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Abstract.

The Central American countries made up of Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama have shared a common electrical network for nine years through an agreement called the Electrical Interconnection System for Central American countries (SIEPAC). This regional project has generated many benefits for the consumers of each country since there are agreements and regulations, the establishment of a regional energy market, cost reduction, and incentives for renewable generation. However, SIEPAC's energy matrix has not managed to improve its diversification and has difficulties in accelerating and substantially increasing renewable energy options. The analysis indicates that considering some isolated efforts in the field of electromobility that some countries of the Central American region have carried out, it is feasible to connect or incorporate the topic of electromobility within the SIEPAC system, managing to accelerate the change in the Energy Matrix of the Electrical Interconnection System for Central American countries; Likewise, the challenges that must be overcome in the regulatory framework to materialize the expected benefits of the combined model of renewable energy and electromobility developed in this research are also indicated.

Keywords:

Central America, electromobility, energy matrix, renewable energy.

ACRONYMS (for its acronym in Spanish)

BID Inter-American Development Bank

BCIE Central American Bank for Economic Integration

CRIE Regional Commission for Electrical Interconnection

CEPAL Economic Commission for Latin America and the Caribbean

CEAC Council for the Electrification of Central America

EPR Owner Company of the Network

EOR Regional Market Operator Entity

GCF Green Climate Fund (for its acronym in English)

ICE Costa Rican Institute of Electricity

IRENA International Renewable Energy Agency (for its acronym in English)

MER Regional Electricity Market

OSD Objectives of Sustainable Development (for its acronym in English)

SIEPAC Central American Countries Electrical Interconnection System

SICA Central American Integration System

UNEP United Nations Environment Program (for its acronym in English)

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1. INTRODUCTION.

Currently, the Central American regional electricity market is governed by the Central American Countries Electrical Interconnection System (SIEPAC for its acronym in Spanish), which has its origins with its first initiatives in the 1960s, based on the General Treaty of Central American Economic Integration, that emerged at the same time, and that was intended to be the global framework for various initiatives to promote and establish a Central American Common Market, which would be characterized by free trade in goods within the territory and the establishment of a common external tariff that would have as previous stages, the Customs Union and the free trade zone, to operate the treaty in reference, the Central American Integration System was created. (SICA¹ for its acronym in Spanish)

Over time, SIEPAC has undergone a process of slow evolution and consolidation, but with significant achievements, reaching various milestones over the years. In 1996 the presidents of the six countries that make up the Central American region signed the Framework Treaty of the Central American Electricity Market or Regional Electricity Market (MER for its acronym in Spanish) in Guatemala City. This instrument was ratified by the respective congresses or legislative assemblies of each country. The Treaty established the regional legal framework necessary for the creation of the Regional Electricity Market and the regional organizations that support it, the formation and gradual growth of a competitive MER (based on reciprocal and non-discriminatory treatment, which contributes to the sustainable development of the region in a framework of respect and protection of the environment) and the bases for the opening of national markets to regional exchange, both in access to electricity transmission and in the opportunities for buying and selling electricity between participants from different countries (Sustainable Energy Strategy 2030 of the SICA Countries, 2020, p. 38).

After several years and after having achieved an energy matrix of the Electrical Interconnection System of the Central American Countries, it is important to mention that the current challenges are focused on improving the regional energy matrix with greater participation of renewable energy; however, minimal growth or stagnation has been

¹ Belize and the Dominican Republic became members of SICA in 2001 and 2013.

identified in recent years, reaching a share in renewable energies that requires significant challenges with respect to the total installed capacity in the Central American region.

On the other hand, each country in the Central American region has made its isolated efforts, including initiatives and actions to incorporate electromobility as a related topic, but without connecting it in a regional strategy and fully associated with the regional energy matrix. All of the above opens a field of opportunity in the research and development of a study that allows comparing the progress of each Central American country in terms of renewable energies and electromobility, posing the challenge of evaluating in this research a model with an integrated approach for all these actions isolated and that can have a positive impact on the energy matrix of the electrical interconnection system of the Central American countries, achieving a common benefit and managing to recover the integrationist spirit with which the regional electricity market originated.

On the subject in question, and as part of this research work, studies carried out by universities in the Central American region were reviewed, finding an important gap since there are studies focused on the promotion and development of renewable energies in each country in isolation. A comprehensive study with a regional approach was not identified that analyzes the energy matrix of SIEPAC, and its link with other initiatives such as electromobility, or the energy transition, issues of vital importance since all the countries of the Central American region depends largely on imported fossil fuels.

Considering what has been described and in order to address the identified gap, this thesis develops a model of renewable energy and electromobility, as factors, to accelerate change and improvement in the Energy Matrix of the Electrical Interconnection System of the Central American countries. It is important to mention that due to the nature of the research topic in question, very valuable information on cross-border energy cooperation has been reviewed, especially comparative information in Europe (Cross-border Cooperation on renewable energy, European Environment Agency, 2020, page 7). Key factors and lessons learned from this type of cooperation scheme have been reviewed, based on the assumption, that delving into this type of experience allows to generate ideas and a frame of reference for the evaluation of the findings of the present thesis.

Another of the key aspects addressed in this research is the demand for electricity in the future required by electromobility, since an electric car decreases the demand for fossil fuels, but increases the demand for electrical energy, the net environmental benefits will depend mainly on the composition of the electrical matrix. This aspect has made it necessary to review the vehicle fleet of each Central American country, energy generation projections, and the level of preparation in infrastructure, including challenges to be overcome in the regulatory framework of each country.

The results of this thesis will have practical relevance in each country of Central America, the information generated in this research could be the basis to encourage greater use of renewable energies in the energy matrix of the electrical interconnection system in Central America. On the other hand, the results of this thesis will promote electromobility, in consequence, it will contribute to decarbonization and reduce the negative effects of local pollution.

This research has the potential to motivate the universities of the Central American countries to develop specific research works as a complement or addition, on the other hand, the Multilateral Development Banks that have a presence in Central America, such as the Inter-American Development Bank, the World Bank and the Central American Bank for Economic Integration, they will be interested to know the results of this research, since these institutions have some action plans to promote electromobility in Central America, as well as renewable energies.

In the development of this thesis, the reader will find in chapter 2 a broad theoretical framework that provides a general context on renewable energy and electromobility, the operation of the electrical interconnection system between the countries of the region is also explained and the state of renewable energy and electromobility in Central America. Finally, a summary and reflections of the reviewed literature are presented. Chapter 3 presents the fundamental bases for the approach of the model and the conceptual model applied in the investigation; on the other hand, chapter 4 explains the methodology for collecting information, the entities that were consulted, and an assessment of the validity, reliability, and usability of the thesis.

It is important to mention that the initial results and findings are indicated in chapter 5, however, the analysis of the results is presented in detail in chapter 6. Finally, chapter 7 is dedicated to conclusions, chapter 8 recommendations, and all the technical literature consulted is indicated in chapter 9.

2. LITERATURE REVIEW.

This chapter shows a broad theoretical framework that aims to provide general information on the current state and trends of the energy transition in the world, renewable energy, and its relationship with electromobility. This chapter ends by providing information on the Central American context of electricity generation and capacity, the explanation of the SIEPAC interconnection line, the participation of renewable energy in the region, and general information on the subject of electromobility in Central America. Finally, the identification of the gap that supports the development of the thesis is presented, as well as a detailed reflection on the technical literature reviewed.

2.1 The global trend towards energy transition.

One of the great topics of discussion around the world is the energy transition, to a greater or lesser extent this topic is discussed in many countries, the need to move from fossil fuels to low carbon solutions is an undeniable aspect that we find widely today analyzed in numerous technical articles, studies and research papers, including energy transition strategies that have been formulated in several countries. However, it is very difficult to know when the energy transition will materialize in the world, but global agreements, strategies, and international action plans are identified that in some way guide countries to meet this challenge, for example, defined guidelines of the Paris agreement signed in 2013 that instructs to limit the increase in the average global surface temperature below 2° Celsius, and the 2030 Agenda of the United Nations General Assembly 2015 that provides the objectives of sustainable development (OSD) and a very strong frame of reference to achieve international cooperation to achieve a sustainable future for the planet.

This agenda defines 17 OSD with 169 goals that will serve to address solutions to extreme poverty, fight inequality and injustice, and protect the planet's environment. It is important to mention that there is a Sustainable Development Goal called OSD7 dedicated to the energy aspect, which establishes that affordable, reliable, and universal access to modern energy services must be guaranteed; substantially increasing the share of renewable energy in the global energy mix; and double the global rate of improvement in energy efficiency (OSD 7 Sustainable Development Goals Report, United Nations, 2017).

The important thing about fulfilling this objective is that it facilitates and contributes to the fulfillment of other OSD which is one of the situations that the world experiences and that is detailed in numerous studies that indicate that carbon dioxide emissions associated with energy account for two-thirds of all greenhouse gases. It is estimated that the current world has reached a point where the development of technology and innovation specifically in renewable energies and electromobility will make it possible to vigorously address the energy transition in the world, also considering that little by little the costs of wind energy and photovoltaic are reduced and become more competitive.

Several national or local experiences on concrete energy transition efforts are identified, in which key success factors are identified, as well as failures. It is important to mention that in the successful cases of energy transitions, energy policy frameworks and regulatory frameworks designed and implemented by governments have shown that they can accelerate energy transitions and determine their direction, some cases are mentioned below (The role of renewable energy in the global energy transformation, IRENA/Shura/Payne Institute, 2019, p.39):

- Brazil created a special program to encourage the use of biomass-based ethanol and created a series of policies and regulatory frameworks that allowed for promoting and maintaining this initiative, however, over time it has been affected by economic cycles and priorities of the government.
- In Germany, a national consensus called Energiewende was successfully developed that aims to reduce emissions by 80% and abandon nuclear energy by 2050, however, it is still perceived that it has had a minor impact in accelerating the transition in the heating, coal, and transport sectors.

- In the case of India, a major renewable energy challenge of 175 GW was established by 2022, which includes 60 GW of wind energy and 100 GW of photovoltaic energy. As the country made good progress, the government increased the target to 227 GW by 2027.
- The need to adjust objectives is also identified, considering the constant evolution of renewable energy in the world, such is the case of the European Union that had set in 2014 27% of its binding objective for the year 2030, however, adjusted the target in 2018 to 32%.
- China has also made significant efforts by setting targets to reduce carbon emissions per unit of gross domestic product by 65% by 2030 from 2005 levels.
- In the United States of America, even with the heterogeneity in its energy sector and the differences, needs, and priorities of each actor that influences the individual energy markets regulated for each of its 50 states and with more than 3000 public services, this The country has transformed its energy sector driven by mechanisms such as tax incentives for renewable energy that have allowed 11% of total energy demand and 17% of all electricity generation in the United States to be supplied from natural resources of renewable energy according to the latest 2017 data from the United States Energy Information Administration.
- The Russian Federation, which has high volumes of fossil fuel resources, established (at least before the Russia-Ukraine conflict) to reach an installed capacity of 5.9 GW of renewable energy by 2024.
- Other countries with emerging economies, such as Turkey, implemented successful short-term strategies based on feed-in tariffs that allowed reaching an installed capacity of 5 GW by 2018; planning and adjustment are pending for 2023 onwards.
- It is considered that for now in the world the great issues of energy transition and the implicit topics such as renewable energy and electromobility are aspects in progress and constant evolution, which are helping to identify areas of action and innovation gaps at a technological and sectoral level.

2.2 Renewable energy and its interrelation with electromobility.

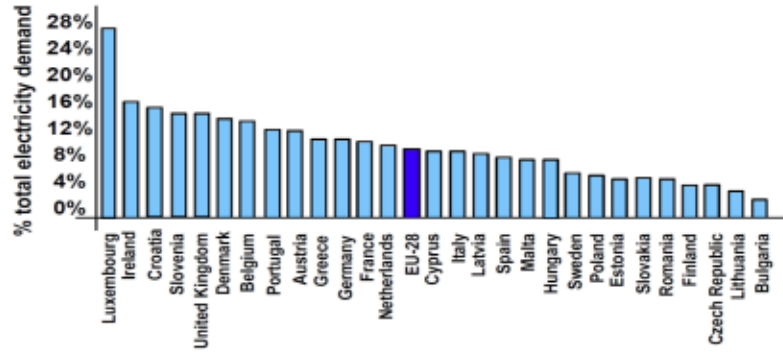
There are various studies, initiatives and projects carried out around the world on both renewable energy and electromobility, it is generally identified that in most cases they are addressed separately and good results are recorded, but without an integrated vision. The case is simple and logical, it will not be of much use in the future for countries to have an electric vehicle fleet if the energy that will be used to meet this demand does not come from clean energy, if this were to happen we would not be contributing positively to climate change.

Considering the above logic, it is known that the vehicle fleet of each country and its population increase over time, therefore, thinking about addressing such a situation in the future without pollution and congestion automatically leads to joining or integrating both issues into one joint and complementary vision. This situation implies a radical change in road transport to achieve a transition to a low-carbon economy, so it would seem that thinking about Smart Mobility and Smart Grid in an integrated manner would contribute to a more sustainable and efficient world.

Many estimates indicate that, in 2050, electricity in the world will become a real issue if early action is not taken, since it will increase from 20% to 50%, doubling gross electricity consumption. In this context, renewable energy generation could offset this global bulk energy demand. One of the main causes of the increase in the demand for energy consumption will be caused by the higher sales of Electric Vehicles.

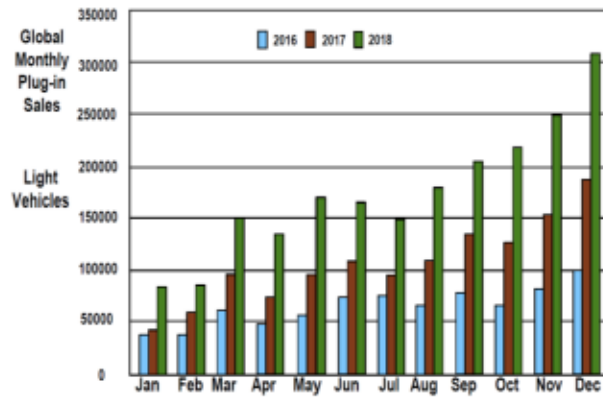
As a reference to what has been described, Chart 2.2.1 shows the energy demand for electric vehicles in Europe as a percentage of the total electricity demand in 2050, and Chart 2.2.2 and 2.2.3 refer to monthly sales of global plug-in electric vehicles in 2016, 2017, 2018 and sales of electric vehicles, as well as the percentage of growth in the year 2017, 2018.

Chart 2.2.1 Electric vehicle energy demand in Europe as a % of total electricity demand 2050.



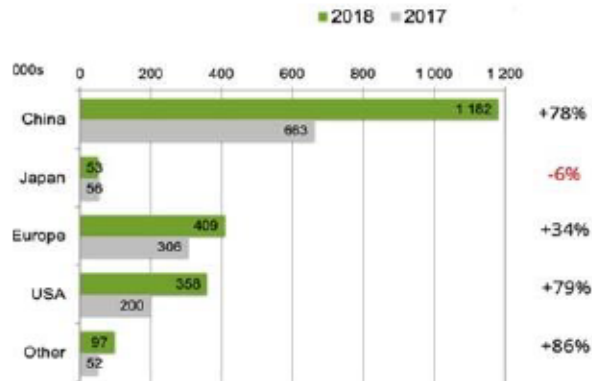
Source: Renewable Energy Generation and Impacts on E-Mobility, G Sree Lakshmi, O Rubanenko, I Hunko, 2020.

Chart 2.2.2 Global monthly sales of Plug-in Electric Vehicles in 2016, 2017, 2018



Source: Renewable Energy Generation and Impacts on E-Mobility, G Sree Lakshmi, O Rubanenko, I Hunko, 2020.

Chart 2.2.3 Electric Vehicles Sales. Percentage growth in the years 2017, and 2018.



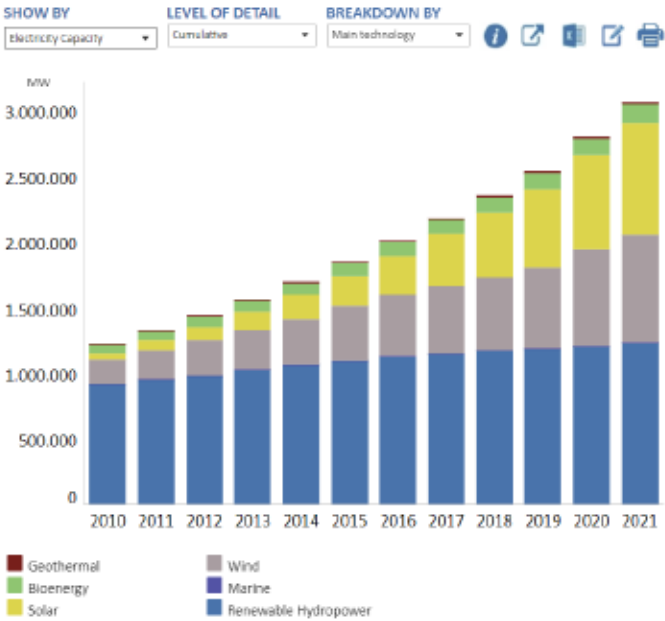
Source: Renewable Energy Generation and Impacts on E-Mobility, G Sree Lakshmi, O Rubanenko, I Hunko, 2020.

It is important to consider that the main cause to switch from the internal combustion engine to electric vehicles is the fall in crude oil prices and air pollution. Evolving to electric mobility offers the opportunity to analyze the renewable energy alternatives which would be the most convenient to promote.

According to the behavior in the last four years (Global energy transformation, International Renewable Energy Agency IRENA, 2019.) renewable energy in 2018 amounted to 2,351 GW and the largest share corresponds to hydroelectric plants with an installed capacity of 1,172 GW, wind and solar energy are registered with capacities of 564 GW and 486 GW. The total increase in renewable energy generation is 171 GW; in this way, the solar energy generated is 109 GW and the wind power is 51 GW.

In summary, it is confirmed that the increase in the generation of renewable energy is mainly due to the new solar and wind plants installed around the world, as example, it is indicated that the solar energy that was produced in Asia has a capacity of 64 GW led by the list China, India, Japan and Republic of Korea. The increase in wind power is explained by 20 GW from China and 7 GW from the US. Finally, the countries with more than 1 GW of generation are Brazil, France, Germany, India, and the United Kingdom. Chart 2.2.4 shows the evolution of the increase in the generation of renewable energy in the world.

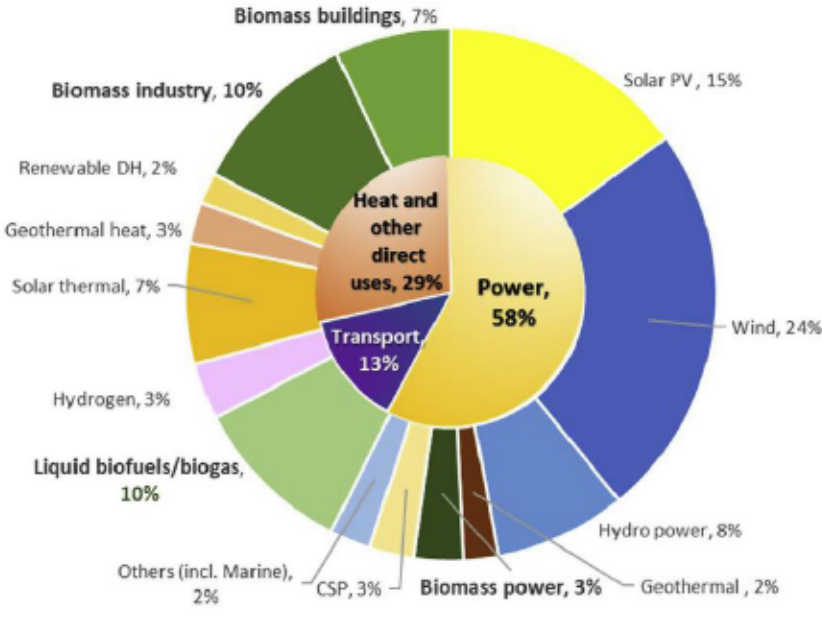
Chart 2.2.4 Global Trends in renewable energy. Electricity capacity MW.



Source: International Renewable Energy Agency IRENA, 2021.

The information described confirms that both renewable energy and electromobility should go hand in hand, energy generated by renewable sources would supply two-thirds of the final energy demand (Renewable Energy Generation and Impacts on E-Mobility, G Sree Lakshmi, O Rubanenko, I Hunko, 2020, p.1). It is identified that if electric vehicles had the opportunity to be powered by renewable energy sources, they would reduce the emission of greenhouse gases and air pollution. This would lead to a decarbonized transport system that meets the 80-95% greenhouse gas emissions reduction target by 2050. Chart 2.2.5 shows the Breakdown of renewables use in total final energy consumption terms, projection to the year 2050.

Chart 2.2.5 Breakdown of renewables use in total final energy consumption terms, projection to the year 2050



Source: IRENA, Global Energy Transformation. A Roadmap to 2050, 2019.

It is evident that given the efforts of countries around the world and the decisions to accelerate the energy transition, it is necessary to be in line with the development of specific infrastructure. This issue is already a major challenge for some countries that are coping with

emerging infrastructure issues such as smart electric vehicle charging, distribution network adjustments, and the role of changing demand and smart grids. All of the above requires strong investments both for power generation capacity and for specific infrastructure, therefore, other aspects such as special financing schemes will be of vital importance in the future, as well as having policies that generate a favorable environment for this development.

2.3 Cross-border cooperation on renewable energy.

Considering that this thesis addresses the issue of cooperation between countries linked to renewable energy, some cases have been reviewed that could provide information and lessons learned on cross-border cooperation in renewable energy. These types of schemes have been implemented in Europe and have been supported by key guidelines contained in the energy and climate policy for 2030, as well as in the European Green Deal. However, despite the multiple benefits that this type of cooperation scheme can generate, few cases have been identified to date, since it has not been easy to reach agreements and materialize them with high impact in a short time, to try to have a scheme with sufficient maturity in the indicated cases has taken more than ten years, and in some cases without materializing any objective. Of course, there are success stories that it is important to review and learn from these experiences. Three experiences have been identified (Cross-border cooperation on renewable energy, European Environment Agency, 2020):

- Joint support schemes were implemented, specifically in the joint market for electricity certificates established between Norway and Sweden. As a result of this experience, the very low cost for consumers of the Norwegian-Swedish certificate market is highlighted, compared to support systems in the other EU Member States. Beyond the purely economic benefits, this case of cooperation created additional opportunities for both countries. By joining Norway in a common market, Sweden gained access to more low-cost hydropower, as well as additional wind power.
- Joint ground-mounted solar photovoltaic (PV) auction between Denmark and Germany. Offers with historically low electricity prices for photovoltaic solar energy in both countries stand out from this experience. As a result, Denmark more than

halved the estimated amount of state aid expected to be awarded for the project. Similarly, Germany gained access to places with a high number of full charge hours in Denmark. This experience opened up the possibility of creating good conditions for future international renewable energy projects, with or without state support.

- Joint project on wind energy between Ireland and the United Kingdom. In this case, public acceptance and political support were negatively affected. This was seen in the case of Ireland and the UK, where some stakeholders feared that Ireland would suffer the environmental impacts of having the wind farms installed in their country and receiving few benefits in return. This project was abandoned.

According to what is indicated in the previous paragraphs, these experiences deal with specific cases or projects, it is not about sharing the electrical network based on a complete and integral interconnection system between countries, however, some aspects are identified that can be considered, for example, confirmation that cross-border cooperation in renewable energy reduces costs and creates new opportunities for countries, and that success requires political will, flexibility, good governance, and communication; Bearing in mind that the keys to overcoming these challenges consist of applying good communication, ensuring that the benefits of cooperation are sufficiently explained to the public, in such a way that trust, together with a clear set of rules, minimizes uncertainties and increases stakeholder confidence in a successful outcome (Cross-border cooperation on renewable energy, European Environment Agency, 2020).

Details of the main recommendations drawn from the case studies reported in this section on cross-border cooperation in renewable energy are provided in **Annex I**.

2.4 The regional energy context of the countries of the Integration System Central American.

The Central American Integration System (SICA) is made up of the following eight countries: Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, and the Dominican Republic. The SICA subregion has a population of around 59 million inhabitants and a territory of 571,000 km². The population is distributed as follows: Belize (0.7%), Guatemala (28.9%), El Salvador (10.5%), Honduras (15.8%), Nicaragua (10.8%), Costa Rica (7.6%), Panama (7.1%),

and the Dominican Republic (18.7%). The first seven countries are located in the Central American isthmus (same geographic region) and represent around 82% of the population and 91% of the territory of the subregion. The Dominican Republic is an island state located in the Caribbean Sea. Regarding the structure of SICA and SIEPAC, the following is commented: Belize and the Dominican Republic joined as full members of SICA in 2001 and 2013, respectively. On energy issues, both countries participate in the Council of Ministers of Energy (CME for its acronym in Spanish), its subsidiary bodies (the Meeting of Directors of Energy and the Committee of Directors of Hydrocarbons), and in the energy cooperation initiatives that emanate from the aforementioned SICA instances. The participation of these two countries (Belize and the Dominican Republic) is important only within the subregional cooperation and complementation schemes that facilitate the formation of an expanded market for energy services and in actions to improve the conditions of hydrocarbon supply for the countries of that subregion. Belize and the Dominican Republic are not part of SIEPAC.

As described SIEPAC is the Electrical Interconnection System of the Central American Countries. The current regional transmission line, known as SIEPAC (Fig. 2.4.1), connects six different countries (Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama) and was developed from a series of bilateral agreements between countries in the region dating back to the 1960s.

In the early stages, energy transfers were limited to amounts ranging between 5 and 50 MW and were carried out in accordance with specific agreements. Such transfers had considerable political support among Central American countries, leading to the 1996 Central American Electricity Market Framework Treaty, which entered into force in 1999. This was the cornerstone of the Regional Electricity Market (MER), which uses the infrastructure established by SIEPAC.

It is important to mention, as the title of this thesis indicates, this research work is limited to SIEPAC in relation to its energy matrix and its connection with electromobility. Therefore, from this section onwards, reference is made only to the countries that make up SIEPAC.

Fig. 2.4.1 System of Electrical Interconnection of the countries of Central America (SIEPAC)



Source: SIEPAC transmission line structure, 2020.

The SIEPAC transmission line has 230 kilovolts with a net transfer capacity of up to 300 MW, this transmission system interconnected (merged) with the national electrical systems allows the exchange of electrical energy between the regional electricity market participants. This current regional transmission capacity of 300 MW may be doubled in the future and reach up to 600 MW (Background, current status and prospects of SIECA, 2014)

The SIEPAC interconnection established by the Central American Electricity Market Framework Treaty is owned by the Owner Company of the Network EPR, which the Treaty also established, together with the Regional Market Operator Entity EOR, and the Regional Commission for Electrical Interconnection CRIE.

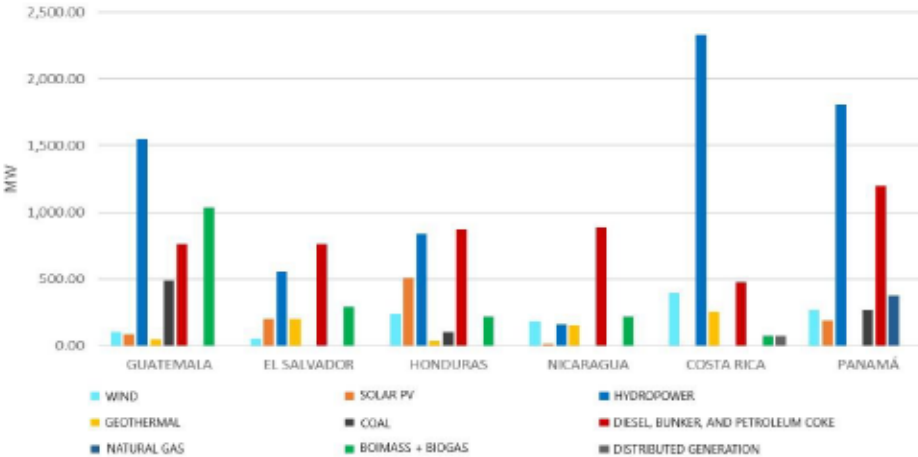
The CRIE is headquartered in Guatemala and began work in 2000, it is directed by its board of commissioners and the executive secretariat. The board has one representative from each country, and this representative is usually also a member of their country's national regulatory board.

Hydroelectric, geothermal, solar, wind (wind) plants, biomass, and thermal plants participate in SIEPAC's energy matrix; the largest share in energy generation is provided by hydroelectric, geothermal, and thermal plants, in Chart 2,4.2 and Chart 2.4.3 shows the energy sources for

each country of the SIEPAC region and the evolution of these energy sources in the last five years.

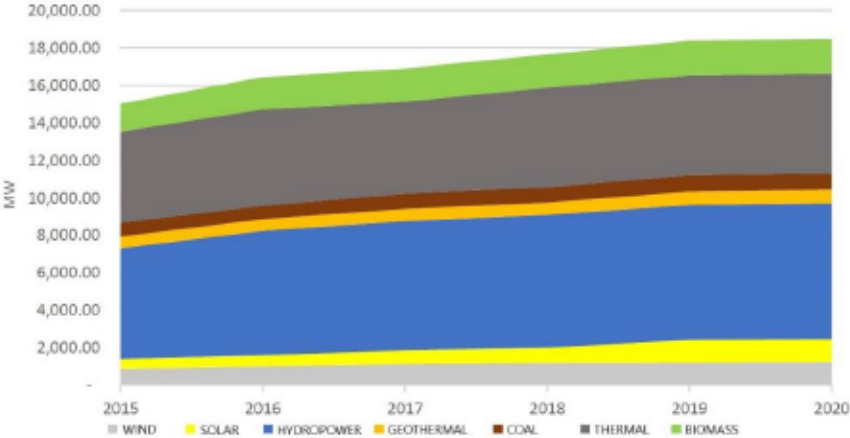
In the future, increasing the use of renewable energy in Central America to generate electricity will be key to decarbonizing the electricity sector and to using renewable energy to electrify energy services in end-use sectors. Based on the characteristics of SIEPAC and its current status, it is clear that to prepare for the future it will be necessary to improve the integration of the regional electricity system and increase renewable energy capacity.

Chart 2.4.2 Installed capacity in the region by technology and country year 2020 (MW)



Source: MER Report, 2020

Chart 2.4.3 Evolution of installed capacity in the region by technology, years 2015 to 2020 (MW)



Source: MER Report, 2020

Regarding the installed capacity of SIEPAC, a total of 18,507.1 MW is registered for the year 2020, where the participation of renewable energy has participation of **66.9%**. On the other hand, the energy generation of SIEPAC for 2020 amounts to 51,552.1 GWh, where the participation of renewable energy has the participation of 78.4% (Statistics of the electrical subsector of the countries of the Central American Integration System SICA, 2021, p. 52); and with respect to the demand for electricity for the year 2020, 52,246 GWh are registered (Operational Planning of Central America 2020-2021, p. 4)

Annex II includes information on indicators of the SIEPAC electricity sector in the period 2011-2020 related to the evolution of the energy matrix, installed capacity, generation, and annual evolution of electricity exchanges between Central American countries.

2.5 Sustainable mobility and electromobility in Central America.

Electromobility is most likely the main aspect of sustainable mobility and represents any land transport system based on vehicles powered by electricity. The technologies used to transfer electricity to vehicles according to current technologies can include the use of batteries that can be recharged while the vehicle is parked or by placing a pre-charged battery, also the provision of energy while the vehicle is in movement (such as trolleybuses), through hydrogen tanks produced via electrolysis and hybrid vehicles that combine electric motors with internal combustion engines.

All of the above, electromobility is a relatively new issue in the countries of Central America, it has barely begun to give thought to these issues, small initiatives are identified and with different scopes in each country, as well as actions carried out in isolation or not fully integrated as a Central American region.

However, the countries of Central America are fully convinced that the transition to electromobility in the countries of the SIEPAC region is of vital importance, considering that they are hydrocarbon importing countries and that their energy matrixes are moving towards the predominance of energies from renewable resources. Likewise, the lower use of oil-derived fuel for public and private transportation will reduce dependence on hydrocarbons and greenhouse gas emissions, particularly if the vehicles used are powered by electricity

from renewable energy sources. Recently, some countries in the Central American region have developed various efforts to promote private and public electromobility, the results of which will begin to be seen in the coming years. Among these efforts are the following (Sustainable Energy Strategy 2030 of the SICA Countries, CEPAL, 2020, p. 137):

Guatemala City and San Salvador have put into operation public transportation systems with dedicated lanes. In Guatemala, other transportation options are being studied (the surface train and the underground train).

- In Honduras, the Ministry of Energy, together with the National Electric Power Company, the Honduran Institute of Land Transportation, and the Electric Power Regulatory Commission, promotes, encourages, and encourages sustainable electromobility, through the use of new clean technologies that reduce emissions of polluting gases into the atmosphere. The initiative is still in the phase of preparing basic studies
- In Panama, the National Electric Mobility Program aims to make the transition to an electric public transport model that saves fuel and reduces emissions. The National Electric Mobility Strategy of Panama proposes lines of action that will serve as a guide for the main actors involved in transportation, and have the purpose of establishing a structure of governance and coordination of the public sector and the private sector, which ensures the implementation of the strategy with concrete initiatives. Panama City has underground train systems. These mass public transport systems contribute to electromobility in these countries and have helped reduce traffic congestion in the metropolises.
- Due to its comprehensive nature, long-term vision, and alignment with decarbonization goals, the actions taken by Costa Rica stand out, as it is the only country in the region that is most advanced in this area. The carbon neutrality initiative promoted by this country considers profound changes in the production and consumption of energy, with transport as one of the axes that will require a profound transformation. The high participation of renewable energies and the situation of having a very broad portfolio of renewable energy projects, which is amplified by the global disruption of solar energy, has prompted the country to advance electromobility plans. In 2019, the National Decarbonization Plan was presented, which contains the country's goals to meet the ideals of the 2030 Agenda and the Paris

Agreement. Its ten main axes are grouped into four major themes: 1) transport and sustainable mobility; 2) energy, sustainable construction, and industry; 3) comprehensive waste management; and 4) agriculture, land use change, and nature-based solutions.

About the vehicle fleet of the Central American region, the following information is available, shown in Table. 2.5.1:

Table. 2.5.1 SIEPAC countries: Historical evolution and projection of the automotive fleet.

Country/Year	2006	2016	2020	2030
Guatemala	1,285,153	3,250,194	4,490,354	8,772,058
El Salvador	643,294	881,673	993,807	1,287,804
Honduras	669,120	1,580,243	2,137,201	3,906,630
Nicaragua	294,961	675,105	840,489	1,332,234
Costa Rica	729,487	1,429,928	1,711,504	2,588,571
Panamá	446,225	940,957	1,144,046	1,781,816
TOTAL	4,068,240	5,507,906	11,317,401	19,669,113

Source: Sustainable Energy Strategy 2030 of the SICA Countries, CEPAL, 2020.

It is important to mention that of the number of vehicles indicated, 70% corresponds to private light vehicles, 20% to heavy cargo vehicles, and 10% to heavy passenger vehicles. In general, the Central American vehicle fleet has an average annual vehicle growth rate of 3.5%.

About the mass transportation system (metro), there is only one in Panama (in the capital of the country), an urban train in the city of San José in Costa Rica and an exclusive lane bus system in Guatemala City and the city of San Salvador (El Salvador). In these last three countries, the indicated mass transportation systems run on diesel and gasoline.

According to estimates, less than 1% of the total fleet in the Central American region is electric, mostly hybrids.

2.6 Summary and reflection of literature review.

LITERATURE	AUTHOR	MAIN ARGUMENT	MAIN FINDINGS	INFORMATION USED
The Sustainable Development Goals Report 2017	United Nations	Objective 7 dedicated to the promotion of the energy aspect was identified.	Guidelines are provided to substantially increase the share of renewable energies in the global energy mix	This information has served in part for the general theoretical framework of this research and the importance of renewable energy in the world.
The role of renewable energy in the global energy transformation, 2019	IRENA/SHURA/PAYNE INSTITUTE	It was necessary to fully understand the issue of energy transition worldwide	Experience and cases in progress were identified worldwide	This document delves into the aspect of energy transition, but provides little information on electromobility
Renewable Energy Generation and Impacts on E-Mobility, 2020.	G Sree Lakshmi, O Rubanenko, I Hunko.	This literature has served to understand the current state of electromobility in the world.	The right way was found to link future energy demand, renewable energy and electromobility	Data on energy demand projections and future estimates of the electric vehicle market were used from this literature. No data was found for Central America in this source.
https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Statistics-Time-Series	International Renewable Energy Agency, IRENA.	On this website useful information was found on historical records worldwide on the evolution of renewable energy.	Reviewing backward (historical) performance of renewable energy, helped to understand the obstacles of each technology	Very useful information on the types of technology that have best evolved in recent years, both in terms of costs and technological aspects.
Global Energy Transformation. A Roadmap to 2050, 2019.	IRENA	It was necessary to search literature with long-term projections	Confirmation of the increase in solar and wind energy in the short and long term due to the reduction in technology costs.	Breakdown of the use of renewables in terms of total final energy consumption, projection to the year 2050.
Cross-border cooperation on renewable energy, 2020	European Environment Agency	Learn about cases from other countries, regarding cross-border cooperation between countries in energy matters	Cases of success and failure in cross-border cooperation in renewable energy were found.	The lessons learned and the key success factors of energy cooperation projects between countries have been assessed. All the cases are European, this literature does not consider experiences in America.
Background, current status and perspectives of SIEPAC, 2014	Company Owner of Red S.A.	It was necessary to know and understand the origin and evolution of SIEPAC.	Strengths and weaknesses of this power line that connects the Central American countries	Historical details of SIEPAC and its evolution were captured. No issues of electromobility between countries were found.
Regional Electricity Market Report (MER), 2020.	Regional Electricity Interconnection Commission	This technical literature has been key to understanding how the electricity market works in Central America	In this document, the detail of renewable energy was obtained for each country that is part of SIEPAC	Data was used to support the historical evolution of renewable energy installed capacity for each SIECA country.
Central America Operational Planning, 2020	Regional Operating Entity EOR	Due to the nature of the subject of this thesis, it has been necessary to know indicators of the electricity sector of SIEPAC	SIEPAC electricity sector indicators for the year 2020.	The most recent data that could be obtained corresponds to the year 2020. Information on installed capacity, energy matrix, generation and purchase and sale of energy between Central American countries.
Statistics of the electricity subsector of the SICA countries, 2021	Economic Commission for Latin America and the Caribbean (CEPAL)	It was necessary to delve into a greater number of indicators to understand the regional electricity sector	Complementary indicators of the regional electricity sector were identified	Historical data and projections of the regional electricity sector. No information on electromobility was found.
Sustainable Energy Strategy 2030 of the SICA Countries, 2020.	Economic Commission for Latin America and the Caribbean (CEPAL)	It is necessary to link renewable energy with electromobility in the Central American context.	Some future projections of the regional electricity sector and some actions that have recently been carried out on electromobility in the SIECA countries were identified.	Projections of demand for the electricity sector to the year 2030 and projections of vehicular traffic, very little information on electromobility in the future.

Source: Own of the author of this thesis.

2.7 Identification of the gap that supports the study.

Considering the results obtained in this chapter, it is confirmed that in general the literature review provides empirical information on regional cooperation strategies, renewable energies and electromobility in Central America; however, it is identified that there is a lack of integration between these issues. The thesis addresses the gap related to the link between renewable energies and electromobility in Central America, to achieve this it is necessary to compare countries on the various electromobility initiatives that have been carried out, in such a way as to identify the actions that are required to equate o level the countries on this issue, and connect these electromobility initiatives with the future electricity demand of SIEPAC, establishing the actions that must be carried out to supply this demand with renewable energies.

3. CONCEPTUAL MODEL / ANALYTICAL FRAMEWORK.

This chapter explains the conceptual model that has been designed to approach this study, the research questions are taken up, a summary of the importance of carrying out the study is provided, and general guidelines are provided on how to carry out the work to develop the research and obtain useful results for the Central American energy sector.

3.1 Fundamental bases for the approach of the model.

Before explaining the conceptual model applied in this study, and in order to clarify the path to follow for the development of this research, the following aspects or questions are validated, which provide structure and rationale for the work to be carried out:

- a) Topic or situation that has been decided to investigate: Proposal of a combined model of renewable energy and electromobility, as factors, to accelerate the change and improvement in the Energy Matrix of the Electrical Interconnection System of the Central American Countries.
- b) Main reason for developing this research: In the SIEPAC region, the following aspects are identified as dissociated or not integrated with the same intensity; first, the

countries of the Central American region have made significant efforts in the last ten years toward the predominance of energies from renewable resources, however, minimal growth or stagnation has been identified in recent years, reaching a share in renewable energies that requires significant challenges with respect to the total installed capacity in the Central American region. In this context, the countries of the region want and seek how to improve the energy matrix of SIEPAC, however, on the other hand, all the countries of the Central American region have historically been and continue to be importers of hydrocarbons, without envisaging short term a lesser use of petroleum-derived fuels. Therefore, the opportunity arises to "connect and integrate initiatives" projecting the future electricity generation that the countries of the region require to be generated with renewable sources, to meet the electricity demand of the various sectors, including a regional electric vehicle fleet.

- c) How the aforementioned problem is addressed in such a way as to develop the indicated research?: The gap related to the link that should exist between renewable energy and electromobility in Central America was identified; this initially requires approaching a comparison between countries on renewable energy and electromobility initiatives, from this last topic actions are identified that are required to equate or level the countries on this topic to achieve a rapprochement as a Central American block and connect said regional analysis of electromobility with the future electricity demand of the SIEPAC, establishing actions that must be carried out to respond to said demand with renewable energy.

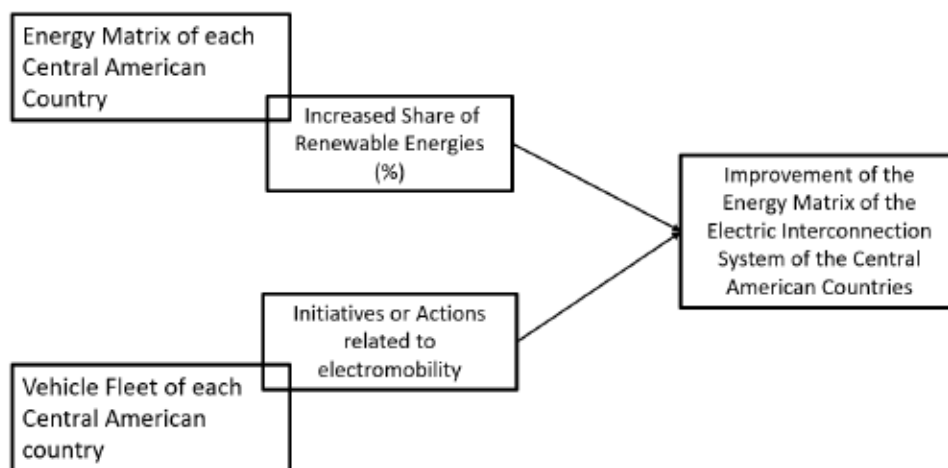
On the other hand, sub-questions or complementary questions have been raised that provide greater body and structure to the investigation, which are answered in chapter five (findings) of this thesis, the questions are the following:

- Are there plans to develop renewable energy projects to meet future demand?
- Is the amount of emissions produced by the vehicle fleet in Central America known?
- Really, are there concrete facts or estimates in Central America that demonstrate the benefits of electromobility?

3.2 Conceptual model applied in research.

Considering the type and nature of the topic that is being investigated in this thesis and taking into account that the number of data points for the two variables identified as independent is low or of lesser data; The research has been characterized as a qualitative study with a heuristic conceptual model². Figure 3.2 shows the proposed scheme.

Fig. 3.2 Conceptual Model to carry out the research.



Source: Own of the author of this thesis.

In relation to the conceptual model described, it is necessary to analyze the energy matrix of each Central American country and the participation of renewable energies required to cause a positive impact on the improvement of SIEPAC's energy matrix; In the same way, it is necessary to analyze the vehicle fleet of each Central American country and achieve benefits in the SIEPAC network by connecting regional electromobility initiatives with future electricity demand in the region, identifying actions that must be carried out to respond to said demand with energy renewable.

² The rationale used for the selection of the method is based on the learned guidelines and specialized literature seen in the research methods module taught by Prof. Dr. Christoph Dörrenbächer, as part of the Master of Science Business Management - Green Energy and Climate Finance, 2022. Berlin School of Economics and Law, Berlin Professional School.

Derived from what is described in sections 3.1 and 3.2, the proposition approach is indicated below:

Proposition 1: The improvement in terms of clean energy achieved in the energy matrix of the electrical interconnection system of the countries of Central America, depends on greater participation in the use of renewable energies and the use of electromobility.

Proposition 2: Electromobility in combination with the use of renewable energy is a model that will contribute to increasing energy security and resilience in the countries of Central America, will help reduce the negative effects on health caused by local pollution, will improve transport services and electricity, and will influence the region's decarbonization process.

Proposition 3: Considering that an electric car decreases the demand for fossil fuels, but increases the demand for electrical energy, the net environmental benefits will depend mainly on the composition of the electrical matrix.

4. METHODOLOGY

This section presents the basic method chosen for the development of this study, the institutions that were consulted, and the data collection process, as well as some comments on the validity and usability of this research.

4.1 Summary of the collection of information for the development of the investigation.

For the construction of the useful information base for the development of this thesis, three typical methods that are usually used for the development of this type of activity were evaluated: a) by using documents, records, and company-related datasets (secondary sources), b) by asking questions, or c) by making observations. The method indicated in literal b) was discarded due to the high risk regarding the time and availability of officials from key entities to provide all possible information on the subject of energy and that they are distributed throughout Central America. In the particular case of literal c) making an observation, this was ruled out as not applicable in this investigation; For this reason, in this study, considering its nature, the methodology using documents, records, and company-

related datasets (secondary sources) has been used, indicated in literal a) of this investigation. Likewise, the knowledge and experience of the author of this thesis have been applied in the evaluation of secondary sources.

4.2 Entities that were consulted and the data collection process.

It is important to mention that the development of this thesis demanded a collection of general information on recent international research, trying to review technical literature from reliable sources, in such a way as to know the current state of renewable energy and electromobility in the world and the great challenges ahead. On the other hand, to channel the research to address the identified gap, it was necessary to consult and review local information in each Central American country related to the issues in question; For this, documents from various institutions that handle the issue of the energy sector in the region were consulted. The main institutions that were consulted and that constitute the Central American regional electricity market MER are detailed below.

a) Institutions consulted to obtain primary information at the regional level: The main organizations or entities that were consulted are indicated here. In most cases, an attempt was made to obtain information through key documents issued by said entities, including statistics from the last 10 years and data projections for the next 10 years, in such a way as to make representative comparisons between parameters or indicators that were reasoned. The institutions where documents or key information for the development of this thesis were found are the following:

- The Regional Electricity Interconnection Commission CRIE, which is the regulatory and normative entity of the Regional Electricity Market MER.
- The Regional Operating Entity EOR, which is the operating entity of the MER.
- The Owner Company of the Network EPR, in charge of developing, designing, financing, building, and maintaining the first regional transmission system that will interconnect the electrical systems of the six countries.

- The Director Council of the Electricity Market (CDMER for its acronym in Spanish), which is responsible for promoting the development of the regional market and adopting the necessary decisions to achieve the comprehensive objectives and purposes of the Treaty and its protocols.
- Council for the Electrification of Central America (CEAC for its acronym in Spanish), makes decisions necessary to achieve the comprehensive objectives and purposes of the Treaty and its protocols.
- SICA Energy Coordination Unit (UCE-SICA, for its acronym in Spanish), carries out operational activities in the regional interconnection system
- Economic Commission for Latin America and the Caribbean CEPAL, supports guidance and advice for the realization of various studies at the regional level.
- International Renewable Energy Agency. Record key information globally.
- Ministry of Public Works of each Central American country. Responsible for managing the road network, and keeping records of traffic volumes. With this information, it was possible to dimension the problem of emissions and the urgent need to include electromobility in the regional analysis of this thesis.
- United Nations Environment Program (UN Environment) through its Regional Office for Latin America, an entity that has promoted and encouraged the development of studies and initiatives on electromobility issues in Latin American countries.

b) Institutions consulted to obtain complementary information at the country level. In order to understand the way in which the entities of the electricity sector work and relate to each other by country and at the level of the Central American region, it was necessary to investigate some documents considered secondary or complementary information that is very useful to fully understand the SIEPAC mechanism. Table 4.2.1 shows the electricity sector institutions by country and their corresponding website references:

Fig. 4.2.1 Complementary information on entities in the electricity sector by country.

Description	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panamá
Governing and regulatory institution	Ministry of Environment and Energy www.minae.go.cr/	National Energy Council www.cne.gob.sv/	Ministry of Energy and Mines www.mem.gob.gt/	My environment www.miambiente.gob.hn	Ministry of energy mines www.mem.gob.ni	National Secretary of Energy www.energla.gob.pa
Regulatory body	Public Services Regulatory Authority www.aresp.go.cr	General Superintendence of Electricity and Telecommunications www.siget.gob.sv/	National Electric Energy Commission www.cnee.gob.gt/	Electric Power Regulatory Commission www.cree.gob.hn/	Statistics National Institute www.ine.gob.ni/	National Public Services Authority www.asep.gob.pa/
State companies	Costa Rican Institute of Electricity www.grupoice.com	Lempa River Hydroelectric Executive Commission www.cel.gob.sv/	National Institute of Electrification www.inde.gob.gt/	National Electric Power Company www.enee.hn/	National Electric Transmission Company www.enatrel.gob.ni	Electric Transmission Company www.etsa.com.pa/
System and market operator		Transactions Unit, S.A. de C.V. www.ut.com.sv/	Wholesale Market Manager www.amm.org.gt		National Cargo Dispatch Center www.cndc.org.ni	National Dispatch Center www.cnd.com.pa
Producers	Costa Rican Institute of Electricity www.grupoice.com Aeroenergy SA www.aeroenergla.com Costa Rican Association of Energy Producers www.acepe.com	Duke Energy www.duke-energy.com.gt La Geo www.cabana.sugar Mill www.geo.com.sv www.ingeniolacabana.com	Santa Ana Corporate Group www.santaana.com.gt Pantaleon Group www.pantaleon.com Association of Generators with Renewable Energy www.ager.org.gt	National Electric Power Company www.enee.hn.com Terra Group www.terra.hn Association of Electric Power Producers www.ahpper.org	Ormat Technologies Inc. - Renewable Energy Expertise www.ormat.com Nicaraguan Electric Corporation, S.A. www.censa.com.ni Nicaraguan Electricity Company www.enel.gob.ni	ENEL Green Power enelgreenpower.com AES Panamá www.aespanama.com Panama Petroterminal www.petroterminal.com/ Pedregal Power Company www.pedregalpower.com
Dealers	National Power and Light Company S.A www.cnfl.go.cr Administrative Board of the Municipal Electric Service www.jasec.co.cr Heredia Public Services Company www.esph-sa.com	AES El Salvador www.aeselsalvador.com Southern Electricity Distributor www.delsur.com.sv	EGGSA Group www.eegsa.com Energuate www.energuate.com		DISNORTE-DISSUR disnorte-dissur.com.ni	Gas Natural Fenosa Panamá www.gasnaturalfenosa.com ENASA Panama www.ersa.com.pa
Marketers		EXCELERGY www.excelergy.com	Central American Electricity Marketer www.cec.com.gt COMEGSA www.comegsa.com.gt Electricity Wholesalers www.mel.com.gt			

Source: Own of the author of this thesis.

4.3 Assessment of the validity, reliability, and usability of the research.

As described in the previous sections, the documents of a general type, primary information documents, and those of a complementary type, that is, documents related to the local conditions of the energy sector in the Central American region, correspond mostly to official documents issued by formal entities or organizations with a long history in the energy and transportation sector, thus confirming the validity and reliability of the documents; As indicated, an attempt has been made to review a range of ten years backward to review the behavior of various indicators, such as the information indicated in **Annex II**, projections have

also been addressed ten years in the future to review estimates that end up form and constitute the framework of analysis of this research (information referred to in chapter 5 and chapter 6 of this thesis).

It is important to mention that the knowledge and experience of more than 20 years of the Author of this thesis in various projects at the Central American level, allows for validating the reliability and usability of the information and the data source. On the other hand, considering the nature of this thesis that guides to review of the data by country and data at the regional level, it is also a way to contrast and validate the information used.

The results of this thesis will be very useful in each country of Central America, the information generated in this research could be the basis to encourage greater use of renewable energies in the energy matrix of the electrical interconnection system in Central America, and help promote greater strength electromobility in Central America, in addition to contributing to decarbonization by helping to reduce the negative effects of local pollution.

This research will motivate the universities of the Central American countries to develop specific research works as a complement or addition, on the other hand, the Multilateral Development Banks that have a presence in Central America, such as the Inter-American Development Bank, the World Bank and the Central American Bank for Economic Integration, they will be interested to know the results of this research, since these institutions have some action plans to promote electromobility in Central America, as well as renewable energies.

5. FINDINGS.

This chapter contains a global presentation of all the results found, and a description of them is made in a structured manner following the logical order of the research questions indicated in section 3.1 of this thesis, it is important to indicate that the detailed analysis or interpretation of the results based on the identified gap and the research questions is carried out in chapter 6 (Analysis and Discussion).

5.1 Results on renewable energy sources in the SIEPAC network and potential for future development of renewable energy projects by country.

In the Central American region, in accordance with the provisions of their respective legal and regulatory frameworks, the countries assign the responsible institutions (ministries of energy, public electricity companies and administrators of the electricity markets) to ensure the national electricity supply in the short and long term, as well as the guidelines (reliability and economy) to obtain a balance between the supply and demand of electricity at reasonable costs and prices. The fundamental instruments for these purposes are the short-, medium-, and long-term national electric power plans. The first are in the sphere of the institutions responsible for the load dispatch centers and the administration of the electricity markets and correspond to the operational security plans.

The medium and long-term plans have been left to the governing institutions of the energy sector (generally the ministries of energy) or the state-owned companies that govern the electricity subsector. In most cases, they are indicative plans that serve as a guide for regulatory entities to call for bidding processes related to long-term energy purchases, which, in turn, is the mechanism for building new generation plants. Only the case of Costa Rica, it is a mandatory compliance plan for its state company, which is responsible for the supply of electricity throughout the country. However, there is a small portion of the Costa Rican market served by private agents, municipalities and cooperatives, all producers of renewable energy. In the other six Central American countries, the company (or state companies) only cover a portion of the electricity market and the other portion corresponds to private generating agents.

In the countries of Central America, the national plans for the expansion of long-term electricity generation are generally made for periods ranging from 15 to 20 years and are formulated in accordance with technical, economic, environmental and social criteria that take into account account the security of supply at cost and reasonable prices (service at the lowest cost), the diversification of supply sources, the participation of renewable sources, the reduction of dependence on fossil fuels, energy security and environmental sustainability. For the moment, in the case of the six countries that make up SIEPAC, the plans consider the Regional Electricity Market MER only for the exchange of surpluses, due to the need to

strengthen and improve the mechanisms that allow and guarantee electricity contracts long term. However, in the operation of the system, the immediate advantages that the interconnection and the regional market offer are fully exploited, buying and selling energy for the benefit of the users of the electrical system.

Once the expansion plans are approved, the countries make their respective electricity transmission plans. In general, that is, the responsibility of the transmission companies (most of them state-owned) which, in turn, present their proposals to the regulatory entities for their approval, including the mechanisms for the repayment of the works considered (by means of toll and transmission services). Tables 5.1 and 5.2 show the projections of the demand for electrical energy and capacity of the SIEPAC countries. The projections were calculated in 2018 based on the growth rates used by the EOR. On the other hand, Table 5.3 and Chart 5.1 show a summary of the additions required for electricity generation in the 2020-2030 period.

Table 5.1 Projection of the demand for electrical energy in Central American countries (GWh).

Year	Total	Guatemala	El Salvador	Honduras	Nicaragua	Costa Rica	Panama
2030	77,328	16,009	7,875	12,663	6,148	15,349	19,283

Source: Own elaboration based on information obtained from the document Sustainable Energy Strategy 2030 of the SICA Countries, CEPAL, 2020.

Table 5.2 Peak power demand projection (MW)

Year	Total	Guatemala	El Salvador	Honduras	Nicaragua	Costa Rica	Panama
2030	12,527	2,624	1,245	2,222	1,179	2,263	2,994

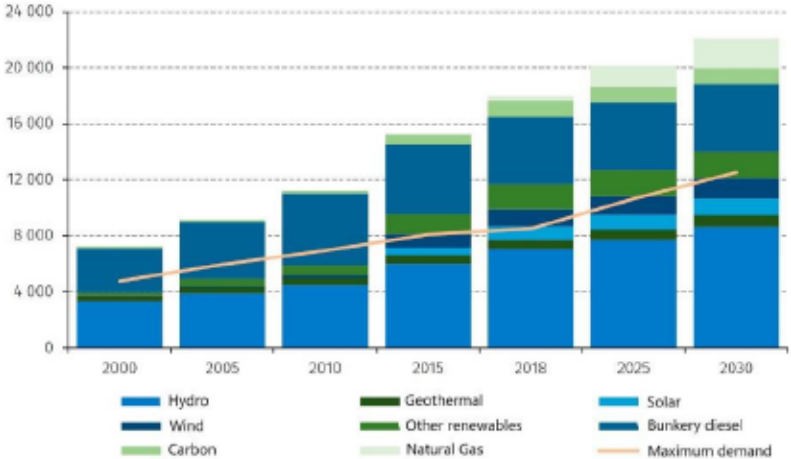
Source: Own elaboration based on information obtained from the document Sustainable Energy Strategy 2030 of the SICA Countries, CEPAL, 2020.

Table 5.3 Additions in new power generation plants (MW).

Years	Hydro	Solar	Wind	Biomass	Geothermal	Bunker	Carbon	Natural gas	Total
2020-2025	640	62	133	64	100	35	0	1,100	2,134
2026-2030	946	153	130	0	71	0	0	660	1,960
Total	1586	215	263	64	171	35	0	1,760	4,094

Source: Sustainable Energy Strategy 2030 of the SICA Countries, CEPAL, 2020.

Chart 5.1 Central American countries: additions in new power generation plants, by technology and projected peak power demand, 2000-2030. (MW)



Source: Sustainable Energy Strategy 2030 of the SICA Countries, CEPAL, 2020.

As can be seen in Figure 5.1, as of 2025, the level of certainty of the proposed projects is lower, especially in the case of projects that do not yet have complete feasibility studies. According to data for the end of 2019, three countries have wide margins of slack with respect to their domestic demand (Guatemala, Costa Rica and Panama, the latter due to recent natural gas and coal projects that came into operation). El Salvador would go into that situation after the entry of a major natural gas project at the end of 2022.

Of the total additions, 56% corresponds to renewable energies: hydroelectric (39%); wind (6%); sun (5%); geothermal (4%) and solar (2%). 44% thermoelectric corresponds almost entirely to natural gas. The coal option was ruled out, since the costs due to the negative externalities of this type of energy have not yet been included in the EOR evaluations.

Likewise, an estimate of the share of electricity production technologies in 2030 shows 82% for renewables (7% higher than in 2018) and 18% for thermoelectrics. By renewable technology, the shares are: hydroelectric (54%), biofuels, mainly agro-industrial biomass (12%), geothermal (7%) and wind (6%). For its part, natural gas enters the MER from projects in Panama and El Salvador.

Currently three countries —Costa Rica, Guatemala, and Panama—have significant reserve margins (adequate capacity minus demand) throughout the year, which allows their agents

to offer their surpluses for export to the MER. However, the reduction in power in various sections of the SIEPAC regional line and the delay in many national transmission works (the so-called national reinforcements) have drastically limited international electricity transactions. For this reason, the second circuit of SIEPAC is a future priority project for the Central American countries. In addition to improving the security of supply, the recovery of SIEPAC's transmission capacity will also bring significant economic benefits (reduced prices and electricity costs).

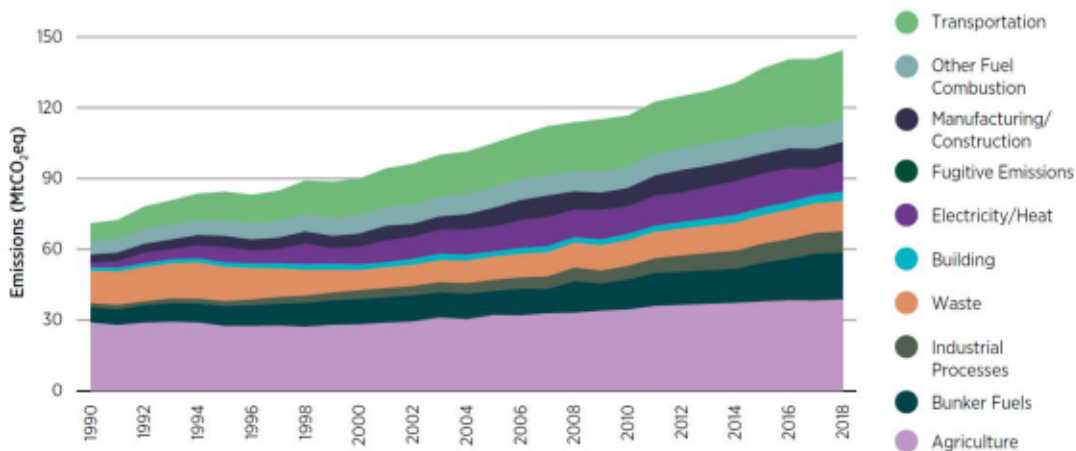
In terms of installed capacity to respond to future demand, the number of renewable energy projects per country that are projected to be built in the next 10 years is shown in **Annex III**.

5.2 Estimated emissions produced in Central America including the transportation sector.

The countries of Central America make up a region with a relatively small territorial extension and population compared to the North American region and the countries of the South American region, on the other hand, the Central American countries are less developed in terms of the number of industrial and urban areas, road network and transportation; however, In 2018, Central America contributed 0.3% of global greenhouse gas emissions (Climate Watch, 2021). It is important to note that emissions from the Central American region have increased gradually since 1990.

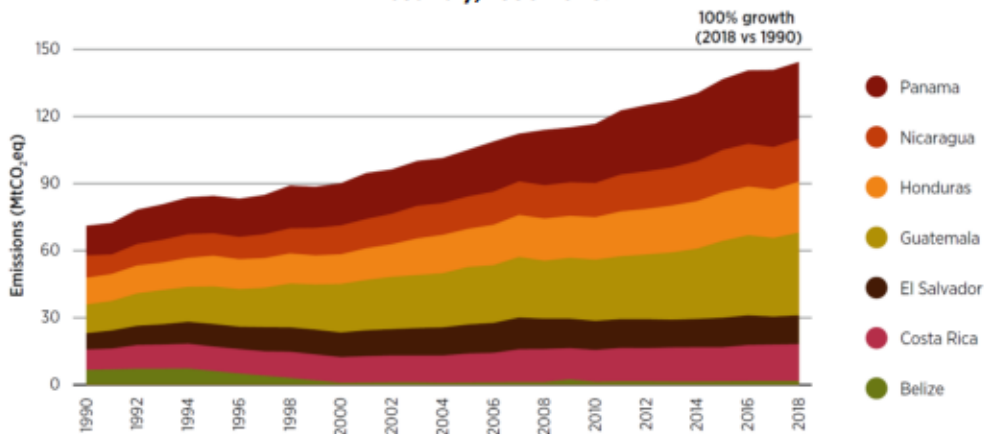
Agriculture contributed most of the emissions in the 1990s, and emissions from the sector increased slightly until 2018. In recent decades, emissions from the sector energy have risen fastest to become the largest contributing sector. The largest sources of these emissions were the transportation sector, bunker fuels, and electricity and heat production, highlighting the need for a greater focus on these subsectors. Chart 5.2 shows historical emissions by sector and Chart 5.3 shows historical emissions by country.

Chart 5.2 Historical emissions (excludes land-use change and forestry) in Central America by sector, 1990-2018.



Source: Climate Watch, 2021.

Chart 5.3 Historical emissions (excluding land-use change and forestry) in Central America by country, 1990-2018.



Source: Climate Watch, 2021.

Considering what is indicated in section 2.5, specifically in Table 2.5.1 “SIEPAC countries: Historical evolution and projection of the automotive fleet”, it is easy to deduce that if immediate actions are not taken in line with decarbonizing the transport sector, emissions could double in the next years.

5.3 Actions carried out in Central American countries in relation to electromobility and its benefits.

In addition to the actions on electromobility carried out in each country of the region indicated in section 2.5 "Sustainable mobility and electromobility in Central America", it is confirmed that currently, the country that has worked the most on this issue in the region is Costa Rica. The findings presented in this chapter investigated as concrete facts carried out in the electromobility field correspond to Costa Rica, the rest of the countries in the region propose to follow a similar roadmap to this country. On the other hand, it is confirmed that to date the issue of electromobility has evolved positively in other regions of Latin America that began years ago with this issue, for example, countries such as Brazil, Chile, Argentina, Colombia, and Mexico, have small systems and electric routes already in operation, in general, in Latin America more than 6,000 light electric vehicles were registered in 2019, apart from fleets of electric buses and electric motorcycles. In **Annex IV**, a diagram is presented with the main advances and electroroutes in Latin America.

Focused on the region of interest in this thesis, as indicated, the countries of the Central American region try to advance based on the results to date in Costa Rica, which are described below:

Costa Rica has made significant progress in electric mobility in recent years. At the national level, the National Decarbonization Plan 2018-2050 was launched, which proposes electric mobility as a key component to achieving the decarbonization of the economy. In terms of transportation, the plan contains three main axes with specific goals for public transportation (70% of zero-emission buses and taxis by 2035 and 100% by 2050), private vehicle fleet (25% of the fleet of light vehicles, private and institutional will be zero emissions by 2035) and cargo transport (20% reduction in emissions from the cargo sector by 2050 through the introduction of new technologies).

The National Electric Transportation Plan 2018-2030 stems from this policy, which focuses on three uses for electric vehicles: public transportation, institutional transportation, and private vehicles. Among the main aspects of the plan, the creation of multisectoral working groups is proposed for the creation of enabling conditions related to charging infrastructure,

exemptions for components related to electric vehicles, and electricity rates for recharging electric vehicles, among others. Additionally, to speed up the replacement of institutional fleets, Directive 033-MINAE-MOPT was developed, which requires public institutions to replace internal combustion vehicles with zero-emission vehicles.

In 2018, Costa Rica approved Law N. 9518, which is the first law on electric mobility in the region. This law establishes fiscal and non-fiscal incentives to accelerate the transition toward zero-emission vehicles. Some of the economic benefits stipulated in the law are valid for five years, effective from its publication. In this sense, regulation N. 41092 MINAE-H-MOPT was published to operationalize law N. 9518 and clarifies the incentives defined in the law in matters related to exemptions, as well as the necessary procedures to obtain them. Executive decree N. 41642-MINAE establishes the necessary construction and operating conditions that load centers must have.

In addition, in 2018, incentives for hybrid vehicles were repealed and benefits and incentives were extended to second-hand electric vehicles less than five years old. There are also regulatory compendiums (INTE/IEC 61851 and INTE/IEC 62196), whose function is to decree different considerations for electric vehicle charging centers.

Costa Rica has around 1,020 100% electric cars imported in the period from 2009 to 2019, 145 plug-in hybrid vehicles, and 1,422 conventional hybrids (for the period 2017-2019). In the country, there are institutional fleets that have incorporated motorcycles and electric cars, such as Costa Rican Post Office, ICE Group (Costa Rican Institute of Electricity), as well as the Road Safety Council.

Regarding recharging infrastructure, by December 2019, the country had a network of 11 fast and 34 semi-fast charging centers installed by ICE Group, as well as other public charging centers installed throughout the country. At the tourist level, the Monteverde Electric Route was created, a community initiative in one of the most visited places in the country, where charging centers were installed in shops and lodging places available to visitors. On the other hand, the Public Services Regulatory Authority defined a single rate for the operation of the national network of fast charging centers for electric vehicles, managed by ICE Group, which is equivalent to 182.72 colones/KWh before taxes (equivalent to US\$0.32/KWh, 2019).

On the other hand, Costa Rica is working on generating the enabling conditions for the electrification of the public transport system in all its modalities (buses, trains, and taxis). Currently, there is a working group at the technical level and another at the level of decision-makers to achieve the proposed goals in terms of electric public transport. These groups meet periodically to discuss aspects necessary to enable the substitution of internal combustion vehicles for zero-emission vehicles, advance in pilot projects to test different technologies, provide support to the private sector, and train and sensitize all interested parties. To date, two electric buses operate in the country, one acquired by the electric company CNFL (a subsidiary of ICE Group) and used for exhibition purposes, and the other by the company BYD, which is being tested and managed by ICE in different routes as in the University of Costa Rica (UCR). The start of a pilot project with three electric buses donated by the German Government is awaited. In addition, Costa Rica has the first hydrogen bus in the Central American region, with a range of 340 km and a capacity for 70 passengers. This bus is currently in the technical testing phase in Liberia, Guanacaste.

The country has three electric taxis that provide service in the provinces of San José and Heredia. Other transportation service platforms have incorporated electric units; however, being unofficial services, the exact amount is unknown.

Similarly, the market for electric motorcycles and bicycles is quite developed. In 2019 alone, 3,284 units entered according to data generated by ASOMOVE (Costa Rican Association of Electric Mobility). There are national companies that import and design this type of unit that has had a major boost through fairs for consumers. In October 2019, a shared bike system called OMNI was established that uses pedal-assist electric bikes that are accessed and used via an app.

Civil society has had a very important role in promoting electric mobility at a national level. Organizations such as ASOMOVE, which brings together more than 200 users of electric vehicles, Costa Rica Clean, the Center for Urban Sustainability, the academy, and the community of Monteverde, to name a few, have been key in the organization of events to make electrical modes of mobilization visible and put citizens in contact with the different technologies. Similarly, the private sector is made up of vehicle, bicycle, and motorcycle distribution agencies; companies dedicated to the installation and design of charging

infrastructure; electric vehicle maintenance and training workshops, training institutes; electricity distribution companies, and the financial and insurance sectors have supported the dissemination and awareness of electrical technologies and zero emissions.

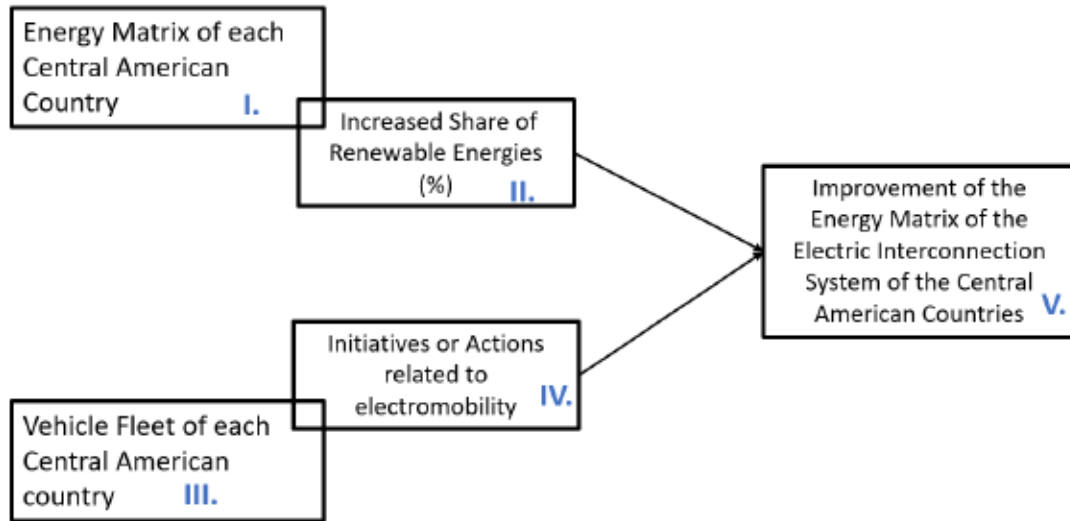
Costa Rica has also promoted better financial conditions for the acquisition of private electric vehicles, as well as for public transport. These improvements include better rates, longer payment terms, lower commissions, and guarantees. For example, in October 2019, in compliance with Law No. 9518, three state banks announced preferential lines of credit for both private electric vehicles and electric taxis and buses.

Finally, it is important to mention that there are other actors that are helping to create synergies and conditions to promote and develop electromobility in all Central American countries, this is the case of the Central American Bank for Economic Integration BCIE (by its acronym in Spanish), which is a multilateral development, which in line with its Environmental and Social Strategy 2020-2024, has supported a series of activities and initiatives focused on zero-emission mobility. Among them, air transport by cable, such as the electric AeroMetro in Guatemala City; as well as the public cable car in Tegucigalpa, Honduras. It has also provided support for rail transport, such as the Electric Passenger Train in Costa Rica, which recently obtained co-financing from the Green Climate Fund (GCF) through BCIE; the Limonense Freight Electric Train-TELCA in Costa Rica; the Pacific Railroad in El Salvador; and the Guatemalan rail freight connection segment in Guatemala; in addition to the line that will connect the cities of Santiago de los Caballeros and Santo Domingo in the Dominican Republic and Line 5 of the Panama Metro.

6. ANALYSIS AND DISCUSSION.

In this chapter, the findings are analyzed and interpreted in light of the conceptual model indicated in section 3.2, and an assessment is made of the coincidence or relationship of the findings with the propositions that were raised; Likewise, theoretical guidelines are provided on how to overcome those challenges that are still identified as fundamental to guarantee the purpose of this thesis. Figure 6.0 is taken from section 3.2 to explain the order of analysis.

Fig. 6.0 Analysis of findings and results based on the proposed conceptual model.



Source: Own of the author of this thesis.

6.1 Summary of results of the analysis performed.

I. Regarding the energy matrix of each Central American country.

As a result of analyzing the energy matrix of each country, it is identified that in each Central American country there is a genuine interest, initiatives, and projects with the aim of increasing the participation of renewable energies, and there are planned projects to develop them in the next 10 years (Annex III) regardless of whether the electromobility initiatives materialize or not; this confirms that although the countries are concerned about the issue of emissions generated by vehicular transport (section 5.2) and some initiatives are being carried out on electromobility (section 5.3), the demand and future capacity of electricity (tables of section 5.1 and tables in Annex III) have not included the demand for electricity that would be generated in the future by an electric vehicle fleet at the regional level.

II. Increased share of renewable energies.

Concerning this aspect and as a result of the analysis, it is confirmed that each country in Central America has more or fewer resources than others, however, they all have the resources to develop and generate new renewable energy projects. As indicated in graph 2.4.3, the share of renewable energy in the SIEPAC energy matrix is 66.9% corresponding to the year 2020, Likewise, an estimate of the share of electricity production technologies in 2030 shows 82% for renewables (section 5.1). These numbers of the current situation and the projections of renewable energies as such are promising and viable. For this reason, there is the potential to cover using clean energy the demand for electricity that would be generated by an electric vehicle fleet. Below is an analysis of the main existing resources in Central America to develop renewable energy projects:

Hydroelectricity.

Hydroelectricity is a renewable energy resource that has been exploited to a great extent in the region, but there is still significant potential. These resources seem to be questioned for some time due to the environmental and social impacts associated with these developments. However, it is a renewable, clean, well-known resource with which the region has vast experience. It is important to continue with its development, with an approach oriented toward society. In general, the enormous potential of untapped water resources must be developed, for this, it is necessary to place special emphasis on socio-environmental licensing, so that it does not become a true environmental threat or a brake on energy development. For this, the application of good environmental management practices and communication with the different interest groups must be reinforced.

In 2019, the installed hydroelectric capacity in the central american countries amounted to 7,195.9 MW, which allowed generating around 31% of the region's electricity production (21,454 GWh). The significant decrease in hydroelectric production in that year should be mentioned (21% lower than that registered in 2018), a singularity that was the result of the reduction in the rainfall regime, caused in turn by the presence of the climatic phenomenon known as ENSO (El Niño Southern Oscillation, a phenomenon originating in the Pacific Ocean)

and another combination of events probably associated with climate change. Notwithstanding the significant decrease in hydroelectric production, the existing reserve capacity in the national electrical systems, and, in the case of Central American countries, the electrical interconnection of SIEPAC, avoided electricity supply crises. The greater vulnerability of hydroelectric resources to climatic phenomena will require a review of reserve criteria and policies and actions for the diversification of the energy matrix of the countries.

Geothermal.

After hydroelectricity, geothermal energy is the second most important renewable energy source in three countries (El Salvador, Nicaragua, and Costa Rica). In two other countries (Honduras and mainly Guatemala), the resource is scarcely used and could substantially increase its participation in the energy matrix. Even considering the long history (of more than seven decades of geothermal prospecting in some countries) the existing inventories of geothermal resources are very limited, mostly consisting of surface geological surveys that do not have enough information to make well-founded calculations with the drilling of sufficient depth and diameter, chemical analysis of fluids, density and temperature, field modeling, among others, of the theoretical potential and the quality of the steam (low, medium and high enthalpy).

Bearing this note in mind, a preliminary estimate of the geothermal potential to be developed in six Central American countries is mentioned, of the order of 2,750 MW of net power delivered by geothermal plants (Sustainable Energy Strategy 2030 of the SICA Countries, CEPAL, 2020, p. 150).

In addition to electricity production, there are many opportunities for the utilization of geothermal heat in industrial processes (waste heat and steam condensates can be used in the dehydration process of fruits and agricultural products, in industries such as ceramics, food, and others), which, even with the abundance of the resource, has been little exploited (especially in El Salvador and Guatemala there are some examples), representing an opportunity to consider for the future development of industrial parks. On the contrary, the

direct use of hot springs for recreational, tourist, and medical purposes is present in all countries, but there is still a very high unused potential. Diagnoses have been made to determine the factors that limit geothermal development in the countries.

In some cases, the greatest weaknesses are found in the institutional frameworks (either in their lack or in their insufficiency), this being more noticeable in the cases in which the development of new plants was left in the hands of private investors. During the initial stages of development, significant investments are required, which affect the perceived uncertainty of the resource. This constitutes a substantial barrier to the mobilization of the risk capital necessary to finance exploratory drilling.

Other existing barriers are related to aspects: institutional (deficiencies in strategic planning, limited inventories); the legal and regulatory framework (concessions, incentives, regulation of the use of groundwater, among others), and environmental issues (especially when the resource coincides with national parks and ecological reserves), however, many benefits of the resource must be recognized. To those already mentioned (low environmental impacts, low production costs, high reliability, firm energy supply, and immunity or indifference of the resource to the harmful effects of climate change), less social conflict should be considered (unlike water resources, which will always have a conflict with the water users in the different parts of the considered basin).

Solar and wind power.

In the Central American case, wind energy and mainly solar energy have emerged as disruptive technologies. In 2020, there were 1,281 installed wind MW and 1,263.7 installed solar MW connected to the transmission and primary distribution networks, which represents an important advance in electricity generation. The task still pending is the use of these renewable energies in the productive sectors (heat, cold, among others) and the increase in their use in homes for caloric uses (for example, water heating).

Technological advances and cost reductions have driven the advancement of these technologies, mainly photovoltaic solar energy. Distribution-scale projects can compete

economically with new generation facilities based on fossil fuels. In the countries of Central America there is no inventory of the square meters of solar collectors installed (and their energy equivalent), nor are there policies to promote their use. It should be borne in mind that greater penetration of variable renewable energies will require national and regional actions, including evaluations of the flexibility of electrical systems to accommodate these technologies.

III. About the vehicle fleet of each Central American country.

It is important to mention that, despite having found very valuable information on the vehicle fleet of each country in the region, this information is recorded differently from one country to another, that is, when it comes to using it as information for the analysis of the "region for electromobility purposes" requires standardizing several parameters and criteria. In general, the information contained in table 2.5.1, which is very useful for specific purposes of transport planning and road projects, requires greater detail and a specific approach interinstitutional and intersectoral useful for articulation plan the electricity network taking into account the volume and type of traffic at the regional level and its eventual evolution towards electric mobility. In summary, the information found on the vehicle fleet presents some difficulties for purposes of use in electromobility, the most important are:

- a) The classification of vehicles is dissimilar, it does not agree in any country, although in certain categories there is consistency (in many cases what is included in each category is specified, but in others, the explanation is only partial).
- b) The classification of the historical data is not consistent and presents differences between periods since the statistical series are not retroplated.
- c) The time series cover different periods, in one case information was found for a single year and in others for two years.

In general, there is no information on transport planning studies "with a focus on the regional level", this information would be key to having a better understanding of the operation of the sector on quantitative bases, such as origin-destination matrices, mobility, among others.

IV. Initiatives or actions related to electromobility.

As a result of the analysis of the initiatives and actions described in section 5.3, a comparison between countries is presented below that makes it possible to visualize the gaps that the countries must overcome to achieve a homogeneous situation, that allows progress towards electromobility as a block or region. Table 6.1 shows the comparison indicated.

Table 6.1 Advances on electromobility initiatives in Central American countries.

Instruments for the promotion and development of electric mobility from the point of view of the regulatory framework by country.							
Instruments		Guatemala	El Salvador	Honduras	Nicaragua	Costa Rica	Panama
Purchase incentives	Purchase tax	■	■	■	■	■	■
	Exemption or reduction of import tax	■	■	■	■	■	■
Implementation of incentives for use and circulation.	Property / circulation tax	■	■	■	■	■	■
	Exception of tolls, parking and others.	■	■	■	■	■	■
Other support instruments.	Vehicle restriction (peak and license plate)	■	■	■	■	■	■
	Differentiated electricity rates	■	■	■	■	■	■
	Implementation of charging centers	■	■	■	■	■	■
	Implementation of electric mobility strategy	■	■	■	■	■	■

no progress
 partial or in design phase
 complete, approved, and progress

Source: Own of the author of this thesis.

V. Regarding Improvement of the Energy Matrix of the Electrical Interconnection System of the Central American Countries.

Considering a closure to the analysis carried out, a brief reflection on the propositions that were established in section 3.2 is indicated below.

Proposition 1: The improvement in terms of clean energy achieved in the energy matrix of the electrical interconnection system of the countries of Central America, depends on greater participation in the use of renewable energies and the use of electromobility.

Reflection: Considering the findings and analysis indicated in this thesis, the Central American region has sufficient resources to generate renewable energy projects and respond to future demand with clean energy. It is necessary to add in the calculations of the future energy demand that consumption is required by the regional electric vehicle fleet. On the other hand,

there is the possibility of applying "Vehicle to Grid" technology, which is a system that allows electric cars to return energy to the grid, so it can serve as a support for the electricity grid to balance production problems. and consumption in real-time.

Proposition 2: Electromobility in combination with the use of renewable energy is a model that will contribute to increasing energy security and resilience in the countries of Central America, will help reduce the negative effects on health caused by local pollution, will improve transport services and electricity, and will influence the region's decarbonization process.

Reflection: As indicated in the findings of this thesis, the condition of air pollution due to emissions from the regional vehicle fleet is evident. The combined electromobility and renewable energy model solution proposed in this thesis is a comprehensive, safe and resilient solution to the current problem.

Proposition 3: Considering that an electric car decreases the demand for fossil fuels, but increases the demand for electrical energy, the net environmental benefits will depend mainly on the composition of the electrical matrix.

Reflection: One of the great aspects learned and confirmed from the environmental point of view in the development of this thesis, is that there will be no positive impacts to evolving toward electromobility if the vehicle fleet will be powered by non-renewable energy sources. This is a powerful reason that supports the proposed combined model of this thesis, to accompany electromobility initiatives in conjunction with renewable energy.

7.0 CONCLUSIONS.

- This thesis shows that electric mobility is a reality and that it is beginning to gain traction in the Central American region. The different countries of the region present multiple possibilities to undertake the transition toward cleaner mobility, considering as an advantage that each country has enormous potential to increase the participation of renewable energies. Even though in Central America there are significant differences between the trajectories, needs, and opportunities of the

different countries based on size, development of their industry, market, and state of their legislation; SIEPAC's existing and operating platform enables the integration of electromobility, allowing the challenge to be tackled on a regional basis.

- Renewable energy and electric mobility in Central America have enormous potential that goes beyond the transportation sector. This combined model brings integrated benefits in the rational use of energy; in the quality of the air that is breathed in urban centers, in addition to being an important measure of climate action that seeks to achieve the commitments acquired by the countries under the Paris Agreement. It also has the potential to become a new engine of development for the region.
- The participation of renewable energies in the SIEPAC energy matrix is 66.9% corresponding to the year 2020. Likewise, an estimate of the participation of electricity production technologies in 2030 shows 82% for renewables. These numbers of the current situation and the projections of renewable energies as such are promising and viable. Therefore, there is the potential to cover with clean energy the demand for electricity that would be generated by a fleet of electric vehicles.
- The countries of Central America make up a region with a relatively small territorial extension and population compared to the North American region and the countries of the South American region. On the other hand, the Central American countries are less developed in terms of the number of industrial and urban areas, road networks, and transportation; however, In 2018, Central America contributed 0.3% of global greenhouse gas emissions. It is important to note that emissions from the Central American region have increased gradually since 1990. it is easy to deduce that if immediate actions are not taken in line with decarbonizing the transport sector, emissions could double in the next years.
- It is identified that in each Central American country there is a genuine interest, initiatives, and projects with the objective of increasing the participation of renewable energies, and there are planned projects to develop them in the next 10 years regardless of whether the electromobility initiatives materialize or not; This confirms that although the countries are concerned about the issue of emissions generated by vehicular transport and some initiatives are being carried out on electromobility; The projected demand for electricity for the year 2030 (77,328

GWh), as well as the analysis of future capacity, have not included the electricity that a fleet of electric vehicles at the regional level would require in the future.

- Currently three countries —Costa Rica, Guatemala, and Panama— have significant reserve margins (adequate electrical capacity minus demand) throughout the year, which allows their agents to offer their surpluses to export to the Regional Electricity Market. However, the power reduction in various sections of the SIEPAC regional line and the delay in many national transmission works (the so-called national reinforcements) have drastically limited international electricity transactions. For this reason, the second circuit of SIEPAC is a priority project for the future of Central American countries that will allow covering the demand for electromobility regardless of its size or scope. In addition to improving the security of supply, the recovery of SIEPAC's transmission capacity will also bring significant economic benefits (reduced electricity prices and costs).
- In order to advance with a regional focus on the issue of electromobility, the countries of Guatemala, El Salvador, and Nicaragua are required to develop or adjust their national electromobility strategies by adopting and adapting measures similar to those already implemented by Costa Rica and Panama.
- Considering that an electric car decreases the demand for fossil fuels, but increases the demand for electrical energy, the net environmental benefits will depend mainly on the composition of the electrical matrix. One of the great aspects learned and verified from the environmental point of view in the development of this thesis is that there will be no positive impacts to evolving toward electromobility if the vehicle fleet will be powered by non-renewable energy sources. This is a powerful reason that supports the combined model proposed in this thesis, to accompany electromobility initiatives in conjunction with renewable energies that allow accelerating the change and improvement of the SIEPAC energy matrix.

8.0 RECOMMENDATIONS.

As a result of the development of this thesis, and the author's own analysis, the following recommendations are proposed, which have been classified in order of priority with the aim of achieving faster connection and integration of electromobility and renewable energy in Central America.

Short-term actions (2022 – 2023)

- **Promote inter-institutional articulation and intersectional:**

During the development of this thesis, the transport sector and the energy sector of each Central American country were analyzed, and it was quickly detected that the promotion of electric mobility unites sectors that traditionally have not had to work together. Although it is considered a transportation problem, it involves the energy sector and all its actors in the electricity subsector, from generators to electricity marketers.

In addition, the Ministries of Finance must be in the conversation, especially for the fiscal incentives they wish to offer, the public and private Banking and the insurance sector must participate in the conversations to know in greater detail what the needs and true associated risks are and thus create specific strategies for these sectors. To materialize this action, it is suggested that inter-institutional and inter-sectorial forums be held, led by SIEPAC and Regional Electric Market.

- **Conducting a traffic study at the regional level with an electromobility approach, determining the future electricity demand required by the electric vehicle fleet.**

The results of this study are required in the early phase, in such a way that they provide basic information for the elaboration of a regional strategy, this action should be led by SIEPAC and the Ministries of Transport of the Central American countries.

- **Establish a strategy at different levels and time horizons.**

It is crucial to develop a clear roadmap in the short and medium term to offer investment certainty toward the electrification of the transport sector. The Central American countries must establish goals that subsequently facilitate the follow-up and evaluation of the progress made to readjust their strategies and plans. Mainly, it is important to define goals for public transport fleets and light vehicles with a focus on electromobility. At the same time, countries must make an effort to adopt greater demands in terms of environmental quality and emissions derived from fossil fuels, this strategy will contribute to accelerating electromobility. It is suggested that this action be led by SIEPAC, the Regional Electricity Market and the Governments of the Central American countries.

Medium-term actions (2023 – 2026)

- **Plan the electrical network considering electric mobility.**

An aspect of great importance identified in this thesis and that still has the possibility of being explored in more detail, is the integration of the electrical network at a regional level with the recharging infrastructure that would be needed to allow the development of electric mobility, to reach this level, It is necessary to add in the calculations of the future energy demand that consumption required by the regional electric vehicle fleet. Although the need to study the expansion of the electricity generation capacity has been considered, attention must also be paid to the impact and potential of integrating the recharging infrastructure with the distribution and electrical transmission systems, this needs to be done in detail in Central America.

For this reason, the type of technology that best suits the service to be electrified, as well as the one that provides the best service to the electrical system, should be properly considered. As has been indicated, in Central America there is great potential for the development of renewable energies, in this way, through greater penetration of renewable energy sources for electricity generation and the electrification of the transport sector, it would stop depending on the importation of hydrocarbons, which would improve the position of energy

independence of the Central American countries with the enormous environmental benefit due to zero emissions.

The coupling of these sectors (energy sector and transport sector) can contribute to decarbonization and cost efficiency by realizing synergies and interrelationships between the different parts of the economy, obtaining potentially higher economic benefits and a greater climate change mitigation impact. Renewable energy management and transport electrification could offer economies of scale, better demand-side management, flexibility in energy storage, and optimized investment generation in both sectors.

- **Facilitate the exchange of experiences and strengthen capacities.**

As indicated in section 5.3 and Annex IV, countries such as Brazil, Chile, Argentina, Colombia, and Mexico, have small systems and electric routes already in operation, this situation should be explored in detail. At the regional level, the exchange of knowledge and experiences, both the successful ones and the lessons learned, should be promoted. Most likely, there is no single solution, but there are similar challenges that could benefit the Central American region. This enrichment will allow the region to advance more quickly and, thus, be able to consolidate the entire region on the subject of electromobility. At the national level, countries and cities must create spaces for feedback with the different sectors related to electric mobility to facilitate this transition (such as ASOMOVE Costa Rican Association of Electric Mobility, indicated in section 5.3). Being able to have regular meetings, both at a technical and decision-making level is important to advance with the different instruments promoted by the countries.

- **Encourage and accept the introduction of new business models and financing structures.**

In recent years, various development banks such as the World Bank, the Inter-American Development Bank, and the Central American Bank for Economic Integration have made available various special support programs to the various countries in terms of electromobility

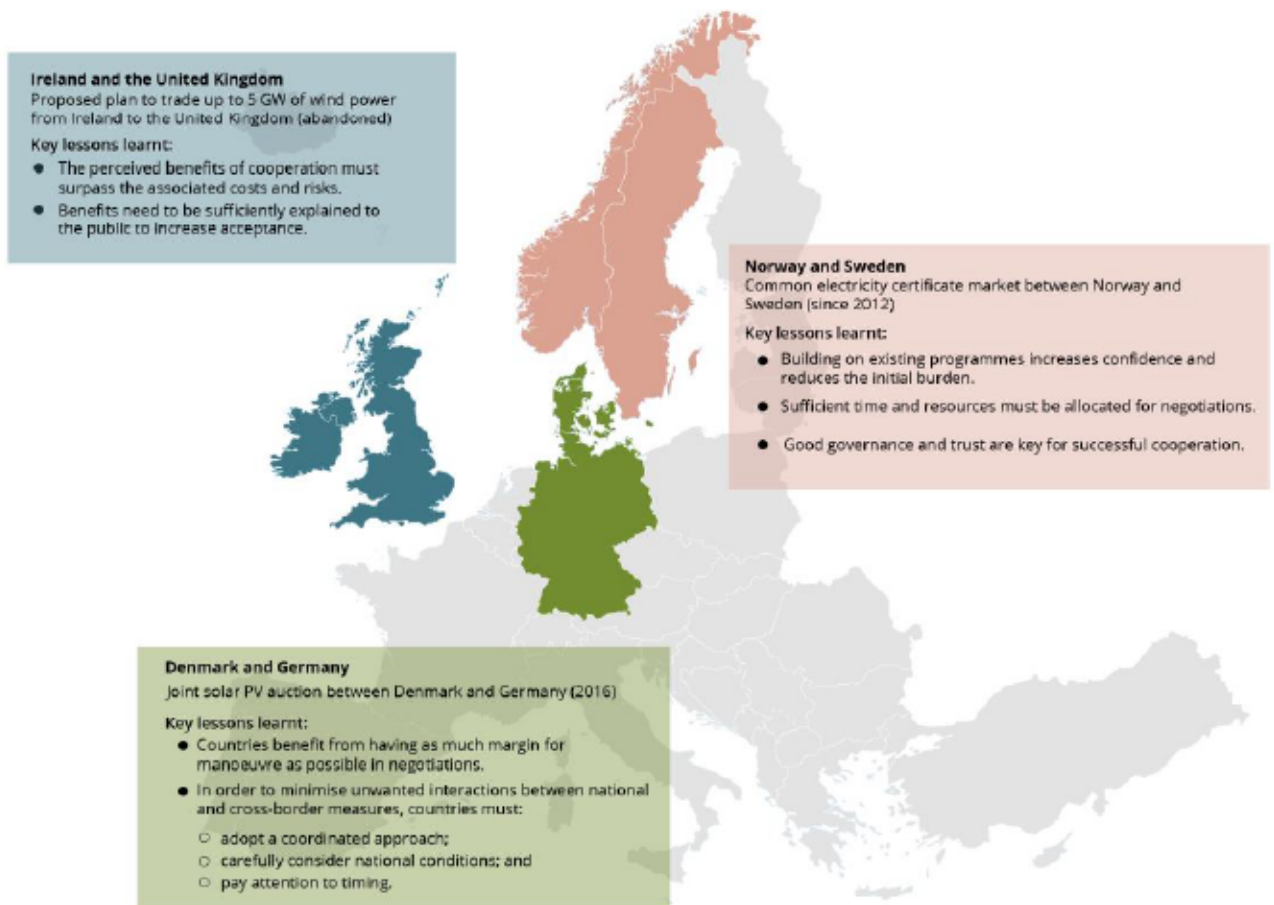
and renewable energy, they have also promoted the appearance of new business models that promote the massive deployment of electric vehicles. On the other hand, it is advisable to explore the possibility of selling electricity to companies outside the traditional industry, up to the integration of electricity distribution companies in the urban transport service business, passing through the commercial use of the second life of batteries. Thus, the generation of new businesses and forms of financing, both for structures and products, facilitates and promotes the process of electrification of transport.

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ANNEX I.

Main recommendations drawn from case studies.



Source: Cross-border cooperation on renewable energy, European Environment Agency, 2020.

ANNEX II.

Information on indicators of the electricity sector from SIEPAC in the period 2011-2020 related to the evolution of the energy matrix, installed capacity, generation, and annual evolution of electricity exchanges between Central American countries.

SIEPAC's Capacity, 2011-2020.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total (MW)	11 756,3	12 298,4	12 732,1	13 463,5	15 222,0	16 501,9	16 951,5	17 999,1	18 370,5	18 507,1
% Growth	4,7	4,6	3,5	5,7	13,1	8,4	2,7	6,2	2,1	0,7
INSTALLED CAPACITY										
(MW)										
Hydropower	4 961,3	5 284,3	5 378,7	5 722,8	6 017,7	6 745,1	6 925,7	7 061,7	7 195,9	7 329,1
Geothermal	558,6	635,6	625,6	625,6	625,5	615,0	650,0	650,0	703,7	707,7
Wind	297,8	395,8	416,7	589,7	944,7	1 026,2	1 134,9	1 196,4	1 209,5	1 228,1
Cogeneration	752,6	849,1	989,8	1 152,3	1 412,1	1 727,6	1 769,7	1 807,2	1 844,8	1 830,8
Solar PV	0,0	1,0	1,0	8,4	528,3	597,3	815,4	978,1	1 227,9	1 263,7
Biogas	10,1	10,1	10,1	6,4	8,9	17,1	20,9	20,8	20,8	19,4
Thermal	5 175,9	5 122,5	5 310,3	5 358,3	5 684,8	5 773,5	5 634,8	6 284,8	6 167,9	6 128,3
Renewable	6 580,4	7 175,9	7 421,8	8 105,2	9 537,2	10 728,4	11 316,6	11 714,3	12 202,6	12 378,9
Non renewable	5 175,9	5 122,5	5 310,3	5 358,3	5 684,8	5 773,5	5 634,8	6 284,8	6 167,9	6 128,3
Public	4 493,2	4 452,5	4 476,4	4 559,5	4 622,9	4 882,1	4 931,6	4 993,8	4 907,8	4 973,0
Private	7 263,0	7 845,9	8 255,7	8 904,0	10 599,1	11 619,8	12 019,9	13 005,3	13 462,7	13 534,1
Participation with respect to the annual total										
(Percentages)										
Renewable	56,0	58,3	58,3	60,2	62,7	65,0	66,8	65,1	66,4	66,9
Non renewable	44,0	41,7	41,7	39,8	37,3	35,0	33,2	34,9	33,6	33,1
Public	38,2	36,2	35,2	33,9	30,4	29,6	29,1	27,7	26,7	26,9
Private	61,8	63,8	64,8	66,1	69,6	70,4	70,9	72,3	73,3	73,1

Source: Economic Commission for Latin America and the Caribbean CEPAL, 2020.

SIEPAC Evolution of the generation 2011 – 2020.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total (GWh)	42 291,8	44 281,6	45 807,7	46 859,1	49 528,8	50 835,2	51 848,9	53 020,3	54 075,7	51 522,1
% Growth	2,8	4,7	3,4	2,3	5,7	2,6	2,0	2,3	2,0	-4,7
Generation (GWh)										
Hydropower	20 626,0	22 143,6	21 671,4	21 341,6	22 223,8	22 490,0	26 829,1	26 568,1	21 454,5	26 617,0
Geothermal	3 188,2	3 542,4	3 778,8	3 819,0	3 664,6	3 725,3	3 598,4	3 676,4	4 146,5	4 414,2
Wind	737,7	1 191,5	1 351,4	2 079,9	3 122,7	3 279,3	3 197,6	4 423,0	4 386,2	3 621,8
Biomass	1 643,5	1 714,6	2 080,0	2 221,5	2 615,3	3 129,0	3 163,1	3 248,9	3 484,5	3 215,7
Solar PV	0,0	0,3	1,4	10,1	590,7	1 166,7	1 458,1	1 756,3	2 165,7	2 412,6
Biogas	19,5	23,1	32,8	33,0	46,9	8,6	60,9	71,3	74,0	94,8
Thermal	16 076,9	15 666,2	16 891,8	17 354,0	17 264,8	17 036,4	13 541,7	13 276,3	18 364,3	11 146,0
Renewable	26 215,0	28 615,5	28 915,9	29 505,1	32 264,0	33 798,9	38 307,2	39 744,0	35 711,4	40 376,1
Non renewable	16 076,9	15 666,2	16 891,8	17 354,0	17 264,8	17 036,4	13 541,7	13 276,3	18 364,3	11 146,0
Public	16 790,0	16 288,1	16 354,7	16 173,8	14 580,5	14 054,0	15 768,3	15 014,5	14 017,2	14 846,6
Private	25 502,0	27 993,5	29 453,1	30 685,2	34 948,3	36 781,2	36 080,6	38 005,7	40 058,5	36 675,5
Participation with respect to the annual total (Percentages)										
Hydropower	48,8	50,0	47,3	45,5	44,9	44,2	51,7	50,1	39,7	51,7
Geothermal	7,5	8,0	8,2	8,2	7,4	7,3	6,9	6,9	7,7	8,6
Wind	1,7	2,7	3,0	4,4	6,3	6,5	6,2	8,3	8,1	7,0
Biomass	3,9	3,9	4,5	4,7	5,3	6,2	6,1	6,1	6,4	6,2
Solar PV	0,0	0,0	0,0	0,021	1,2	2,3	2,8	3,3	4,0	4,7
Biogas	0,046	0,052	0,072	0,070	0,095	0,017	0,117	0,134	0,137	0,184
Thermal	38,0	35,4	36,9	37,0	34,9	33,5	26,1	25,0	34,0	21,6
Renewable	62,0	64,6	63,1	63,0	65,1	66,5	73,9	75,0	66,0	78,4
Non renewable	38,0	35,4	36,9	37,0	34,9	33,5	26,1	25,0	34,0	21,6
Public	39,7	36,8	35,7	34,5	29,4	27,6	30,4	28,3	25,9	28,8
Private	60,3	63,2	64,3	65,5	70,6	72,4	69,6	71,7	74,1	71,2

Source: Economic Commission for Latin America and the Caribbean CEPAL, 2020.

SIEPAC: Annual evolution of electricity exchanges between countries, 2013-2020.

YEAR	Total	Guatemala	El Salvador	Honduras	Nicaragua	Costa Rica	Panamá
EXPORTS BY COUNTRY							
(GWh)							
2013	690,4	478,4	98,9	6,1	16,2	19,7	71,2
2014	1 445,8	986,4	238,0	4,1	49,0	69,7	98,5
2015	1 368,4	842,6	82,2	2,7	21,5	280,1	139,4
2016	1 947,4	1 110,2	224,0	16,2	17,9	181,2	397,9
2017	2 446,8	1 741,1	143,8	12,7	1,0	230,0	318,2
2018	2 651,3	1 798,9	209,1	8,4	0,2	307,5	327,2
2019	3 073,9	1 657,1	656,7	5,9	0,2	322,6	431,5
2020	2 820,7	1 066,0	550,6	0,0	0,0	623,8	580,3
IMPORTS BY COUNTRY							
(GWh)							
2013	687,7	0,0	382,1	116,9	51,9	61,5	75,2
2014	1 403,6	1,4	618,8	320,4	22,3	251,5	189,2
2015	1 358,1	1,9	981,4	151,7	33,5	172,5	17,1
2016	1 960,8	5,2	1 212,2	195,3	204,8	313,4	30,0
2017	2 444,4	19,2	1 729,1	331,1	326,6	31,8	6,6
2018	2 640,8	9,7	1 968,3	381,3	201,1	65,7	14,7
2019	3 088,3	9,5	1 948,8	259,5	434,4	339,8	96,3
2020	2 863,1	92,1	1 193,2	292,0	1 070,7	117,7	97,4

Source: Economic Commission for Latin America and the Caribbean, CEPAL, 2020.

ANNEX III.

Summary of capacity of candidate renewable projects for the expansion of generation in Central America in the next 10 years (MW).

Countries	Total	Renewable	Hydro	Geothermal	Wind	Solar	Biomass	Non-renewable
Costa Rica	2 574,3	1 634,3	962,3	162,0	300,0	210,0		940,0
El Salvador	995,2	395,2		58,0	73,0	264,2		600,0
Guatemala	155,0	155,0		95,0		60,0		
Honduras	891,3	891,3	871,3	20,0				
Nicaragua	1 885,2	1 580,2	849,2	527,0	40,0		164,0	305,0
Panamá	3 591,5	1 791,5	333,9		836,0	621,6		1 800,0
Centroamérica	10 092,5	6 447,5	3 016,7	862,0	1 249,0	1 155,8	164,0	3 645,0

Source: Economic Commission for Latin America and the Caribbean (CEPAL), on the basis of information from the Regional Operator Entity (EOR), Long-Term Planning of regional generation and transmission corresponding to the period 2019-2028 Volume 1, San Salvador, October 2018.

Country/Region	Resource	Projects	Total Capacity MW
Central America	Total renewable		6 447,46
Costa Rica	Wind	Proyectos Eólicos 50 MW (6 proyectos)	300
			162
	Geothermal	Geo Borinquen 1	52
		Geo Borinquen 2	55
		Proyecto Geo Genérico 1	55
	Hydro		962,3
		Diquis3	623
		Hidro Fourth Cliff	69
		Hidro Llanos	93,3
		Mini Diquis 1	27
		Proyectos Hidro 50 MW (3 proyectos)	150
	Solar		210
		Proyectos Solares 20 MW (3 proyectos)	60
Proyectos Solares 50 MW (3 proyectos)		150	
El Salvador		395,2	
	Wind		73
		Eólico MetCel	40
		Eólico Vientos de La Canada	33
	Geothermal		58
		Ampliación Geo Ahuachapán	6
		Ampliaciones Geo Berlin (2 etapas)	36
		Geotérmica Chinameca	8
Geotérmica San Vicente	8		
	264,2		

Source: Regional Operator Entity (EOR), 2020.

Country	Resource	Projects	Total Capacity MW
	Solar	Solar 15 de Septiembre	14,2
		Solares genéricos (6 proyectos)	250
Guatemala	Geothermal		155
			95
		Geotérmica GUA	25
		Geotérmica JUT	50
		20	
	Solar		60
		Solar SRO I	30
		30	
Honduras	Geothermal		891,3
		Geopower	20
	Hydro		871,3
		Hidro El Tablón	20
		Hidro Jicatuyo	172,9
		Hidro Llanitos	98,2
		Hidro Patuca 2	270
	150		
		160,2	
		1 580,2	
Nicaragua	Biomass	Proyectos biomasa (5 proyectos)	164
	Wind	Eólico Valle 1	40
	Geothermal		527
			105
			50
			72
			70
			70
			50
			70
		40	
	Hydro		849,2
		Hidro Boboke	68
		Hidro Cangiles	27
		Hidro Copalar Bajo	150
Hidro Corrie Li		40	
Hidro El Barro		32	
Hidro El Carmen		100	
Hidro El Consuelo		21	
Hidro Pajaritos		21,7	
Hidro Piedra Cajón		22	
Hidro Piedra Fina		44	
Hidro Salto Y-Y		25	
Hidro Sirena	17,5		
Hidro Tumarín	253		
Hidro Valetín	28		
		1 791,46	

Source: Regional Operator Entity (EOR), 2020.

Country	Resource	Projects	Total Capacity MW
Panamá	Wind		836
		Proyectos eólicos Zona Chiriquí (2 proyectos)	44,8
		Proyectos eólicos Zona Coclé (4 proyectos)	382
		Proyectos eólicos Zona Panamá (2 proyectos)	168
	Hydro	Proyectos eólicos Zona Veraguas (3 proyectos)	241,2
			333,86
		Hidro Barriles	1
		Hidro Cana Blanca	7,8
		Hidro Changuinola 2 (Bocas del Toro)	214,76
		Hidro Cotito	5
		Hidro El Recodo	10
		Hidro La Herradura	5,2
		Hidro Mini Changuinola 2 (Mini Bocas del Toro)	13,7
		Hidro Ojo de Agua	6,5
		Hidro Río Piedra	9
		Hidro San Andrés 2	7,6
		Hidro San Bartolo	19,4
		Hidro San Bartolo G3	1
		Hidro Santa María 82	28,4
	Hidro Tizingal	4,5	
	Solar		621,6
		Proyectos solares Zona Chiriquí (5 proyectos)	89,8
		Proyectos solares Zona Coclé (22 proyectos)	514,8
Proyectos solares Zona Panamá (3 proyectos)		17	

Source: Regional Operator Entity (EOR), 2020.

Annex IV.

Scheme of main advances and electro corridors in Latin America.



Electro Routes

for electric vehicles in Latin America and the Caribbean



- 1 Mexico**
- Route of 620 km from SL Potosi-CDMX-Puebla. Chargenow network with more than 600 charging centers
- 2 Costa Rica**
Network of 47 Charge centers (4 installed)
- 3 Panama**
Network of 12 Charge centers.
- 4 Barbados**
Network of 50 charge centers.
- 5 Colombia**
Route of 50 charge centers Bogota - Medellin.
- 6 Brasil**
Route of 434 km with 6 charge centers Rio de Janeiro - Sao Paulo
- 7 Uruguay**
Network of 30 charge centers.
- 8 Chile**
Route of 730 km from Marbella to Temuco. Route of 500 km from Temuco to Chiloé.
- 9 Argentina**
Route of 212 km province of San Luis. Integrated charge center Argentina - Chile in Neuquén.

Source: Electric Mobility - Advances in Latin America and the Caribbean 2019. United Nations Environment Program, Office for Latin America and the Caribbean, Panama.

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