR-363) which has seven kilometers of extension. This study considers a daily mileage of 16 kilometers for passenger vehicles (one round trip per day), corresponding to 5,840 kilometers per year.

The total cost of ownership corresponds to the purchase price of an asset plus the costs of operation. It gives a bigger picture of what the product is and what its value is over time. A wider comprehension considers the residual value after the final usage period.

This study includes operation costs as yearly license tax, insurance, maintenance, and energy cost and they constitute an important variable for the impact of energy transition toward electrified vehicles. FIPE index expresses average vehicle prices announced by sellers in the national market, serving only as a parameter for negotiations or evaluations. The prices charged vary depending on the region, conservation, color, accessories, or any other factor that may influence the conditions of supply and demand for a specific vehicle (FIPE, 2021)

License Tax:

- Motor Vehicle Ownership Tax (in Portuguese “Imposto sobre a Propriedade de Veículos Automotores”) (IPVA):
    - ICE vehicles: 2.5% of the FIPE index.
    - EV: tax exemption.
- License Fee: R$98.91
- Insurance: as this varies according to each owner’s profile, this study considers 2.5% of the FIPE index.
- Maintenance: shown in table 14

  Entry segment: vehicles from A and B class

  Medium segment: vehicles from B+ and SUV class

  Upper segment: vehicles from C and C+ SUV class

  EV segment: vehicles from B and B+ class

TABLE 14 - MAINTENANCE COST

Segment	20,000 km	40,000 km	60,000 km
Entry	R$300	R$1,000	R$1,000
Medium	R$500	R$2,000	R$2,000
Upper	R$800	R$3,000	R$3,000
EV	R$100	R$500	R$500

SOURCE: AUTHOR (2021)

Energy costs considered are:

- Gasoline: end-user price R$7.82/ Liter (March/2021) (MARINHO, 2021).

- Electricity: valid from April 2021 to April 2022 (CELPE, 2021).
    - Residential B1, B3: Consumption active: R$0.61948/ kWh.
    - Tax: PIS 1.21%, COFINS 5.59%, ICMS 0%.

The average age of the in-use fleet corresponds to 7.7 years while in Brazil average is 10 years and for simulation. This study considers fleet renewal each year and it serves as a model to calculate the baseline for the 2030 fleet average CO_2 emission and energy consumption (ANFAVEA, 2020).

The baseline for CO_2 emission and Energy consumption examines the Brazilian Vehicle Labelling program of INMETRO (2020). This program allows consumers to compare the energy efficiency of vehicles from the same category for conscious choice, in addition to providing information about the fuel consumption of light vehicles sold in Brazil. These reference values are obtained from consumption measurements made in the laboratory, according to the NBR 7024 standards. For this purpose, Brazilian standard use fuels and pre-established driving cycles carried out in standardized laboratory measurements and they are the ideal way to measure the energy consumption, regardless of the laboratory used. They allow all models to be tested in a standardized manner, under controlled conditions, ensuring that measurements can be repeated under the same conditions and used in a uniform comparison between different vehicle models, within the same category.

In 2018, CONAMA published Resolutions 490 and 492, which stated the new phases of PROCONVE L7 and P8 from 2022. The new L7 phase brings a significant reduction in fuel vapors that are lost in the atmosphere, while the P8 phase should significantly reduce the emission of nitrogen oxides. These two actions complement each other and reduce the formation of oxidation compounds in the atmosphere of large urban centers, especially ozone gas.

To compose a traceable and specific simulation tool, this study considers the Labelling Program (PBEV) records (CO_2 and Energy Consumption), grouped and allocated by market segment depending on vehicle size.

To comply with future emission legislation set by CONAMA and energy consumption set by ROTA 2030, the automotive industry is obliged to introduce new technologies. Considering the records of the target from 2012 to 2026, the yearly rate reduction is -2%/year. This reduction will be the reference for the simulation baseline for energy consumption MJ/km and CO_2 g/km as shown in table 15.

TABLE 15 - FUEL EFFICIENCY PROGRAM IN BRAZIL

Program	Law	Vehicle Mass	Period Baseline	Period Target	Energy Cons. Baseline	Energy Cons. Target	Period Reduction	Yearly red. rate
		kg			MJ/km	MJ/km		
Inovar Auto	12715/ 2012	1,121	2012	2017	2,070	1,820	-12%	-2%
ROTA 2030 Step 1	13755/ 2018	1,121	2017	2022	1,820	1,620	-11%	-2%
ROTA 2030 Step 2	Not defined	1,121	2022	2027	1,620	1,442	-11%	-2%

SOURCE: AUTHOR (2021)

5.3 MOBILITY AND ENERGY TRANSITION IN FERNANDO DE NORONHA

The mobility and energy transition in Fernando de Noronha consist of the gradual replacement of fossil fuel-powered vehicles to BEV while shifting the energy sources from Diesel Generators to solar panels and battery storage systems. Local government policy sustains this transition by the “Noronha Zero Carbono”, followed by the Research and Development Program defined by ANEEL (National Electric Energy Agency) established by law nº 9,991 / 2000.

This transition toward cleaner transportation modality must encompass the electric energy sector from generation, infrastructure, and distribution, the automotive sector by offering affordable BEV, the public sector by promoting cleaner mobility and renewable energy modalities, and finally the population awareness toward sustainability actions. Similar programs exist in Porto Santo in Portugal, Utrecht in Holland, Island of Astypalea in Greece, and Island of Scilly in England.

Fernando de Noronha’s population relies on tourism activities and depends on the attractiveness of its natural resources to encourage visitors during the year. The fact that today BEV may contribute to the ecosystem is not seen clearly by the press and by the local population as the main impact of energy generation is the additional Diesel consumption to generate electricity.

The energy and mobility transition in Fernando de Noronha must match economic and technological aspects to limit the amount of investment needed. The introduction of solar panels will imply a new panorama of energy sourcing, storing, and delivering to the mobility of the local population, while reducing the dependence on Diesel oil brought from the continent.

The optimization of energy sourcing and consumption must rely on advanced techniques such as vehicle-to-grid communication, solar panels linked to hybrid inverters (on-grid and off-grid) and battery storage, and smart charging scheduling.

6 METHODOLOGY AND RESULTS

According to EVO (Efficiency Valuation Organization) by using International Performance Measurement and Verification Protocol, a "base case" is determined, and this is done before the performance project. Then energy use after the project is measured to determine the savings. In the lifetime, the measurements are kept ensuring that their savings persist. Industry experts agreed that the measurement of energy savings required both metering and a methodology, hence the need for a protocol. However, existing protocols were considered a patchwork of inconsistent, sometimes unreliable efficiency installation and measurement practices that prevented new forms of lower-cost financing. The North American Energy Measurement and Verification Protocol were published in March 1996 to help overcome these impediments.

To simulate and provide a reliable source of measures, which can help to address the mobility and energy with data records from the field, this project consists to frame the mobility transition in Fernando de Noronha toward BEV by collecting data about the present fleet and its characteristics, its energy consumption and CO_2 emission records during a predetermined period. By employing this process, the proposed project can be replicable, scalable, and auditable in other cases, by confronting details of simulation and the future objects. This gives credibility for energy saving reports, thereby increasing the value of the project for the local authorities and Environmental agencies. If properly integrated, Measurement and Verification activities will serve to increase and strengthen the Fernando de Noronha target for Zero Carbon ambition.

6.1 DETERMINATION OF MEASURING LIMITS

Fernando de Noronha’s isolation from the continent of 540 km from Recife (PE) and 380 km from Natal (RN) allows to precisely determine the measuring geographic limits, mobility, and energy frontiers for this project, already defined before. A non-exhaustive list of parameters that may influence the forecasted energy consumption and emissions is detailed ahead.

6.2 BEV INSERTION

The simulation migration from combustion to BEV and impact on energy, emission, and economical benefits for mobility contains four different hypotheses:

- Baseline line: Introduction of BEV at 30% percent in 2030. This low mix would be a result of the low interest of the population toward clean mobility, the high acquisition cost of BEV, and relaxed regulation toward this transition.
- EV introduction mix: introduction of BEV at 50% in 2030. This mix would be a result of early adopters' interest in new technologies and reduce the dependency on gas prices, the established public policy toward clean mobility. Acquisition cost for BEV remains high compared to combustion vehicles.
- Massive mix: introduction of BEV at 70% in 2030. This mix would be a result of incentives toward clean energy generation in houses and commercial sectors, the availability of affordable vehicles with low in-use cost, the restriction of circulation of combustion vehicles with more polluting and fuel consumption, and limited availability of smart charging energy systems.
- Full mix: introduction of BEV at 100% in 2030. This mix would be a result of the circulation ban of combustion vehicles, the availability of massive incentives toward clean energy generation in houses and the commercial sector, and the full availability of smart charging of energy.

Table 16 displays the different scenarios for BEV insertion.

TABLE 16 - BEV INSERTION SCENARIOS

Hypothesis of adoption	Mix	Population interest in clean mobility	Acquisition Cost of EV	Regulation toward Transition	Smart Charging Penetration
Base Line	30%	Low	high	low	No
Introduction	50%	early adopters	high	medium	No
Massive	70%	medium	medium	high	Low
Full	100%	high	medium	high	High

SOURCE: AUTHOR (2021)

6.3 TRAVELED DISTANCE

The geographic, commercial, and service activities and population characteristics of Fernando de Noronha determine the number of average kilometers traveled by drivers. This project assumed that the transition toward BEV would not limit the daily mileage.

The island tourist spots spread along with the cost. The longest distance is from Mirador Air France in Vila dos Remedios to Baía do Sueste and it amounts to eight kilometers. If one round-trip of 16 kilometers is considered, it equals 5840 kilometers per year.

The monitoring of daily trips could be possible by frequently controlling the monthly traveled distance or by using telematics units embedded in the vehicles. These devices would inform a central monitoring system of the exact amount of energy consumed instantly and based on smart adaptive controlling the later battery charging would be balanced and adjusted accordingly.

For all passenger vehicles, this study assumed a constant distance traveled around the year in the model and it is not considered the mobility transition to other modalities such as electric motorized bikes or public transport.

6.4 ENERGY DISTRIBUTED GENERATION WITH SOLAR PANELS

ANEEL Normative resolution N°482/ 2012 (ANEEL, 2012) determines the exploitation of microgeneration and mini-generation and the following items for the electricity distribution system and energy compensation:

1. Distributed Microgeneration: electric power generating plant, with installed power less than or equal to 75 kW and that uses qualified cogeneration, according to ANEEL regulations, or renewable sources of electrical energy, connected to the distribution network using consumer units;
2. Distributed Mini-generation: electric power generating plant, with installed power greater than 75 kW and less than or equal to 5 MW and using qualified cogeneration, as ANEEL regulation, or renewable sources of electric energy, connected to the distribution network through consumer unit facilities;

3. Electric energy compensation system: a system in which the active energy injected by consumer unit with microgeneration or distributed mini-generation is assigned, through a loan free of charge, to the local distributor and subsequently compensated with the consumption of active electricity;
4. Improvement: installation, replacement, or refurbishment of equipment in existing distribution systems, or the adequacy of these facilities, to maintain the provision of adequate electricity;
5. Reinforcement: installation, replacement, or refurbishment of equipment in existing distribution systems, or the adequacy of these facilities, to increase distribution capacity, reliability of the distribution system, useful life or for connecting users;
6. Shared generation: characterized by the gathering of consumers, within the same concession or permission area, through a consortium or cooperative, composed of individuals or legal entity, which has a consumer unit with microgeneration or mini-generation distributed in a different form the consumer units in which the surplus energy will be compensated;
7. Remote self-consumption: characterized by consumer units owned by the same Legal Entity, including central office and affiliates, or Individual that has a consumer unit with microgeneration or mini-generation distributed in a different location from the consumer units, within the same concession or permission area, in which the excess energy will be offset.

Although the energy generated in solar panels in an isolated region as Fernando de Noronha plays a critical role, according to ANEEL (2020b). Sixteen solar plant units produce 934 kW. However, if Public solar plants of Noronha I and Noronha II are deducted (362 kW and 497 kW), the total non-public power amounts to only 75 kW (8% of the total power) producing 128,761 kWh/year spread on an area equivalent of 423 m^2. These non-public solar panels energy contribute 0.7% of 19.2 GWh/ year on the island, as shown in table 17.

TABLE 17 - SOLAR UNITS INSTALLED POWER

Sector	Modality	Installed Power	Units
Commercial	Generation in own Unit	61	7
Public	Remote self-consumption	362	1
	Shared generation	497	1
	Generation in own Unit	5	2
Residential	Remote self-consumption	2	1
	Generation in own Unit	8	4
Total		**934**	**16**

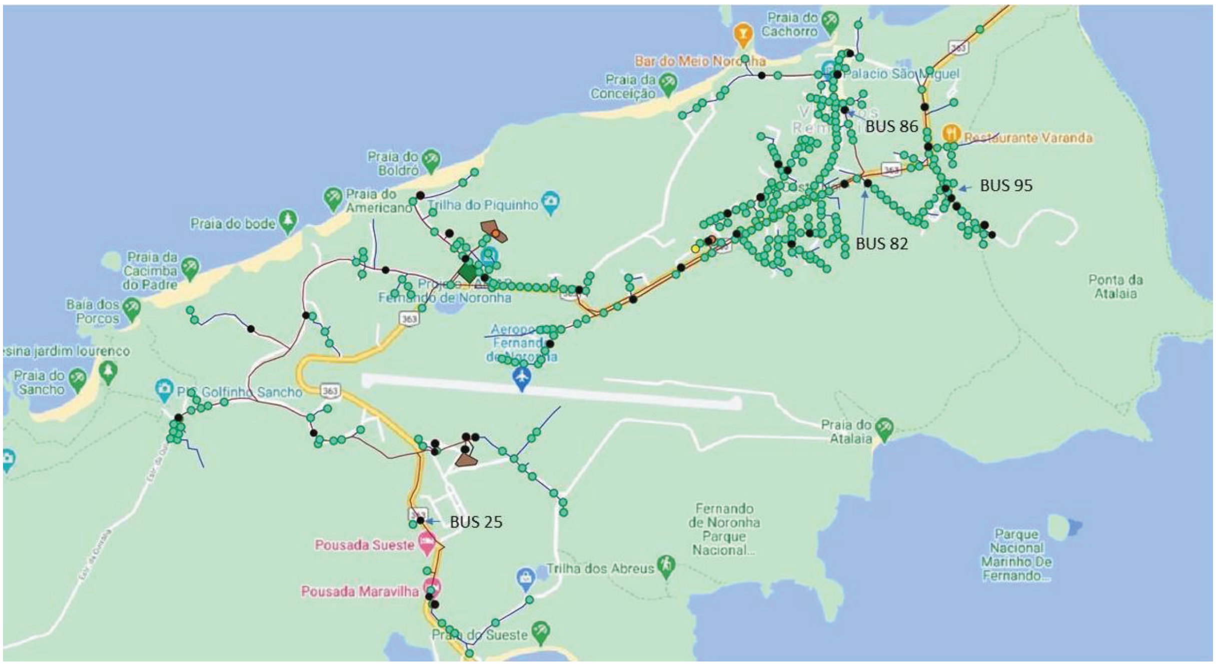
SOURCE: AUTHOR (2021)

The combination of public incentives by financing the implementation of energy efficiency programs combined with a consortium of consumers as identified in section 5.1 (80% of consumed energy is divided unequally within 20 units) is a key element to reduce the dependence on fossil fuel.

Based on CELPE's data, each 100-kWh produced by solar source saves 34 L of Diesel fuel and 88 kg CO_2. It corresponds to R$180.38 compensated by the Electric Energy Commercialization Chamber (CCEE), based on CELPE's report from December 2020 on which R$70 corresponds to maritime freight of Diesel transported from the continent.

As described in item 5.1, the grid structure in the island has an identified weakness whereas power demand and distribution may suffer mismatching or curtailment. The areas concentrated on branch 95 demand power reinforcement and this could be supplied by concentrating small solar panel plants, which will serve to stabilize the grid in the case of electric charger stations. Figure 30 shows the distribution network.

FIGURE 30 - DISTRIBUTION NETWORK DIAGRAM



SOURCE: AZEVEDO (2021)

6.5 ROADMAP

This section described the comparison between different BEV mix scenarios and their effects on energy, emission, and economics.

The fleet energy consumption and emission are calculated based on PBEV register from 2009 available to each vehicle and for the one without any information, an approximation based on similar vehicles and engine were considered. For leisure vehicles, this study considered the fuel economy informed by an interview with the driver and consulting the supplier database on the Internet. This simulation considered 0.6 MJ/km as energy consumption for all vehicles present on the island, which represent Renault ZOE and Renault KANGOO homologation reference in the PBEV database.

The calculated baseline from the current fleet panorama is forecasted to 2030 based on energy reduction from recent Fuel Economy programs (Inovar Auto e ROTA 2030) with a result of -2%/year for the new registrations. This study simulates a fleet reduction of 0.5% by year and it will represent in 2030 -4.9 % vs 2020.

6.6 ENERGY AND EMISSION CALCULATION

The total number of registered passenger vehicles 147 vehicles of which 90% (132 units) were identified in PBEV records from 2009 to 2020 and were used for this calculation. For 15 vehicles, whose records were not at PBEV, it was considered the average values from the fleet as baseline (INMETRO, 2020).

The analysis of 147 vehicles reveals total energy consumption of 247 MJ/km, which produces 17,348 gCO_2/km in 2020.

In case it is assumed 6000 km per year as an average mileage traveled, this corresponds to baseline (147 vehicles) of energy consumption 0.412 GWh per year and 104 tCO_2 per year. Based on the assumption of -4.9% in 2030, this corresponds to 0.3916 GWh per year and emission of 99 tCO_2 per year.

The removal of 30% of combustion vehicles (44 vehicles) eliminates the consumption of 0.1174 GWh per year and 29 tCO_2.

Considering an energy consumption of 0.66 MJ/km for each BEV, the replacement of these 44 vehicles adds 0.044 GWh with no generation of CO_2 in the tailpipe. Assuming energetic value of 28.99 MJ/ liter of gasoline E22 (gasoline with 22% alcohol) if a BEV consumes 0.66 MJ per each kilometer, it is equal to an energetic consumption of 43.92 km/ liter.

The net impact is a reduction of 0.069 GWh and the elimination of 29 tCO_2 from the tailpipe emission with 30% (44 vehicles) obtained from BEV insertion.

To calculate the impact of electric energy production for BEV from the Diesel generator in the Tubarão plant, this study considers the available CELPE information, as shown in table 18.

According to CELPE's declaration at the ANEEL site, in 2020 the Energy generation reached 18,033 MWh and consumed 5,091,404 liters of Diesel. The consumption of one liter of Diesel corresponds to 3.54 kWh and it costs R$6.01. The corresponding gas emission is 0.7121 CO_2/ kWh (WWF, 2021).

TABLE 18 - ENERGY GENERATION

Item	Unit	Average
Generation Cost	2020	30,846,388
Energy Generation	MWh	18,033
Fuel	L	5,091,404
Ratio Energy/ Fuel	kWh/L	3.54
ANP Diesel Price	R$/ L	3.07
Performance average	R$/MWh	292.94
Ration Energy/ Cost	kWh/ R$	0.59
Reimbursement CCC	R$	25,203,354
Ratio reimbursement/ Fuel	R$/L	4.91
Total Cost generation / Fuel	R$/L	6.01

SOURCE: ANEEL (2020)

For the energy generated by solar panels is considered from current declared values from CELPE (Noronha I 600 MWh and Noronha II 770 MWh) divided by 3400 modules (ratio 0.4029 MWh per module) as a yearly average.

The production of electric energy for this fleet of 44 vehicles of 0.044 GWh would absorb 13,704 liters of Diesel and R$82,363. Alternative to this fossil fuel consumption, if it is considered the energy produced by solar panels distributed in the solar farms or installed at the rooftop, the corresponding area is calculated as 162 m^2 and it would require 84 solar modules.

The investment in solar panels for energy generation in Fernando de Noronha is limited due to costly transport and the lack of local specialized technician workers. This barrier is confirmed by the first assessment with a solar company offering to install a solar panel of 4.5 kWp consisting of 10 modules covering 23 m^2, generating 7.7 kWh/ year. The total equipment cost (solar modules, DC/ AC inverter 5 kW, mounting components) amounts to R$22,000 and it must be added to the material transport (R$3,000), technician transport, and lodging (R$11,000). The equivalent ratio of the total cost to installed energy is R$4.67/ kWh. To take profit of installing in several residences and locations to an equivalent energy generation of 77 kWh/ year, it is assumed R$220,000 of equipment, R$15,000 of material transport, and R$33,000 technician transport and lodgment, which results in a ratio of R$3.51/ kWh. More solar equipment and installation contracts are sourced, the lower the ratio R$/ kWh is reached. The second benefit is to decrease the diversity of modules and inverters, which results in negotiation advantage with suppliers and less maintenance cost (repair parts and operational servicing). An alternative solution is a shared generation, established by ANEEL (2015) in Normative Resolution 687/2015 in which a consortium of partners is created by investing a micro or mini-generation source, in the same concession or permission area.

In this case, to install a 48.51 MWh/year required for 44 BEV, the total cost is R$170,000 and this corresponds to less than two years of fossil fuel consumption by CELPE generator.

Finally, each replaced combustion engine by BEV requires 3.7 m^2 of solar panel with equivalent average characteristics of Noronha I and II, an investment of R$3,850 which saves 310 Liters of Diesel per year. These factors change depending on new BEV characteristics and performance, the photovoltaic solar localization and setting, and the management of charging during the operation.

The factor R$ 3.51/ kWh installation corresponds to a first case assumption, it serves as a reference for this study, and a public agency as ANEEL should be further assessed, together with the local government, and CELPE to promote a wider insertion of solar energy as a scope of Noronha Zero Carbon program.

Table 19 demonstrated scenarios of 50%, 70%, and full switch to electric passenger vehicles (147 units) and the number of solar panels.

TABLE 19 - BEV INSERTION FOR PASSENGER VEHICLES

		MIX VE	30%	50%	70%	100%
	Quantity of BEV	unity	44	74	103	147
Energy Generation Diesel source	Energy for BEV	kWh/ year	48.51	80.86	113.20	161.712
	Generation cost	R$/ L	6.01	6.01	6.01	6.01
	Energy per Liter	kWh/ L	3.54	3.54	3.54	3.54
	Diesel consumption	L	13,704	22,840	31,977	45,681
	Generation cost	R$	82,363	137,273	192,182	274,546
Energy Generation Solar source	Energy for BEV	MWh/ year	48.51	80.86	113.20	161.712
	Area	m^2	162	270	378	541
	Quantity of modules	unity	84	140	196	280
	Installation cost rate	R$/ kWh	3.5	3.5	3.5	3.5
	Final installation cost	R$	169,798	282,997	396,196	565,995

SOURCE: AUTHOR (2021)

The second hypothesis includes 702 vehicles with more variety of vehicles and segments. As leisure vehicles represent 50% of this fleet and there are no valid homologation records in PBEV, it is necessary to make some assumptions, as shown in table 20. These numbers correspond to information gathered at the manufacturer site and checked with one vehicle's owner.

TABLE 20 - LEISURE VEHICLES ENERGY CONSUMPTION

Total	Fuel Consumption	Energy Consumption	Emitted CO_2	Quantity
Manufac. year	km/l	MJ/km	g/km	
2021 - 2010	9	2.8115	209	191
2009 – 2000	7	3.5823	265	124
< 2000	6	4.2881	318	39

SOURCE: AUTHOR (2021)

Table 21 shows the fleet consumption and emission for all segments:

TABLE 21 - ENERGY CONSUMPTION AND EMITTED CO_2

Segment	Quantity	Energy Consumption [MJ/km]	Emitted CO_2 [g/km]
Buggy	354	1149	85,312
Jeep	40	18	1,316
Medium Pick-Up	6	13	1,096
Passenger Vehicle	147	247	17,348
Pick-Up	113	267	20,797
Small Pick-Up	7	15	830
SUV	35	96	7,400
	702	**1,806**	**134,099**

SOURCE: AUTHOR (2021)

The fleet consumes 1,806 MJ/km and it emits 134.1 kgCO_2/km in reference 2020 and this corresponds to 3.01 GWh and an emission of 804 tCO_2 in case of an annual mileage of 6,000 km. Applying the projected reduction of -4.9% in 2030, this amounts to 2.86 GWh and 765 tCO_2. The necessary energy to 702 BEV corresponds to 772 MWh/year and saves 765 tCO_2/year.

Table 22 shows the final calculation for BEV insertion.

TABLE 22 - BEV INSERTION FOR AUTOMOBILES

		MIX VE	30%	50%	70%	100%
	Quantity of BEV	unity	211	351	491	702
Energy Generation - Diesel source	Energy for BEV	kWh/ year	231,678	386,130	540,583	772,261
	Generation cost	R$/ L	6.01	6.01	6.01	6.01
	Energy per Liter	kWh/ L	3.54	3.54	3.54	3.54
	Diesel consumption	L	65,445	109,076	152,707	218,153
	Generation cost	R$	393,329	655,549	917,769	1,311,099
Energy Generation - Solar source	Energy for BEV	MWh/ year	232	386	540	772
	Area	m^2	775	1292	1806	2584
	Quantity of modules	unity	400	668	936	1,336
	Installation cost rate	R$/ kWh	3.5	3.5	3.5	3.5
	Final installation cost	R$	810,874	1,351,458	1,892,041	2,702,916

SOURCE: AUTHOR (2021)

Solar plants Noronha I and Noronha II provide 1,400 MWh per year and this corresponds to two times the required annual electric energy to the replacement of combustion vehicles by BEV as shown in table 23.

TABLE 23 - ENERGY GENERATION BY SOLAR PANELS

		Noronha I	Noronha II	Total
Inauguration		2017	2018	
Power	kWp	400	550	950
Quantity of modules		1,644	1,836	3,480
Energy Generation	MWh/year	600	800	1,400
Fuel economy Diesel	L/year	300,000	400,000	700,000
Area m^2	m^2	5,000	8,000	

SOURCE: AUTHOR (2021)

The replacement process from engine combustion to BEV requires further analysis by CELPE and Public administration supported by specialists from the automotive industry and suppliers to identify bottlenecks in the transmission and distribution, location of charging spot, and solar panel plant.

One bottleneck is the disposal and location of electric chargers for the fleet. The implementation methodology and physical layout in the grid rely on the simulation of charging typology and data communication between vehicle and the grid, called “smart charging”. Through this technique, a management system monitors the charging stations' availability, electricity usage, and vehicle status and controls the loading to reduce the usage of non-renewable sources and limit the power in peak conditions. Ideally, the BEV charging peak is self-adjustable to fit the real-time electricity demand gap at off-peak hours.

The gradual fleet transition to BEV, the geographic limitation which restricts the access of vehicles and heavy energy consumers (industries, services), and the controlled energy availability by CELPE configure an ideal scenario to implement a smart charging management program in Fernando de Noronha. Specialized companies as BluWave~AI and The Mobility House integrate the Internet of Things, Artificial Intelligence (AI), Machine Learning, Data Science to offer grid optimization for Distribution Utilities, Microgrids, and Fleet Electrification and increase the use of renewable energy sources.

6.7 TOTAL COST OF OWNERSHIP CALCULATION

The operational cost of a vehicle comprehends maintenance, energy running cost, and compulsory fees (insurance, federal tax). The losses incurred due to the depreciation of the vehicle (purchase expense minus resales income deducted by interest rate) configures the detention cost. The operation and detention cost establish a total cost of ownership (TCO).

Based on vehicles listed prices obtained on April 21, running cost assessed on market research and taxes compiled from Fernando de Noronha, it is calculated a TCO from an entry segment gasoline vehicle (Renault KWID), a medium-segment segment vehicle (Renault STEPWAY), an electric medium-segment vehicle (Renault ZOE), an electric light commercial vehicle (Renault KANGOO) and a pick-up (Mitsubishi L200).

Running cost assumptions are built on gasoline price at R$7.82/L, Electricity price at R$0.85/kWh, the Insurance cost from a market survey. IPVA (annual fee for automotive vehicles) in Pernambuco is 3% list price for internal combustion engine vehicles and zero for a BEV. Table 24 shows the Energy consumption from PBEV records.

TABLE 24 - MODELS OWNERSHIP COST

Model	Energ y	List Price	CO_2	Fuel cons.	Energy cons.	Energy Equiv (gasoline E22)
		R$	g/ km	km/ l	(kWh /100 km)	km/ l
Kwid Outsider	Petrol	58,669	104	16		
Stepway E2 Cvt	Petrol	83,301	126	11		
Zoe Neo Zen	EV	217,511			14	57.1
Kangoo L2	EV	212,800			15	53.6
Mitsubishi L200	Petrol	236,197	189	9.85		

SOURCE: AUTHOR (2021)

Due to the high purchase price for a BEV, the holding (detention) cost represents an important fraction for the TCO while for combustion vehicles it is less significant depending on the period and kilometers of usage. As the forecast depreciation cost is yet imprecise for the BEV segment in Brazil, this study considers residual value as follows in table 25.

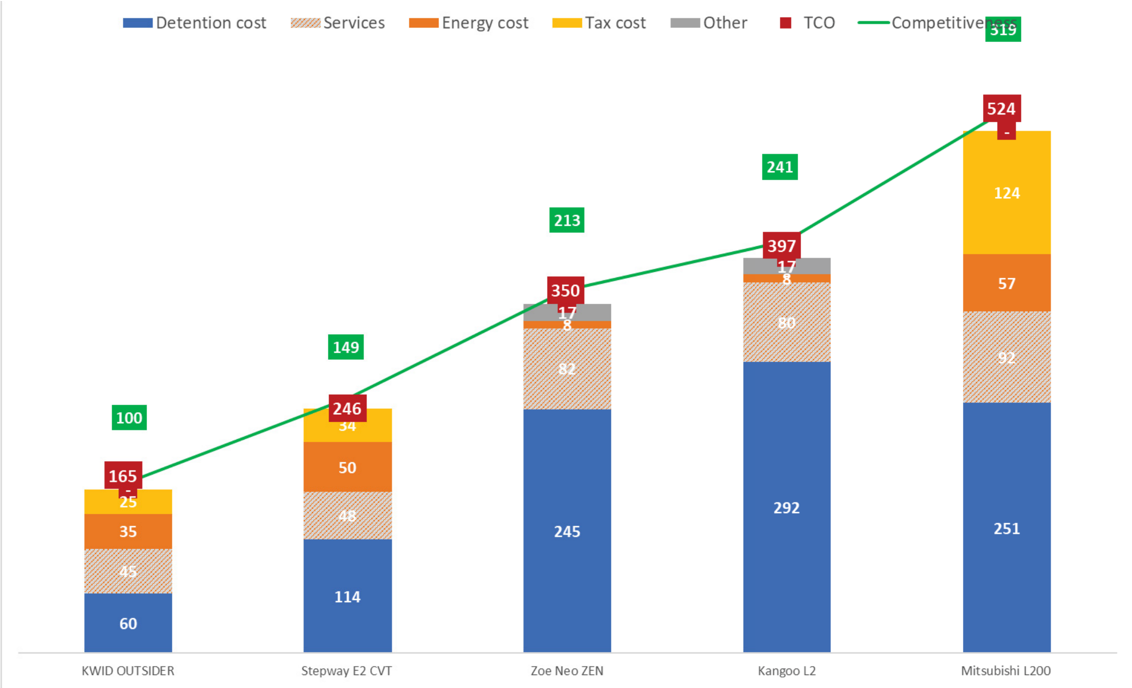
TABLE 25 - MODEL RESIDUAL VALUE

Model	Residual value
KWID OUTSIDER	75%
STEPWAY E2 CVT	60%
ZOE NEO ZEN	70%
KANGOO L2	60%
MITSUBISHI L200	70%

SOURCE: AUTHOR (2021)

For the first TCO simulation with an annual running mileage of 5,000 km for five years, Renault ZOE is 2.1 times more expensive compared to the reference of Renault KWID, the holding (detention) fraction is 77% of the total ownership cost, as shown in Figure 31.

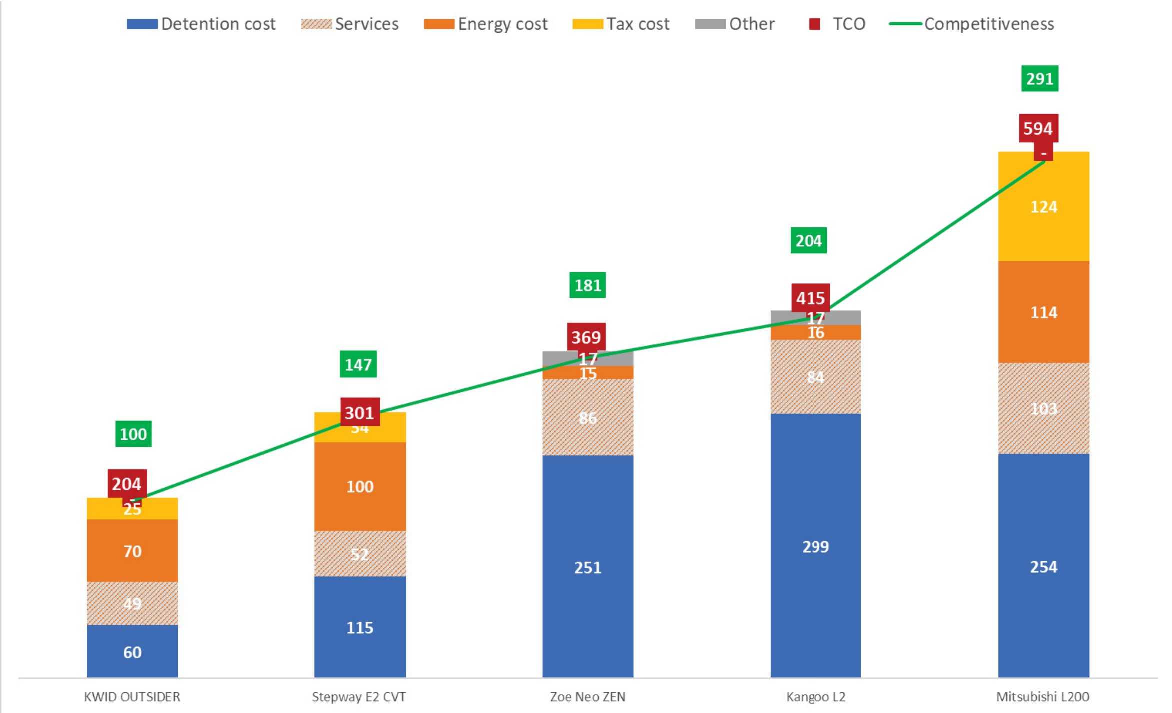
FIGURE 31 - TCO COMPARISON, 60 MONTHS, 5,000 KM/YEAR



SOURCE: AUTHOR (2021)

For the second TCO simulation with an annual running mileage of 10,000 km for five years, Renault ZOE is 1.8 times more expensive compared to the reference of Renault KWID and the detention fraction decreases to 68% from total ownership cost, as shown in figure 32.

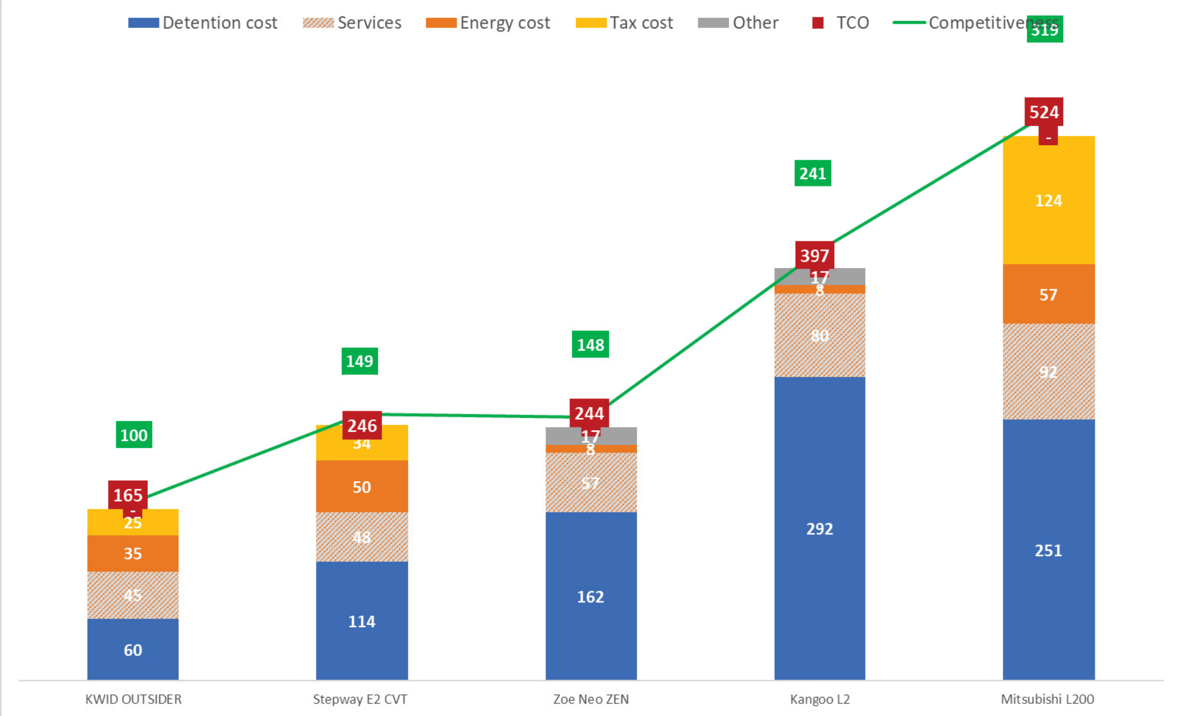
FIGURE 32 - TCO COMPARISON, 60 MONTHS, 10,000 KM/YEAR



SOURCE: AUTHOR (2021)

A third simulation expresses the maximum purchase price of a BEV, which is competitive to offset the gap to a Renault STEPWAY for five years and 5,000 kilometers of usage. Figure 33 shows the gap minimized with R$135,000 instead of R$204,428.

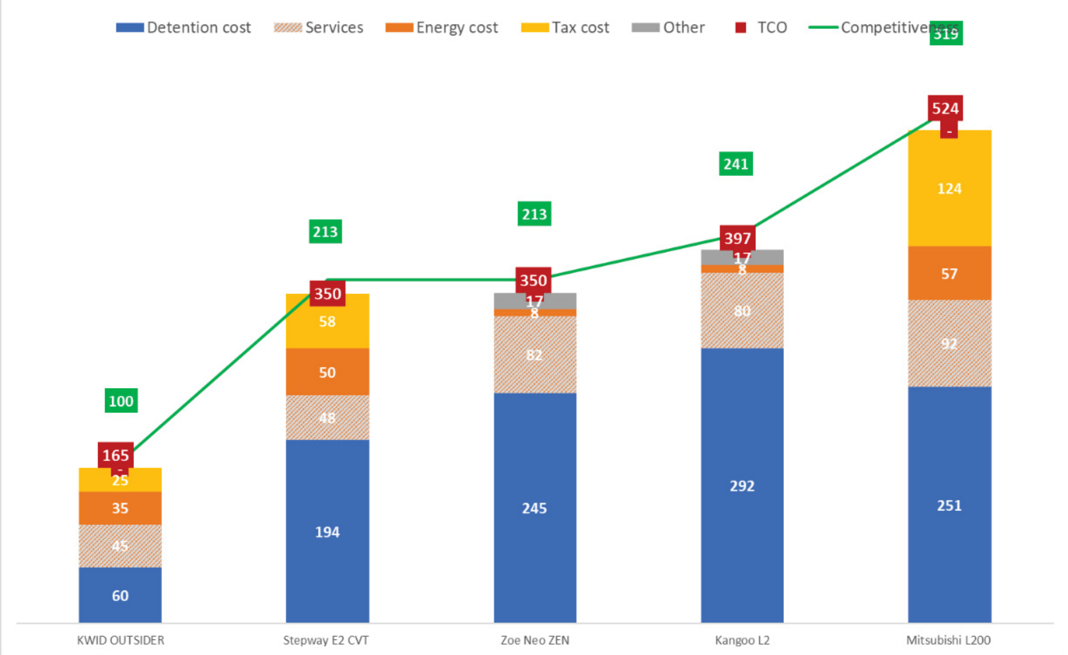
FIGURE 33 - TCO COMPARISON - EV PRICE BAND TO OFFSET GAP VS RENAULT STEPWAY



SOURCE: AUTHOR (2021

The fourth simulation indicates a probable scenario in which a combustion engine vehicle incurred an extra fee for circulation allowance. This approach has the goal to promote the transition of a new vehicle to a BEV. Taking as reference a Renault STEPWAY, this fee amounts to R$57,710 (+73% from the original price), as shown in figure 34.

FIGURE 34 - TCO COMPARISON — MINIMAL PENALTY FOR ICE VEHICLE



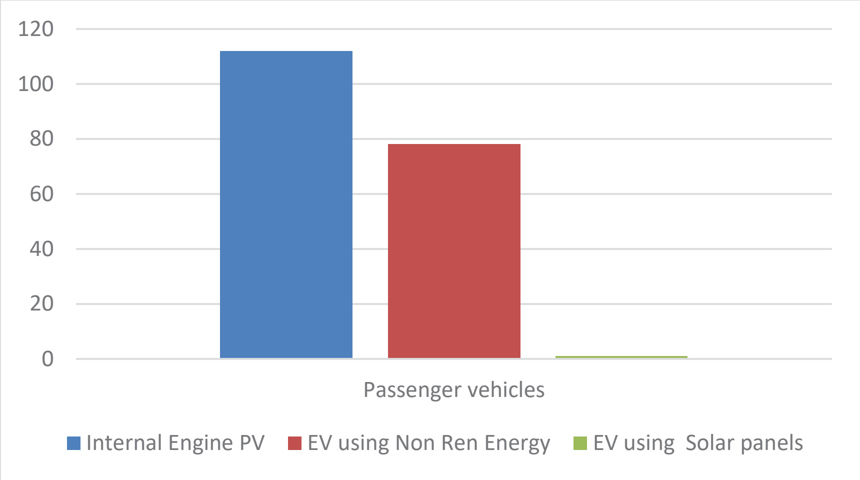
SOURCE: AUTHOR (2021

This analysis evidences that local legislation for the transition to a BEV must be supported by promoting a significant reduction of detention costs. Another alternative is to put forward an affordable BEV sized to the daily circulation of 500 kilometers per month and capable to transport at least 4 passengers and with half of the detention cost of Renault ZOE.

6.8 DISCUSSION

TESLA (2019) reports disclosed in 2019 informed that Model3 consumes 180 grams of CO_2 per mile using a U.S. national energy generation mix, but as electricity generation is becoming renewable, this emission could decrease consequently and reach 100 grams of CO_2 per mile if energy is generated by solar-powered. These numbers were confirmed in this study in a similar approach, as the fleet average reduction for passenger vehicles of 78 gCO_2 grams per kilometer from switching from internal combustion to BEV and potential to 112 gCO_2 grams per kilometer in case of energy source is supplied by solar panels, as shown in figure 35.

FIGURE 35 - CO_2 EMISSION REDUCTION (gCO_2/km) WITH RENEWABLE ENERGY GENERATION



SOURCE: AUTHOR (2021)

Lopes (2013) concluded that BEV contributes to the achievement of environmental targets: reduction of CO_2 emissions and air pollution and increase of RES provided that appropriate strategies be applied to accompany their development. However, improvements at several levels are needed to reduce the BEV costs and increase their efficiency and range. In this respect, R&D work is necessary to solve these challenges and of course, it would require investments from different stakeholders. The development of an efficient and reliable recharging infrastructure with enough geographical coverage is also mandatory.

The integration of electric distribution, grid operations, and service suppliers and EV users becomes even more critical and necessary in a remote location with limited energy generation to allow a growing insertion of BEV. The shifting of BEV charging during renewable generation excess periods in the day and limiting the peak hours are some examples to avoid extra expenditures in equipment reinforcements, extra consumption of Diesel fuel to generate electricity.

Considering BEV as a simple uncontrollable load that consumes a large amount of power, it is necessary to foresee major congestion problems in already heavily loaded grids, low voltage problems, peak load, energy losses increase, large voltage drops, and load imbalances between phases in Low voltage grids.

Choma, Ugaya (2017) compares internal engine vehicles and BEV and states that the increasing insertion of BEV is contrary to a potential reduction of CO_2 footprint, as Brazilian energy generation is based on a high mix of renewable energy.

Kempener et al. (2015) stated that electricity Generation in an isolated grid relies on a non-intermittent source to prevent any energy shortage and reliability for the population and in some cases, a second renewable source serves as an alternative to reduce energy consumption and air pollution. A total of 5.4 Million liters consumed by the Tubarão plant and with an average cost of R$6.1/ liter indicates how important it is to reduce it and promote the spread use of solar panels for the community. The necessary area of 2,500 m^2 necessary to supply the energy in case of the complete shift for BEV corresponds to less than 1% of the total area and it can be allocated in the currently available rooftops and public buildings. The efficiency monitoring and maintenance for the implemented solar panels turn out to be important to secure the reliability and stability of the network.

The insertion of Photovoltaic into the grid mentioned by Worighi et al. (2019), requires innovative controls such as Artificial Intelligence and Machine learning to encompass the transient conditions created by dynamic loads, battery energy storage systems, and distribution capacity in the grid. This is essential to invest in the grid according to BEV users' profile of usage and to educate these users to take the most benefit of renewable energy.

Marra et al. (2012) reported that the charging management to cope with renewable power fluctuations, electricity price, and local grid constraints. The absence of high-speed streets, slopes, and limitation of circulation is a preferable scenario to provide a secure implementation strategy for charging. The vehicle model diversity reduction, different battery capacity, and charging options (from 2 kW to 22 kW AC) helps to propose a reliable charging management system and integration of renewable sources.

The insertion of BEV in Fernando de Noronha demonstrated the energy availability from renewable sources to power 30% of passenger vehicles (44 vehicles) which would request 162 m^2 of solar panels. This area is equivalent to twelve parking slots (12.5 m^2 each) which could serve as a carport integrated with the grid. In case the quantity grows to 100% passenger cars (147 vehicles), this area would be equivalent to 540 m^2. In a hypothetical case, the requested area is available at Palacio Sao Miguel, the Island’s administration center.

To feed the augmented fleet of 211 vehicles, which include passenger cars and other types, the calculated energy is 231 MWh/ year and request an area of 775

m^2. This range of area can be accommodated in a combination of the public and private buildings as Tamar's Project (549 m^2) and CELPE administration rooftop (482 m^2).

An analogy to complete offset the electric energy consumption for water desalination which amounts to 356,707 MWh/year, it is necessary to invest in an area of 1292 m^2, equivalent to a medium soccer field, and this energy would feed 50% of vehicles (351 vehicles) registered in the island.

The last step is the total requested area to generate energy for 702 vehicles in 2,584 m^2. This would represent the same range as Noronha I and it would save 300,000 liters of Diesel per year, which costs R$1.8 Million.

The approach to determine the energy and CO_2 for a limited fleet in a restricted geographic limitation area is feasible in the condition that these data are available from standard homologation records combined with annual running mileage.

The TCO is a relevant tool to demonstrate the economic gap from vehicle internal combustion engine to BEV and how it can be reduced by fostering mechanisms to replace and with affordable BEV offers.

More stratified analysis for each automotive segment reduces the incertitude of this simulation by applying, including measurement procedures of energy consumption and daily mileage. This is especially important to track and anticipate major shifts in vehicle consumption and circulation during seasonal periods in the year.

7 CONCLUSION AND PROPOSALS FOR FUTURE PROJECTS

The mobility and energy sectors merger create a new era of opportunities for business and specific knowledge. In developed economies such as Europe, Asia, and the United States the level of investment and technical resources are growing at the same pace as regulation restrictions to reduce carbon footprint and to comply with environmental targets. This affects the whole value chain from the energy sector to the mobility industries and creates new possibilities for rational use of resources. The lack of economic resources in developing countries like Brazil is a limitation, which hinders severely the progress in areas as Fernando de Noronha.

The assessment of private mobility in Fernando de Noronha considering energy consumption and CO_2 emission was carried out based on official records of the PBEV system, which consists of a reliable and measurable database, even in some cases the limitation was presented to vehicles not homologated as models from older than 2009 and leisure vehicles. For the BEV insertion, this study was referenced in one single BEV and energy consumption of 0.66 MJ/km (or energetic equivalent of gasoline with 22% alcohol 43.92 km/ liter) which can be further deployed with different vehicle categories from A-Segment to Pick-up and matching it with each replaced vehicle.

The fleet consumption reference was forecasted to 2030 (-4.9% fuel consumption versus 2020) which represents a continuation of ongoing energy efficiency programs as ROTA 2030 (BRASIL, 2020).

This study was based on energy generation based on public information from CELPE and ANEEL. From one side, the fuel consumption to generate electricity is recorded and continuously available at the ANEEL site, from the other side the photovoltaic energy generation from Noronha I and II are not available for the public. Solar panels performance degradation, preventive and corrective maintenance, modules balancing, and cleaning are not subject to a monitoring process available to the public. Aeronautic Force received Noronha by donation and Noronha II is under the responsibility of the Island Administration. Even before in the case of mobility electrification, a monitoring program integrates to guarantee system stability and performance in these sites.

The energy demand and generation in terms of renewable and non-renewable, consumption daily curve, and energy tariffs were evaluated and modeled to identify grid sensitivity in case of additional load due to BEV.

The integration of electricity generation, renewable insertion, and the adoption of a BEV is a subject exploited by start-ups, partnerships, and worldwide companies, as well reported in IEA and IRENA studies to reduce the carbon footprint of energy generation, manufacturing, services, and mobility's areas.

The study's primary intention was to have a complete outlook of dynamic energy balance integration smart charging technique combined with data processing of vehicles battery to foresee the charging profile and then to identify system limitations and propose a shift of charging to a more convenient period. These subjects require expertise in programming, machine learning, and advanced computational expertise, which is not available for this project.

The geographic boundary of Fernando de Noronha limits the insertion and changes of different agents, which can interfere with the results of this study. The occurrence of a temporary increase of tourists at a specific time of the year modifies the energy dispatch. Brazilian network operation does not influence the energy system capacity. In the case of cities in the continental part, this energy integration and mobility dynamism turns to make the calculation more complex and with limitation to efficient control.

As electric mobility is turning to be an essential path toward carbon neutrality, it is necessary to know all system interfaces, optimize the integration with new technologies and promote the education and training of professionals beforehand. The areas which deserve attention are the energy battery storage for on-grid and off-grid application using the second-life battery and adapted to house needs, the integration of vehicles mobility and grid intelligence, the smart charging technics with Vehicle to grid and Vehicle to load combination, and finally the regulatory agencies panorama to support these new activities and business.

The mobility and energy sectors merging turn to be a new business field, integration completely different sectors of the economy. The aggregation of expertise and specialized partnership become a fundamental step to propose new sustainable solutions to reduce Carbon footprint and GHG and limit Global warming.

This study analyzed the electricity generation in Fernando de Noronha, the grid robustness to adopt the renewable sources in a distributed architecture and identified the demand curve by solar panels adoption replacing partially the Diesel Power Units.

This study demonstrated energy and CO_2 simulation based on a reduced number of vehicles in Fernando de Noronha's fleet crossing with PBEV records and future energy programs as ROTA 2030. The data diversity of vehicles and their performance was assessed by trying to keep as close as possible to the available homologation records.

The objective was to propose a replicable, measurable, and scalable procedure, which can be used for similarly limited fleet, circulations conditions, and energy consumers.

The optimization of energy generation coupled with mobility dynamics is a new field of business and services, based on on-the-edge techniques for simulation, system integration, and data measurement.

It concluded that BEV contributes to the achievement of environmental targets: reduction of CO_2 emissions and air pollution and increase of renewable energy sources provided that appropriate strategies are applied to accompany their development. However, improvements at several levels are needed, to reduce the BEV costs, and increase their efficiency and range. In this respect, R&D work is necessary to solve these challenges and of course, it would require investments from different stakeholders. The development of an efficient and reliable recharging infrastructure with enough geographical coverage is also mandatory

The study proposed a roadmap for the progressive adoption of BEV in Fernando de Noronha Island focusing on energy efficiency and a full scope of emission balance.

- **REFERENCES**

ABSOLAR, **Solar Photovoltaic Energy in Brazil**, 2020. Available in https://www.absolar.org.br/wp-content/uploads/2021/02/2020.11.30%20ABSOLAR_Infographic.pdf

Almeida M. P, **Implicações Técnicas da Inserção em Grande Escala da Geração Solar Fotovoltaica na Matriz Elétrica**. Universidade de São Paulo. 2017

ANEEL, **Resolução Normativa No. 482**. 2012. Available in: < http://www2.aneel.gov.br/cedoc/bren2012482.pdf>

ANEEL, **Resolução Normativa No. 687**. 2015. Available in: < https://www.aneel.gov.br/geracao-distribuida?p_p_id=101&p_p_lifecycle=0&p_p_state=maximized&_101_struts_action=%2Fasset_publisher%2Fview_content&_101_assetEntryId=14461914&_101_type=content&_101_groupId=656827&_101_urlTitle=geracao-distribuida-introduc-1&inheritRedirect=true>

ANEEL, **Resolução Normativa No. 801.** 2017. Available in: < https://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/1388418/do1-2017-12-27-resolucao-normativa-n-801-de-19-de-dezembro-de-2017-1388414>

ANEEL, **Resolução Normativa No. 819. 5**. 2018. Available in: http://www2.aneel.gov.br/cedoc/ren2018819.pdf

ANEELb, **Chamada de P&D da ANEEL atinge meio bilhão de reais de investimentos em mobilidade elétrica, 2020**. Available in https://www.aneel.gov.br/sala-de-imprensa-exibicao-2/-/asset_publisher/zXQREz8EVlZ6/content/chamada-de-p-d-da-aneel-atinge-meio-bilhao-de-reais-de-investimentos-em-mobilidade-eletrica-eficiente/656877/pop_up?_101_INSTANCE_zXQREz8EVlZ6_viewMode=print&_101_INSTANCE_zXQREz8EVlZ6_languageId=pt_BR

ANEELa, **Unidades Consumidoras com Geração Distribuída, 2020,** Available in < https://www.aneel.gov.br/outorgas/geracao/-/asset_publisher/mJhnKIi7qcJG/content/registro-de-central-geradora-de-capacidade-reduzida/655808?inheritRedirect=false&redirect=http%3A%2F%2Fwww.aneel.gov.br%2Foutorgas%2Fgeracao%3Fp_p_id%3D101_INSTANCE_mJhnKIi7qcJG%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26p_p_col_id%3Dcolumn-2%26p_p_col_pos%3D1%26p_p_col_count%3D2>

ANFAVEA, **BRAZILIAN INDUSTRY AUTOMOTIVE HANDBOOK**, ANFAVEA, 2020. Available in https://anfavea.com.br/anuario2020/anuario.pdf

ArcGIS, **Open Streetmap**, accessed May 31, 2021, at 21h46, Available in < https://www.openstreetmap.org/#map=16/-3.8556/-32.4273>

Azevedo, V.L.A,. **Impact on The Distribution Grid Due to The Introduction of Electric Vehicles on Fernando De Noronha Island,** Universidade Federal do Paraná, 2021

Barros, J. J. C., Coira, M.L., López, M. P. de la C., Gochi, A. del C. **Assessing the global sustainability of different electricity generation systems**. **Energy**, 89, 473–489. 2015. Available in <https://doi.org/10.1016/j.energy.2015.05.110>

Brasil, Ministério da Economia, **Rota 2030 - Mobilidade e Logística, 2020**, Available in https://www.gov.br/produtividade-e-comercio-exterior/pt-br/assuntos/noticias/mdic/competitividade-industrial/rota-2030

Brasil, Subchefia de Assuntos Jurídicos, **LEI Nº 13.755, DE 10 DE DEZEMBRO DE 2018, 2018,** Estabelece requisitos obrigatórios para a comercialização de veículos no Brasil; institui o Programa Rota 2030 - Mobilidade e Logística; dispõe sobre o regime tributário de autopeças não produzidas; e altera as Leis n º 9.440, de 14 de março de 1997, 12.546, de 14 de dezembro de 2011, 10.865, de 30 de abril de 2004, 9.826, de 23 de agosto de 1999, 10.637, de 30 de dezembro de 2002, 8.383, de 30 de dezembro de 1991, e 8.989, de 24 de fevereiro de 1995, e o Decreto-Lei nº 288, de 28 de fevereiro de 1967. Available in < http://www.planalto.gov.br/ccivil_03/_Ato2015-2018/2018/Lei/L13755.htm>

CELPE, **Fernando de Noronha, Ilha da Inovação,** 2019, Available in <https://www.cinase.com.br/wp-content/uploads/2019/10/Caso-Fernando-de-Noronha_CELPE_compressed-2.pdf>

CELPE, **TABELA DE TARIFAS DE ENERGIA ELÉTRICA,** 2021. Available in https://servicos.celpe.com.br/residencial-rural/Pages/Baixa%20Tens%C3%A3o/tarifas-grupo-b.aspx

Choma, E. F., Ugaya, C. M. L. **Environmental impact assessment of increasing electric vehicles in the Brazilian fleet.** ***Journal of Cleaner Production***, *152*, 497–507. 2017. https://doi.org/10.1016/j.jclepro.2015.07.091

Climate Action Tracker, **Elaborating the decarbonisation roadmap, Paris Agreement Compatible Sectoral Benchmarks, 2020**. Available in https://climateactiontracker.org/documents/754/CAT_2020-07-10_ParisAgreementBenchmarks_SummaryReport.pdf

Climatelinks**, Greenhouse Gas Emissions Factsheet: Brazil,** 2019. Available in https://www.climatelinks.org/resources/greenhouse-gas-emissions-factsheet-brazil#:~:text=Brazil's%20total%20GHG%20emissions%20in,totaling%202.78%25%20of%20GHG%20emissions.

CONAMA, **Resolução Normativa No 18** 1986. Dispõe sobre a criação do Programa de Controle de Poluição do Ar por veículos Automotores – PROCONVE. Available in <http://www2.mma.gov.br/port/conama/legiabre.cfm?codlegi=41>

CONAMAa, **Resolução Normativa No 490** 2018. Estabelece a Fase PROCONVE P8 de exigências do Programa de Controle da Poluição do Ar por Veículos Automotores

– PROCONVE para o controle das emissões de gases poluentes e de ruído para veículos automotores pesados novos de uso rodoviário e dá outras providências. Available in < http://www2.mma.gov.br/port/conama/legiabre.cfm?codlegi=739>

CONAMAb, **Resolução Normativa No 492** 2018. Estabelece as Fases PROCONVE L7 e PROCONVE L8 de exigências do Programa de Controle da Poluição do Ar por Veículos Automotores – PROCONVE para veículos automotores leves novos de uso rodoviário, altera a Resolução CONAMA nº 15/1995 e dá outras providências. Available in < http://www2.mma.gov.br/port/conama/legiabre.cfm?codlegi=742>

CRESESB, **Manual de Engenharia para Sistemas Fotovoltaicos,** 2004, Centro de Pesquisas de Energia Elétrica, Centro de Referência para Energia Solar e Eólica Sérgio de Salvo Brito. Grupo de Trabalho de Energia Solar, Rio de Janeiro.

DENATRAN, **Frota de veículos, 2021.** Accessed May 31st., 2021 at 21h56. Available in < https://www.gov.br/infraestrutura/pt-br/assuntos/transito/conteudo-denatran/frota-de-veiculos-2021>.

EPE, **Atlas da Eficiência Energética do Brasil**, 2020, Relatório de Indicadores (EPE), Available in < https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-556/Atlas%20consolidado_08_03_2021.pdf>

EUROPEAN UNIONa, **Low Emission Zones**, 2020. Accessed May 31st. 22h00. Available in < https://urbanaccessregulations.eu/low-emission-zones-main>

EUROPEAN UNIONb, **CO_2 emission performance standards for cars and vans**, 2020. Accessed May 31st. 22h00. Available in < https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en>

FIPE, Fundação Instituto de Pesquisas Econômicas, **Preço Médio de Veículos, 2021** Available in <https://veiculos.fipe.org.br/>

GEROSSIER, A.; GIRARD, R.; KARINIOTAKIS, G. Modeling, and Forecasting Electric Vehicle Consumption Profiles. **Energies**, v. 12, n. 7, p. 1341, 2019.

IEAa, **Regulation (EU) 2019/631 setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles (vans) in the EU for the period after 2020,** 2019. Available in < https://www.iea.org/policies/8788-regulation-eu-2019631-setting-co2-emission-performance-standards-for-new-passenger-cars-and-for-new-light-commercial-vehicles-vans-in-the-eu-for-the-period-after-2020>

IEAd, **Key Energy Statics**, 2020. IEA, Paris, Available in < https://www.iea.org/countries/brazil>

IEAa, **CO_2 Emissions from Fuel Combustion**, 2020, IEA, Paris. Available in < https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview>

IEAa, **Data and statistics,** 2021. Available in < https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=TPESbySource>

IEAb, **Global Energy Review 2020**, IEA, Paris. Available in https://www.iea.org/reports/global-energy-review-2020
IEAg, **Global EV Outlook 2020**, IEA, Paris. Available in https://www.iea.org/reports/global-ev-outlook-2020

IEAc, **Global EV Outlook 2021**, IEA, Paris. Available in < https://www.iea.org/reports/global-ev-outlook-2021>

IEAd, ***Key World Energy Statistics 2020***, IEA, Paris. Available in https://www.iea.org/reports/key-world-energy-statistics-2020

IEAe, **Promoting vehicle efficiency and electrification through stimulus packages**, 2020. IEA, Paris. Available in https://www.iea.org/articles/promoting-vehicle-efficiency-and-electrification-through-stimulus-packages

INMETRO, **Tabelas PBE Veicular,** 2021. Available in < http://www.inmetro.gov.br/consumidor/tabelas_pbe_veicular.asp>

INMETRO, **PROGRAMA BRASILEIRO DE ETIQUETAGEM PBE,** 2020. Available in http://www.inmetro.gov.br/consumidor/pbe/veiculos_leves_2020.pdf

INPE. **Atlas brasileiro de energia solar**. 2.ed. São José dos Campos: INPE, 2017. 80p. Available in <http://doi.org/10.34024/978851700089

IRENA, **Global energy transformation: A roadmap to 2050 (2019 edition)**, International Renewable Energy Agency, Abu Dhabi.

Jakhrani, A. Q., Right, A. R. H., Othman, A. K., Samo, S. R., Kamboh, S. A. **Estimation of carbon footprints from Diesel generator emissions**. Proceedings of the 2012 International Conference in Green and Ubiquitous Technology GUT 2012, 78–81. 2012. Available in https://doi.org/10.1109/GUT.2012.6344193

Kempener, R., Lavagne, O., Saygin, D., Skeer, J., Vinci, S., & Gielen, D. **Off-Grid Renewable Energy Systems: Status and Methodological Issues**. IRENA, 29. 2015. Available in http://www.irena.org/DocumentDownloads/Publications/IRENA_Off-grid_Renewable_Systems_WP_2015.pdf

LACTEC. **Multiobjective Optimization of Distributed Power Resources for Isolated Microgrid,** 2016. PD 0043-0516-2016. Project Manager: Carlos Eduardo Ferreira Soares. Project Coordinator: Juliano de Andrade

Le-Petit, Y., **Electric vehicle life cycle analysis and raw material availability,** 2017, Transport & Environment, Available in https://www.transportenvironment.org/sites/te/files/publications/2017_10_EV_LCA_briefing_final.pdf

Lopes, J. A. P., Soares, F. J., Almeida, P. M. R. **Integration of electric vehicles in the electric power system**. Proceedings of the IEEE, 99(1), 168–183. 2011. Available in https://doi.org/10.1109/JPROC.2010.2066250

Lin, H., Fu K., Wang Y., Sun Q., Hailong L., Yukun, H., Sun B, Wennersten R., **Characteristics of electric vehicle charging demand at multiple types of location - Application of an agent-based trip chain model. -**, v. 188, p. 116122, 2019

Marra, F., Yang, G. Y., Traholt, C., Larsen, E., Rasmussen, C. N., You, S. **Demand profile study of battery electric vehicle under different charging options**. IEEE Power and Energy Society General Meeting. 2012. Available in https://doi.org/10.1109/PESGM.2012.6345063

Machado, N., **Mercado de armazenamento de energia vai deslanchar, mas tributação é empecilho no Brasil, diz diretor da BYD,** 2021. Available in < https://epbr.com.br/mercado-de-armazenamento-de-energia-vai-deslanchar-mas-tributacao-e-empecilho-no-brasil/>

Marinho, A. C., **Fernando de Noronha tem quinto aumento do ano no preço de combustíveis e litro da gasolina chega a R$ 7,82**. 2021. Available in, https://g1.globo.com/pe/pernambuco/blog/viver-noronha/post/2021/03/02/fernando-de-noronha-tem-quinto-aumento-do-ano-no-preco-de-combustiveis-e-litro-da-gasolina-chega-a-r-782.ghtml

Marinho, J. **Sistema único de baterias no país é instalado em Fernando de Noronha**, 2019. Available in < https://www.wwf.org.br/?69702/Sistema-unico-de-baterias-no-pais-e-instalado-em-Fernando-de-Noronha>

Masson, G., Kaizuka, I., **Trends in Photovoltaic Applications**, 2020. Available in https://iea-pvps.org/wp-content/uploads/2020/11/IEA_PVPS_Trends_Report_2020-1.pdf

NEOENERGIA, **Sustentabilidade, Fernando de Noronha, 2021**. Available in < https://www.neoenergia.com/pt-br/sustentabilidade/Paginas/fernando-de-noronha.aspx>

Pernambuco State, **LEI ORDINÁRIA Nº 16810, DE 7 DE JANEIRO DE 2020,** Veda o ingresso, circulação e permanência de veículos a combustão, no âmbito do Distrito Estadual de Fernando de Noronha**.** Available in < https://leisestaduais.com.br/pe/lei-ordinaria-n-16810-2020-pernambuco-veda-o-ingresso-circulacao-e-permanencia-de-veiculos-a-combustao-no-ambito-do-distrito-estadual-de-fernando-de-noronha>
Silveira, E. F., Taygoara, O., Oliveira, F. D. E. **Cenários de Geração Renovável em Fernando de Noronha.** 93. 2013

Saadullah Khan, Samir Shariff, Aqueel Ahmad, Mohammad Saad Alam. **A Comprehensive Review of Fast Charging Infrastructure for Electric Vehicles. Smart Science**, v. 6, n. 3, p. 256–270, 2018.

Tejeda, F. A., Cruz, D. E. L. A., Lauretis, O. N. S. D. E., Goubet, F. B. C., Rte, C. L. **Economic and environmental benefits of electric vehicle smart charging in a**

large-scale EV integration scenario in France, Cigre e-section Paris 2020. 1–13. 2020.

Tesla. **2019-Tesla-Impact-Report**. Annual Report, 57. 2020. Available in https://www.tesla.com/ns_videos/2019-tesla-impact-report.pdf

Thiel, C., Nijs, W., Simoes, S., Schmidt, J., van Zyl, A., Schmid, E. **The impact of the EU car CO_2 regulation on the energy system and the role of electro-mobility to achieve transport decarbonization.** Energy Policy, 96(2016), 153–166. 2016. Available in https://doi.org/10.1016/j.enpol.2016.05.043

Transport & Environment. **How clean are electric cars?** 1–33. 2020. Available in: https://www.transportenvironment.org/sites/te/files/downloads/T%26E's EV life cycle analysis LCA.pdf

Tremblay, O.; Dessaint, L. A. Experimental validation of a battery dynamic model for EV applications. **24th International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exhibition 2009, EVS 24**, v. 2, p. 930–939, 2009.

Vargas, J. E. V., Seabra, J. E. A., Cavaliero, C. K. N., Walter, A. C. S., Souza, S. P., Falco, D. G**. The new neighbor across the street: An outlook for battery electric vehicles adoption in Brazil**. World Electric Vehicle Journal, 11(3), 1–16. 2020. Available in https://doi.org/10.3390/WEVJ11030060

WHO, **Climate change, 2021.** Available in https://www.who.int/health-topics/climate-change#tab=tab_1

Worighi, I., Maach, A., Hafid, A., Hegazy, O., Van Mierlo, J. Integrating renewable energy in smart grid system: Architecture, virtualization, and analysis. **Sustainable Energy, Grids and Networks**, 18, 100226. 2019. Available in https://doi.org/10.1016/j.segan.2019.100226

WWF, **Geração de Energia em Fernando de Noronha**, Alternativas para a diminuição de CO_2 no transporte e eletricidade, Brasil, 2021. Available in https://wwfbr.awsassets.panda.org/downloads/geracao_de_energia_fernando_de_noronha_versao_web_1_1.pdf