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哥斯大黎加再生能源的演變及其社會經濟影響：個案研究

The Evolution of Renewable Energy in Costa Rica and Its Socioeconomic Impact: A Case Study

拉蕊

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Abstract

This research studies the transition of Costa Rica to renewable energy and its socioeconomic impact. This research provides a fascinating example of how public institutions' autonomy, strategic planning, and social support can lead to a successful outcome. The study shows that fossil fuels are responsible for human-caused global warming, which has exacerbated the world global climate change crisis. More importantly, the research stresses the importance of transitioning to renewable energy to stop climate change and achieve sustainable development and focuses on the case of Costa Rica. This study provides a sample of the most representative renewable energy projects in Costa Rica, according to the different renewable energy sources available in the country (hydro, wind power, and geothermal), and describes the financial sources for each renewable energy project and their generated amount of renewable energy. The study describes some socioeconomic benefits that transitioning to renewable energy provides worldwide, focusing on Costa Rica's case. It is well known that every country is different from others. Nevertheless, the Costa Rican case can serve as an example for other countries in the Latin America and the Caribbean region (LAC), which can gain valuable insight into how renewable energy can transform a country's society and economy, foster sustainable development, and secure a sustainable future for the world.

Key Words: Costa Rica, Strategic Planning, Renewable Energy, Socioeconomic Benefits, Sustainable Development.

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Chapter 1: Introduction

Energy is indispensable to survival. History demonstrates that most development has been achieved throughout the implementation of energy in its basic form. All types of industries have seen benefits and provided solutions to society thanks to energy use.

Nevertheless, the modernization we all enjoy has negatively affected our environment. Historically, the primary source of energy for implementation and use has been derived from fossil fuels. Such implementation has constituted a deterioration of the natural environment and the climate.

As time passes, the climate worsens and threatens all living species. As a result, governments are currently facing the task of reverting or minimizing such negative impacts brought by the continuous use of fossil fuels to produce energy.

According to the Environmental and Energy Study Institute (2021),"Fossil fuels formed millions of years ago from carbon-rich remains of animals and plants, as they decomposed and were compressed and heated underground." Fossil fuels include coal, oil, and natural gas. The Environmental and Energy Study Institute (2021) points out that "Fossil Fuels have been driving the world's economies for over 150 years, and by 2021 it supplied about 80 percent of the world's energy". The use of fossil fuels has indeed played a critical role in the development of our world, but the use of fossil fuels has not come for free. Its production and consumption represent a major source of carbon dioxide (CO2) and other greenhouse gas emissions, which have caused dramatic changes to Earth's climate.

U.N-Climate Action points out that fossil fuels are the most significant contributors to global climate change, accounting for over three-quarters of global greenhouse gas emissions and nearly 90 percent of all carbon dioxide emissions (United Nations, n.d.). However, why

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should we all be worried about greenhouse emissions? As greenhouse emissions are released, they blanket the Earth trapping the sun's heat, causing global warming and increasing climate change and its devastating effects on the world. Nowadays, temperatures are higher than they were before. This phenomenon has caused weather patterns to change, disrupting the balance of nature and thus putting all human beings and all other living species on Earth at imminent risk of extinction (United Nations, n.d.). For a more in-depth account of climate change, see Appendix A.

There is a positive correlation between global warming and human-caused climate change. Human-caused climate change represents a worldwide crisis that requires everyone's active involvement to solve. All members of society must work together to implement different actions to mitigate greenhouse gas emissions and, thus, their adverse effects. Most importantly, alternative solutions must be implemented, such as transitioning to renewable energy. Transitioning to renewable energy can reduce greenhouse gas emissions, which will stop global warming and, thus, human-caused climate change, and at the same time, it will secure a sustainable world for us and future generations. Hence, mitigating climate change and implementing green energy is not a matter that only concerns developed countries. Social consciousness and interest in rescuing our planet is a task responsible developing countries execute.

In this sense, Costa Rica has demonstrated a great deal of interest to revert the negative impact of fossil fuel implementation by adopting a robust social responsibility regarding using renewable energy as an alternative to traditional energy production.

According to Parker et al. (2023), Costa Rica is one of the smallest countries in terms of territory in Central America. It shares limits with Nicaragua to the north, the Caribbean Sea along the northeastern coastline, Panama to the Southeast, and the Pacific Ocean along the

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southwestern coast. Two mountain chains run along most of its territory. They are denominated by their names in Spanish as The Cordillera Volcánica (with volcanic activity), which extends from north to south, and it is divided into three areas: Cordillera de Guanacaste, The Cordillera de Tilarán and the Cordillera Central. On the other hand, the Cordillera de Talamanca (The Talamanca Range) and La Amistad National Park (Friendship National Park) extend along the border between Panama and Costa Rica. They are granite mountains unique in geographic location, one of the largest forest areas in Central America, and an affluent niche of biodiversity. In 1972, UNESCO declared it a World Heritage site because of these unusual characteristics.

Costa Rica has a relatively high standard of living. It has a total area of 51,100 sq km. By 2022 its estimated population was 5,204,411, with an estimated Population Growth rate of 1.01 percent. It has a trade-based upper-middle-income economy. Among its natural resources, hydropower is listed as one of the most important. After implementing diverse measurements, the country has been able to reverse deforestation, invest in generating electricity from different renewable sources, and thus became a green economy leader in Central America Region (The World Factbook, 2023).

Despite being a developing country, for more than a century, Costa Rica has been steadily working on transitioning to renewable energy sources. Costa Rica's strategic vision has been able to add together well-design policies, strategic planning, and gathering the support of different stakeholders to successfully develop multiple renewable energy projects that have served as the foundation of Costa Rica's transformation into a worldwide leader in the development and transition to renewable energy. Costa Rica is also taking all necessary steps to adapt its processes to achieve a circular economy and consolidate the country as sustainable. Like many other countries, Costa Rica strategically plans its transition to

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renewable energy. Yet, one of the most noticeable facts about renewable energy in Costa Rica is that the country started exploring and using renewable energy more than one hundred years ago when the climate crisis was not yet challenging the world's well-being.

In the Central American region, The Electrical Interconnection System for Central America, known by its acronym in Spanish as SIEPAC, has the highest share of renewable energy globally, with 66 percent. It also represents the most diverse combinations of biomass, geothermal, wind, solar, and hydroelectric power. This unique integration model seeks to provide security and supply competitive prices to all 45 million inhabitants in the Central American Region (Dannemann, 2022).

Hence, green energy is an alternative that Costa Rica has adopted because of its importance in minimizing the consequential damage of the energy produced with fossil fuel by being a member of the SIEPAC. Despite being a developing country, Costa Rica stands out from its peer neighbors because of the unique characteristics explained above.

1.1. Problem Statement

Climate change and the consequential detriment of nature have caused the entire world to take action to transition from fossil fuels to sustainable renewable energy. Fossil fuels are the predominant energy source for all daily activities. Additionally, highly industrialized countries consume most energy derived from fossil fuels, which translates into producing the highest amount of carbon emissions. Most countries still heavily rely on fossil fuels, which has slowed the transition to renewable energy. As a result, the damage to the natural environment and not utilizing green energy is a latent problem. The transition to green energy has been slow; not every country is equally invested in this process. Yet, Costa Rica, a small

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developing country with limited resources, has taken on this task, which was started over a century ago.

Therefore, delaying the implementation and transition to renewables represents a problem for the world as actions and determination to explore green energy by countries are not taken as a top priority in the national agendas of the nations.

1.2. Research Questions

To better understand the case of Costa Rica's transition to renewable energy, this case study aims to answer the following questions:

a. How a developing country such as Costa Rica could achieve a transition to and implementation of renewable energy?

b. What are the socioeconomic benefits of implementing renewable energy in Costa Rica?

1.3. Research Outline

The current research is divided into six chapters. The first chapter provides an introduction. Then it introduces the problem statement, which leads to formulating the research questions, to end with the research outline.

The second chapter depicts a literature review related to the research questions proposed in this study.

The third chapter describes the research method and design used in this study and some of the sources of information used in the research, to end with an explanation of why a SWOT analysis was selected as a tool for project analysis for this study.

The fourth chapter centers on the case study of Costa Rica. It starts by introducing the foundations for green energy generation in Costa Rica. It describes the diverse sources of

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renewable energy used in the country as well as the levels of energy generated by each source. Then, it introduces a sample of the most representative renewable energy projects in Costa Rica and their funding sources. It also describes the socioeconomic benefits of the transition to renewable energy. The chapter ends by introducing the future of renewable energy in Costa Rica from two complementary perspectives: The national decarbonization plan and the costs and benefits derived from implementing it.

The fifth chapter focuses on the case study analysis by implementing a SWOT analysis of renewable energy in Costa Rica. The SWOT analysis leads to the findings of the case and concludes with the limitations encountered while conducting this research.

The sixth and last chapter provides the conclusions of this research and recommendations for future studies.

To better understand the previous information, please refer to Figure 1, which depicts the research outline.

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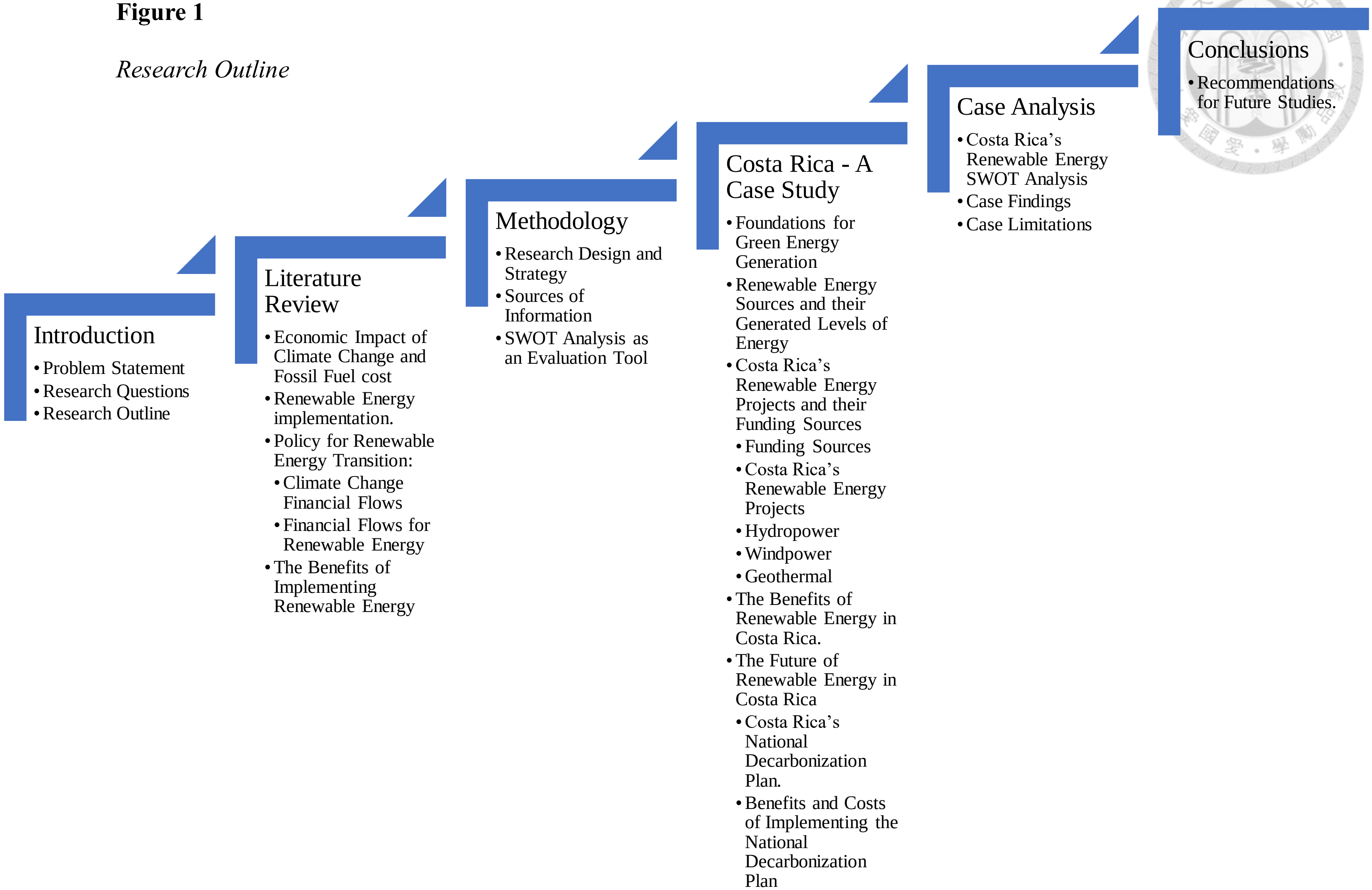
Figure 1

Research Outline



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Chapter 2: Literature Review

Implementing green energy is both the result and remedy to minimize the use of energy derived from fossil fuels. To this extent, knowledge about fossil fuels and their negative environmental impact is necessary to spark green energy transition.

Hence, for the countries transitioning to renewables, it is essential to understand fossil fuels, climate change, and the available financial resources to develop green technologies.

2.1. The Economic Impact of Climate Change and Fossil Fuel Cost

Since the Industrial Revolution, fossil fuels have driven the development of the world. Oil, natural gas, and coal have been the key energy sources in the 20th and 21st centuries. From 1990-2019 the world's total energy supply increased by almost 70% and passed 600 exajoules (EJ) for the first time (UN Department of Economic and Social Affairs Statistics Division, 2022). In the same period, the largest energy sources were oil, coal, and natural gas, representing 82% of total primary energy production (UN Department of Economic and Social Affairs Statistics Division, 2022). In 2019 alone, China produced 86% of the world's total coal, while the United States produced 32% of the world's total oil production. While Russia, the United States, Iran, and China produced half of the world's natural gas (UN Department of Economic and Social Affairs Statistics Division, 2022). The world's top producers are the world's top consumers and rely heavily on a reliable supply of energy for their well-being and the world's production. Moreover, oil, natural gas, and coal prices heavily depend on world peace and order.

The World Energy Outlook by the International Energy Agency (2022) reports that the Russia-Ukraine conflict caused skyrocketing oil and natural gas prices to levels never-before-seen for natural gas. Energy security is prime importance for every country, and reducing the

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risk of future disruptions is crucial. Natural gas accounts for an increase in worldwide electricity prices by 50%, whereas oil is responsible for 90% of the average rise in cost for electricity generation worldwide (International Energy Agency, 2022). This increase has caused a surge in demand for alternative sources of energy production, particularly renewable ones; however, in the short term, the crisis has caused a great demand for alternate sources for coal and oil as natural gas (International Energy Agency, 2022). The report further states that gains from the crisis can lead to faster research and development for alternative energy sources and faster progress in electrification and efficiency, such as electric cars (International Energy Agency, 2022). In addition, the crisis has reminded the world of the frailty of the current energy system.

The reality is that human life is entangled with fossil fuels, which has created dependency, insecurity, and global warming. For a long time, fossil fuels have been easy and convenient, making us build our economies around them; transitioning from fossil fuels is an important and challenging job. Because of their state and energy density, fossil fuel found their use in transportation (Gross, 2020). The same transportation that moves goods globally through air, land, and water. Transitioning to renewable sources would mean transforming the freight industry completely. Assuring that goods can be transported equitably by transportation fueled by fossil fuels to transportation fueled by alternative low-emission sources is a complex task. It would require the replacement of a whole infrastructure system, machinery, and vehicles that carry out the task in the worst-case scenario and, in the best case finding an adaptable one that can use existing structures and machines to avoid disruptions and lower costs. Again, a challenging task. The truth remains that fossil fuel dependency does not lessen soon.

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However, a recent report by reinsurance, insurance, and insurance-based risk transfer Swiss Re (2021) states that the world will lose 10% of its total economic value if the Paris Agreement goals and 2050 net-zero emissions are unmet (Swiss Re Institute, 2021). Climate is to significantly affect areas worldwide, leaving developing countries the most at risk, with East Asia and Latin America being the ones most at risk. Northern and Eastern Europe are expected to face increasing precipitation and floods (Swiss Re Institute, 2021). Swiss Re Institute (2021) reports that Southeast Asia, if action is not taken to reduce emissions, might lose up to 25% of its GDP due to climate change. Top global CO_2 emitters such as the United States, China, the European Union, and Canada (Borenstein, 2022) are more capable of bearing the effects of climate change as they have better adaptive capabilities, while China, the world's top emitter, is on route to catch up.

Quantifying the economic losses to climate change is hard, and accounting for all variables takes work. Nevertheless, most predictions agree that rises in global temperature will impact economies negatively. In economic modeling by the Swiss Re Institute (2021), if the Paris Agreement goal of slowing global temperature below 2°C by 2030 is reached, global losses in GDP could be mitigated at 4.2%, yet at the current pace of surpassing 2°C global losses in GDP are expected to reach 11%. Worst case scenario show surpassing 3.2°C with losses exceeding 18% (Swiss Re Institute, 2021). The report further explains that climate change affects economies through physical risks like damage to physical property, trade interruption, or loss of productivity and transitional risks related to how economies react and transfer to new technologies to mitigate the effects of climate change (Swiss Re Institute, 2021). Analyzing the aftermath of Hurricane Harvey one year after the hurricane hit southeast Texas, South Texas Economic Development Center's College of Business from Texas A&M University reports that the economic relief implemented by the United States Federal

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Government is nothing compared to the loss caused by the impact of the hurricane (South Texas Economic Development Center-College of Business, 2018). Direct losses were quantified to lead to upwards of US$ 125 billion by the National Oceanic and Atmospheric Administration of the United States. However, as the study points out, the more challenging part is quantifying indirect losses, such as disruptions in trade, productivity, lost utilities, and damage to structures (South Texas Economic Development Center-College of Business, 2018). In this case, interventions by the government, insurance payments, and displacements due to employment managed to jumpstart the economy, but full recovery will take years to achieve (South Texas Economic Development Center-College of Business, 2018). If climate change is to worsen climactic conditions and increase the frequency of events such as Hurricane Harvey, no government or insurance payouts would be able to mitigate the effects of such natural events continuously. It might be even worse if we consider that the occurrence of wildfires, floods, droughts, and hurricanes will become an unmitigable situation.

The Swiss Re Institute (2021) concludes that economic loss will happen even if the current accords are achieved. In order to avoid reaching a worst-case scenario of global warming, globally coordinated action is required to mitigate climate risk and to transition to a low-emissions economy. The study recommends accelerating and amplifying public policy, including sustainability criteria as collaterals by central banks, fiscal incentives for carbon reduction, capture, and climate resiliency development, transparency, and active support from civil society and businesses alike, among others.

Calculating the economic costs of climate change takes work, especially when considering indirect costs. Economic crises due to human mishaps have been weathered at a high cost, yet we do not know how to weather nature's economic crisis on a global scale. Although, as the Swiss Re Institute (2021) states and echoes the Stern Review (2007), the

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benefits of firm and on-time transition, regardless of cost, are non-negotiable, action must be carried out because the cost of staying idle is far too high to pay.

2.2. Renewable Energy Implementation

Transitioning to renewable energy sources has high costs and entry barriers and requires an energy system overhaul. Kleinpeter (1995) states that investing in energy economics is like investing in other sectors, yet they have high financial requirements that last for a long time. These investments are loans that need to be repaid over a period of time. Moreover, there is considerable time between the building of a power plant and the start of operations, a time in which intercalary interests carry until the payment of the first quotes of the loans. Kleinpeter (1995) further explains that every country has unique needs and not one case is like another and warns that before employing renewable energies, there needs to be consideration of the technologies invested in, the inflated costs of investments for developing countries, training of personnel, automation of operation of plants, among others. Moreover, energy consumption is an indicator of development, and a person living in a developing country consumes 1.5% of the energy consumed by a person in a developed country (Kleinpeter, 1995). So, developed nations with a liberalized economy and a for-profit energy sector might have higher incentives to transition to cheaper energy and be willing to incur the commitment or higher costs to transition to renewable sources.

Regarding implementing renewable sources, careful consideration must be accounted for as using hydraulic, wind, and solar resources might be free to use. However, it does not mean they can be used whenever needed (Kleinpeter, 1995); there is drought, night, and wind does not always blow. The same applies to biomass and geothermal as they are location-dependent and have limited and localized possibilities (Kleinpeter, 1995). Renewable source

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technologies have improved since the first push for renewable sources in the late 1970s. Then rushed applications of wind farms and solar farms that used new, untested, and less-than-optimal technology led to unfavorable results (Kleinpeter, 1995).

Today, technological development, costs, and incentives brought about by climate change, the Kyoto Protocol, and Paris Agreement have made transitioning to renewable energy production more attainable and efficient than before. In recent years, countries like Sweden, Scotland, China, Iceland, Germany, Uruguay, and Costa Rica (the focus of this paper) have pledged to transition to renewable energies completely, and they are ahead of the pack in this regard (Climate Council, 2022). The UN Environment Programme (2022) reports in its interview with Niklas Hagelberg that the most significant barriers holding back transitioning to renewable energies are government policies that promote lower mass transportation tariffs, facilitating the rapid installation of renewable energy sources, and stopping fossil fuel subsidies.

The implementation of renewable energy sources has lower entry costs than before. Improved technology, knowledge, and financial incentives have made it accessible for developed and developing countries to implement renewable energy sources. However, the key to successful implementation is choosing the appropriate technology suitable for each country and government policies that motivate and facilitate the implementation of renewable sources.

2.3. Policy for Renewable Energy Transition

As discussed in previous sections, renewable energies, in one shape or another, have been around for over a hundred years. The convenience, abundance, and cost of fossil fuels have made them the go-to source for energy production. Nevertheless, the various oil crises

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have highlighted the frailty of energy security for countries worldwide. Additionally, human-caused global warming has created much harsher living conditions for people globally. Both issues have made countries search for alternative energy sources to ensure their energy security and attempt to reverse the effects of climate change.

Although transitioning to a renewable energy system is challenging and costly, the transition contributes to the conservation of the environment. Governments and international actors have had to create frameworks and strategies to incentivize transitioning to renewable energies. Transitioning to renewable energy sources has come with issues such as implementing modern technologies with high entry costs and socio-political issues regarding acceptance, desire for implementation, and perception of renewable energy sources by stakeholders.

Incentives for transitioning to renewable energy can take the shape of policy-making and financial incentives (which work in tandem) and technological and social (Juarez et al., 2023; Lu et al., 2020; Tryndina et al., 2022). Policy-making incentives change the energy sector through legislation. Moreover, Fowler and Breen (2014) assert that the leading promoter of renewable energy is governments through policy use. These policies, in turn, create the economic incentives that lower the costs of transitioning to renewable energies into a more viable solution (Fowler & Breen, 2014; Juarez et al., 2023; Lu et al., 2020; Tryndina et al., 2022). Tryndina et al. (2022) identify that, on the one hand, policies can directly promote renewable energy through financing projects, grants, subsidized loans, feed-in tariffs, and tax breaks, among others. On the other hand, policies can indirectly influence the transition to renewable energy sources by levying taxes on fossil fuels and setting greenhouse gas and carbon emission levels, among others. Technological factors are crucial in determining a successful renewable energy transition. Encouraging the development of

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renewable energy technologies reduces maintenance costs, reassures secure sustainable energy, and improves the efficiency of power generation at a competitive cost (Dincer, 1999; Juarez-Rojas et al., 2023; Rexhäuser & Löschel, 2015). Additionally, research and development determine energy goals and lower the risk of uncertainty, increase the utilization of renewable energy, and lower application costs (Rexhäuser & Löschel, 2015; Tryndina et al., 2022; Xu et al., 2019). Finally, the participation of stakeholders in the process of policy creation affects the effectiveness of the objectives and efficiency of renewable energy policy. Participation of interest groups in policy creation lowers misconceptions of renewable sources, increases awareness of its benefits and costs, and increases the funds available for renewable sources (Juarez-Rojas et al., 2023; Tryndina et al., 2022; Xu et al., 2019).

2.4. Climate Change Finance Flows

The United Nations Framework on Climate Change (UNFCC), in its latest biennial assessment and overview of climate finance flows, has created a well-documented summary, as the final report is yet to be published, that compiles financial flows to address climate change. Climate change funding is provided from private and public financial flows. The UNFCC reports that tracking private climate funds is more complex as the methodology, reporting, and data availability are only sometimes present (United Nations Framework on Climate Change, 2022). According to the UNFCC's latest report, funding might have affected reporting, mobilizing, and provisioning funds due to the COVID-19 pandemic (United Nations Framework on Climate Change, 2022).

Global climate finance funds increased by 12% in the current period over the past 2017-2018 period reaching an annual average of $803 billion US (United Nations Framework on Climate Change, 2022). This growth was propelled by investment in energy-efficient

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buildings, sustainable transport, and adaptation finance. In addition, the cost of wind, offshore wind, and photovoltaic power have decreased, yielding a greater impact per investment (United Nations Framework on Climate Change, 2022).In the same period, public climate finance funds flows increased from developed countries to developing countries through bilateral channels, multilateral climate funds, and multilateral financial institutions. Multilateral development banks provided US$ 91 billion to developing and emerging economies during the 2019-2020 period giving an annual increase of 17% (United Nations Framework on Climate Change, 2022). Even so, the United Nations Framework on Climate Change (2022) reports that most of this finance was meant for mitigation (loans) efforts rather than adaptation (grants). The OECD (2022a) and the United Nations Framework on Climate Change (2022) report that the pledge set at the UN Climate Summit in Copenhagen in 2009 of annual US$ 100 billion by 2020 for developing countries was unmet. Investments in sustainable transport and renewable energy decreased from US$ 3.2 billion to US$ 2.6 billion in 2019-2020.

2.4.1. Financial Flows for Renewable Energy

International Renewable Energy Agency (IRENA) and Climate Policy Initiative (CPI) have jointly published a report on the latest situation regarding renewable energy finance in 2023. The report states that despite growth in investments in renewable energy, more is still needed to stay on pace to reach IRENA's 1.5°C by 2030.

Preliminary data reported by IRENA and CPI (2023) state that, in 2022, US$ 499 billion was invested globally in renewable energy. Despite these, the flows are not sufficient to reach the annual $1 trillion goal or the 2030 sustainable development goals. Additionally, financing has been concentrated in already developed technologies, and diversification to

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other areas is needed to achieve a diverse energy production mix. Predominantly, solar photovoltaic (43%), onshore (35%), and offshore (12%) wind have attracted the largest share of funding (IRENA & CPI, 2023). Due to their modularity, off-the-grid solar investments attracted 92% of the investment between 2010 and 2021, and their applications were mainly residential (IRENA & CPI, 2023). Applications supporting energy-intensive tasks, such as industry and agriculture, must catch up (IRENA & CPI, 2023). In addition, for IRENA and CPI (2023), investments in end usage applications must catch up in areas like transportation and heating.

The geographic distribution of funds is another issue IRENA and CPI (2023) raise. Investments are found to be concentrated in a group of regions and countries. For example, East Asia and the Pacific region attracted 66% of the global total in 2022, with China as the primary beneficiary. Equally, the European Union, Canada, and the United States, where tax breaks in production and policy have driven investment to phase out fossil fuels. In comparison, areas such as Latin America and the Caribbean (6.1% in 2019 and 4.9% in 2020), South Asia, the Middle East, North and Sub-Saharan Africa, and Eurasia received less (IRENA & CPI, 2023). In 2022, more than half of the world's population, mainly in developing and emerging countries, received 15% of global investments in renewable energy (IRENA & CPI, 2023). Moreover, funding to carry out projects in these areas is mainly done through domestic funds, indicating reliance on international finance to reach their goals on renewable energy. The reliance on international finance is echoed in the United Nations Framework on Climate Change (2022) report, which states that developed nations carry out most work in adaptation technology.

A bright spot highlighting the recognition and importance of climate change is heavy investment in transition technologies such as energy storage, hydrogen, carbon capture,

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electrified transportation, and energy efficiency, as mentioned by IRENA and CPI (2023). Despite the supply chain crisis, pandemic, and other global issues, investments increased by 19% to reach over US$ 1.3 billion in 2022 (IRENA & CPI, 2023).

From 2013 through 2020, the private sector carried out over two-thirds of investments in renewable energy (IRENA & CPI, 2023). In 2020, this investment reached US$ 240 billion, 69% of the global total. This investment is mainly in mature technology such as bioenergy and solar power (IRENA & CPI, 2023). Conversely, geothermal and hydropower projects rely heavily on public finance as their execution time, associated risks, and upfront capital are higher (IRENA & CPI, 2023).

Finally, while considerable progress has been made toward renewable energy funding has been achieved, at the same time, heavy investment in fossil fuels continues. COVID-19-related decrease in fossil fuel investment might have been perceived as a way forward with renewable energy. However, investment in fossil fuels has bounced back to pre-pandemic levels, reaching almost US$1 trillion (IRENA & CPI, 2023) or over a trillion US$, as reported by the IEA. It is expected that up to 2030, every year, US$ 570 billion will be invested in new oil and gas development and exploration (IRENA & CPI, 2023). Investors and multinational banks are committed to fossil fuel development well past the requirements to meet the 1.5°C target. Some have exceeded their average commitments, reaching upwards of US$ 750 billion annually.

Transitioning to renewable energy will take time and will be costly. Nevertheless, it must happen to mitigate and reverse climate change's adverse effects and improve the world's energy system and the uncertainties tied to fossil fuel prices. However, at the same time, there is great interest in financing the status quo, which does not translate to the urgency and necessity to transition to renewable sources.

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2.5. The Benefits of Implementing Renewable Energy

As previously discussed, energy is vital for all human beings and indispensable to carrying out most, if not all, activities related to our daily routines. As the population increases, the consumption of energy increases too. The same correlation can be deduced between economic growth and energy consumption. An increase in energy consumption derived from fossil fuels causes an inevitable increase in greenhouse emissions; the previous stresses even more, the importance of transitioning to renewable energy.

According to Halkos and Gkampoura (2020), renewable energy production has zero adverse environmental impact, contributing to tackling climate change, global warming, and air pollution. Additionally, there are many possible economic benefits derived from renewable energy, such as increasing employment and low operation cost in the production process. Moreover, they stated that some of the social benefits linked to renewable energy include securing energy to distribute it later equally among citizens, reduction of greenhouse gas emissions and pollution levels, and a potential increase in the employment rate. Finally, because of its renewable nature, renewable energy is a reliable source from which energy can be produced indefinitely to supply the world's demand.

Furthermore, the study by Gielen et al. (2019) affirms that the initial investment cost necessary to transition to renewable energy is high, yet the consequent benefits offset the costs. They consider a cumulative GDP gain from 2015 to 2050 could be around US$ 52 trillion. Moreover, they estimated that as the investment in renewable energy projects increases, by 2050, approximately 19 million extra direct and indirect jobs will be created. As countries progress with sustainability and implementing renewable energy, the fossil fuel industry will suffer an estimated 7.4 million job losses. However, transitioning to renewable

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sources will offset this cost with the number of created jobs from multiple economic sectors such as construction, manufacturing, operations, and maintenance.

As per Vergara et al. (2014), the estimated societal benefit of implementing non-traditional renewable energy technologies, such as solar, geothermal, and wind energy, is more than enough to implement renewable energy in the Latin American and Caribbean Regions. The study also found that benefits will occur from the integrated collaboration between countries in the region, particularly if all the countries shift to the electrification of the transport sector.

Based on the literature review, we might argue that once most of the countries understand that continuous dependency on fossil fuel is risky and that new approaches, such as renewable energy, are needed to minimize the negative impacts on the climate, the high cost of starting the development of green energy technology cannot be compared to the requirement of reverting the damage created so far to the natural environment. As a result, utilizing green energy financial sources could be a starting point and tool to fix the climate change problem.

However, a gap can be identified in the literature review. Most of the studies address implementing renewable energy to tackle climate change. While the existence of renewables and their implementation is not recent, it has become an accepted topic as a compulsory response to environmental detriment.

The uniqueness of Costa Rica is that the country did not start developing and transitioning to renewable energy recently or because of climate change. The application of renewables in Costa Rica does not derive from the negative impact of fossil fuel in the present time but from the wise decision to utilize its water resources to secure energy production for its citizens as a national policy.

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Moreover, most of the available literature regarding the benefits of shifting toward renewable energy refers to developed economies. Therefore, it could be inferred that transitioning to green energy could not be possible or could not be achieved by a developing country such as Costa Rica. Consequently, it is significant to carry out this research focusing on a developing country, Costa Rica. A country that does not count with the financial and technological resources equivalent to those of a developed country and is located in a small geographic region.

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Chapter 3: Methodology

This qualitative research will focus on Costa Rica's transition model to renewable energy and its socioeconomic impact on Costa Rica's population as a case study by analyzing primary and secondary sources provided by both national and international institutions, such as Costa Rica's Ministry of Environment and Energy (MINAE), Climate Change Directorate (CCD), The University of Costa Rica (UNA), the Costa Rican Institute of Electricity (ICE), The Inter-American Development Bank (IADB), The European Union (EU), among others.

This section describes the research method, design, and strategy followed in this research, including a description of the most important sources of information used and an explanation of the study's process. Finally, a description of a SWOT analysis is presented as a tool to assess *the evolution of renewable energy in Costa Rica and its socioeconomic impact*.

3.1. Research Design and Strategy

According to Yin (2014), a case study is one of the diverse ways in which a researcher can undergo a study about a specific topic. Case studies have served as a research method design in different endeavors, including social and business settings. Case studies are the best alternative to carry on research to answer proposed questions. In a case analysis, the researcher wants to deeply understand a current-extraordinary event within a real-life context (Yin, 2014). Hence, to fulfill the main objective of the present research, a qualitative single case study approach will be followed as the primary strategy to answer the specific research questions proposed in Chapter 1.

This qualitative single case study will offer an in-depth vision of a singular event, as Yin (2014)proposed. A case study allows researching the topic in context and considering related facts, so a clear understanding of this unique topic can be acquired.

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3.2. Sources of Information

This research will use different primary sources, such as news, webpages, journals, and official reports from credited databases of recognized international organizations and information collected from official databases of the Costa Rican Government. Some of them are:

- Banco Centro Americano de Integración Económica- BCIE: an international multilateral development financial institution that continuously invests (in the form of loans or donations) in different projects that will contribute to the development of its country members and to reduce poverty and inequality in those countries. One of its main focuses is environmental sustainability.
- International Energy Agency: an independent intergovernmental organization offering recommendations, in-depth analysis, and comprehensive data on the global energy sector.
- Instituto Costarricense de Electricidad (Costa Rican Institute of Electricity): is part of the conglomerate known as Grupo ICE, the Costa Rican government-run electricity and telecommunications service provider. ICE is considered a reference in the research and development of renewable energy projects. It has an electric matrix of diverse sources such as hydroelectric, geothermic, solar, wind, and biofuels.
- International Trade Administration-ITA: A US government agency that promotes US trade and provides information and data about the global markets.
- International Renewable Energy Agency-IRENA: It is a global intergovernmental organization that assists countries in their transition to sustainable development, energy access, and energy security to guarantee a climate-proof future.

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- Presidencia de la República Costa Rica: the Costa Rican Presidential House, which official news and information pertinent to the country.
- The Intergovernmental Panel on Climate Change-IPCC: founded by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP), is an organization that evaluates all the science linked to climate change.

3.3. SWOT Analysis as an Evaluation Tool

After all pertinent information to the qualitative single case study has been collected, an analysis of the case study will be necessary; a SWOT analysis will be conducted as the chosen analysis tool.

The SWOT analysis is a well-known tool commonly applied to marketing analysis, yet, it can also be used to analyze a project's performance, as in the case of this research. The European Union states that a SWOT analysis "combines the analysis of the strengths and weaknesses of an organization, a geographic area or sector, with the study of the opportunities and threats to their environment." (European Union, 2022). Additionally, a SWOT analysis can be conducted before implementing a project, during its execution, or even after a project is concluded. Therefore, using it to analyze or evaluate Costa Rica's macro project of transitioning to renewable energy is ideal.

According to Armstrong and Kotler (2013), a SWOT analysis is a matrix of four elements that analyze a particular project or organization's internal and external environment. Figure 2 presents the SWOT analysis matrix.

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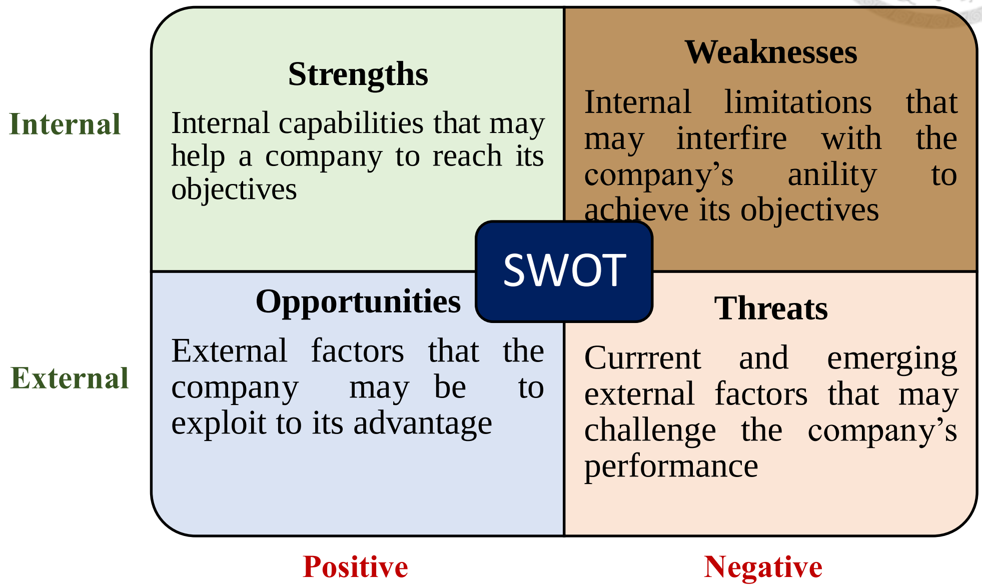
Figure 2

SWOT Analysis Matrix



Adapted from: "Marketing: an introduction," Armstrong, G. and Kotler, P., 2013.

Carrying out the SWOT analysis will yield conclusions and recommendations based on the data collected from the sources used.

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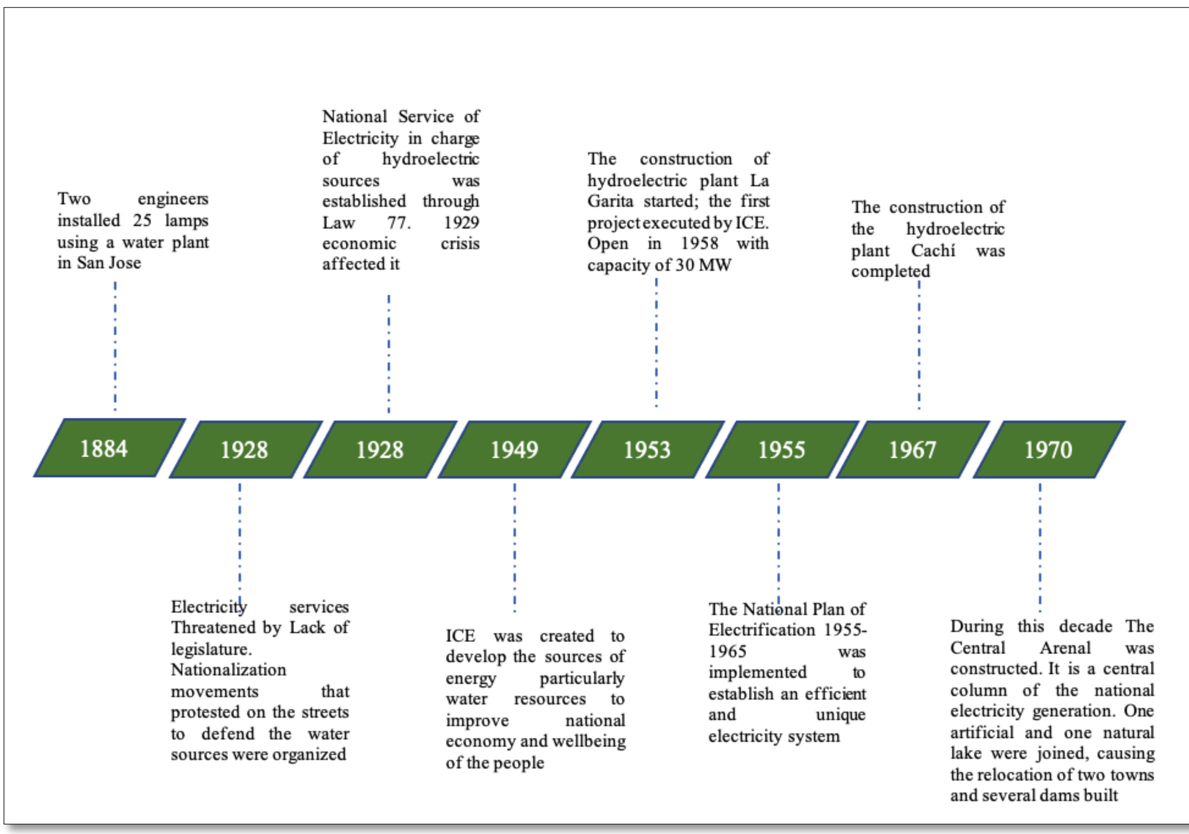
Chapter 4: Costa Rica- A Case Study

Renewable energy development in Costa Rica has always been central to national policy and development strategy. Costa Rica has strategically planned the use of its natural and renewable sources in a balanced way by executing a sustainable matrix to optimize and guarantee the electricity supply. The participation of the public and private sectors has been vital to its development (Instituto Costarricense de Electricidad, 2015a). With this vision in mind, the reality of green energy was put into practice more than a hundred years ago. Figures 3 and 4 show the timeline of renewable energy in Costa Rica.

Figure 3

Evolution of Renewable Energy in Costa Rica



Adapted from *We are Renewable and Solidary Energy*, by Grupo ICE, 2020 (https://www.grupoice.com/wps/wcm/connect/579dfc1f-5156-41e0-807d-d6808f65d718/Fasciculo_Electricidad_2020_ingl%C3%A9s_compressed.pdf?MOD=AJPERES&CVID=m.pGzcp).

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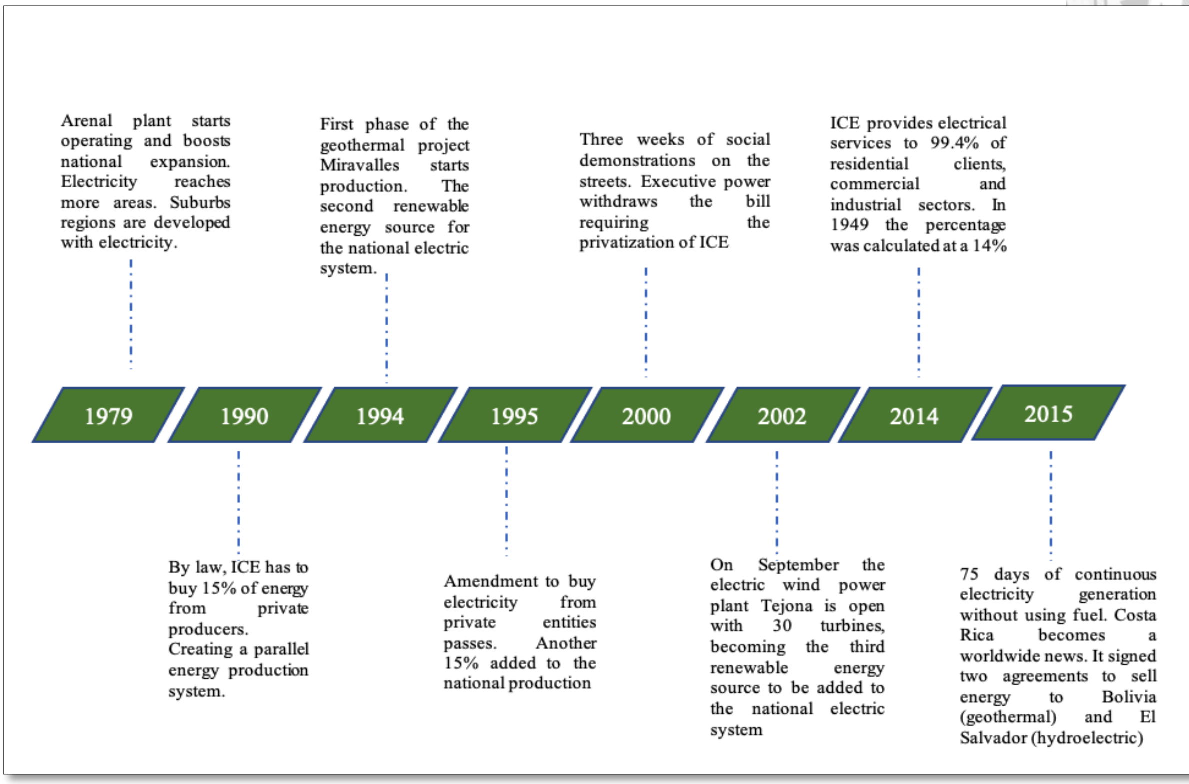
Figure 4

Evolution of Renewable Energy in Costa Rica



Adapted from *We are Renewable and Solidary Energy*, by Grupo ICE, 2020 (https://www.grupoice.com/wps/wcm/connect/579dfc1f-5156-41e0-807d-d6808f65d718/Fasciculo_Electricidad_2020_ingl%C3%A9s_compressed.pdf?MOD=AJPERES&CVID=m.pGzcp).

4.1. Foundations for Green Energy Generation

Costa Rica's development of renewable sources has been a process that has lasted over a century and has been stimulated by multipartisan efforts. By nationalizing hydrological sources for energy production and creating the Instituto Costarricense de Electricidad (ICE), Costa Rican governments have ensured that energy production and policy would be at the government's discretion and in the country's best interest.

At first, the production of energy and the creation of power plants was solely financed by the government and Costa Rica's central bank. Financing later changed, allowing ICE to borrow funds from international financial institutions and the emission of bonds. Up to the

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1980s, energy production heavily relied on fossil fuel-powered plants. Rising fuel costs and oil crises created a change in policy in the early 1990s that marked the start of the transition in energy production from fossil fuels to renewable sources. Costa Rica is a developing country and, as such, with scarce financial resources. Costa Rica has faced the high opportunity cost of funding renewably sourced energy production and confronted high foreign indebtedness, among other issues.

As the phasing out of thermal energy happened, thermal energy plants have been kept as a backup. This commitment was strengthened by the increasing prices of oil and due to climate change. Climate change created several droughts in the 1990s that forced the use of thermal energy plants and increased the cost of energy generation. These events highlighted energy insecurity and bunker dependence for mitigation purposes. The response was to produce more renewable energy by creating more hydroelectric dams and solar, wind, and geothermal plants.

The commitment to renewable energy has transcended political parties and time. It has also created a social conscience for the Costa Rican people culminating in complete renewable energy production over the past seven years. Moreover, Costa Rica has slowly transformed its economy into a zero-emissions economy. This process was consolidated with the Decarbonization Plan 2018-2050, highlighting the importance of transitioning to electric vehicles, complete renewable sources of energy production, digitalization, and innovation.

The highest emitting sector in the Costa Rican economy is the sector of energy, in which 75.4% of emissions come from transportation (Madriz, 2022). Oil dependency for transportation is not a problem limited to Costa Rica but a global problem across all countries. Even though oil consumption has increased steadily year over year, the Decarbonization Plan

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will strive to lower emissions from this sector which will be discussed in section 4.4 of this chapter.

Why did Costa Rica implement renewable energy despite the myriad issues afflicting developing nations? As mentioned before, this has been a process lasting over a century, and for Wilde-Ramsing and Potter (2005), the key to success in the implementation lies with the creation of ICE. Wilde-Ramsing and Potter (2005) argue that the origin, connections to Costa Rica's grassroots civil society groups and intellectuals, and historical and energy context at the moment of ICE's creation allowed ICE to have the autonomy to create long-term planning in energy development that allowed for social and economic development. ICE has held this autonomy and monopoly over energy production because of its not-for-profit nature, ties to civil society, technical expertise, and financial and political independence (Wilde-Ramsing & Potter, 2005). This autonomy and social acceptance have created conditions that strengthen the commitment to renewable energy. Social trust has allowed legislation to be passed that permits capped private production of renewable-based electricity from private contractors under the distribution of ICE (Wilde-Ramsing & Potter, 2005). Social trust in ICE was shown by the demonstrations against the attempts to restructure ICE in 2000. Protests against "combo ICE" happened because laws about to be passed in the National Assembly would strip ICE of some of its functions and open the door to the privatization of ICE (Aguilar, 2010; Menjívar, 2012). The response was mass protests; among the protestors were student unions, ICE worker's unions, opposition legislators, environmentalists, the Church, and community leaders (Aguilar, 2010; Menjívar, 2012).

Costa Rica's successful implementation of renewable energy has been due to a mixture of reasons, including ICE's administration and performance, civil society support, and multipartisan government support. Renewable energy production is a task that all members

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of Costa Rican society have taken up. Social conscience and the understanding of the issues of climate change and global warming are rooted in Costa Rican society. Otherwise, the process would have collapsed decades ago in favor of cheaper, oil-based energy production.

4.2. Renewable Energy Sources and their Generated Levels of Energy

Costa Rican energy policy is based on the principle of sustainable energy for the country with low emission levels, as stated in their VII National Plan of Energy 2015-2030 in its latest revision in 2020. Costa Rica aims to have an energy supply system that emits low levels of greenhouse gases by implementing renewable energy sources to satisfy the increasing demand. Additionally, it endeavors to provide competitive prices and welfare to the Costa Rican population (Ministerio del Ambiente y Energía (MINAE) mediante la Secretaria de Planificacion del Subsector Energia (SEPSE), 2020).

The Instituto Costarricense de Electricidad Gerencia de Electricidad (2023) informs that up to 2021, the installed capacity of the Costa Rican electric grid was 3,482 MW. It was produced by hydroelectric plants (67%), thermal power stations (12%), geothermal power stations (11%), wind farms (11%), bagasse (2%), and solar power (0.16%), as can be seen in Figure 5.

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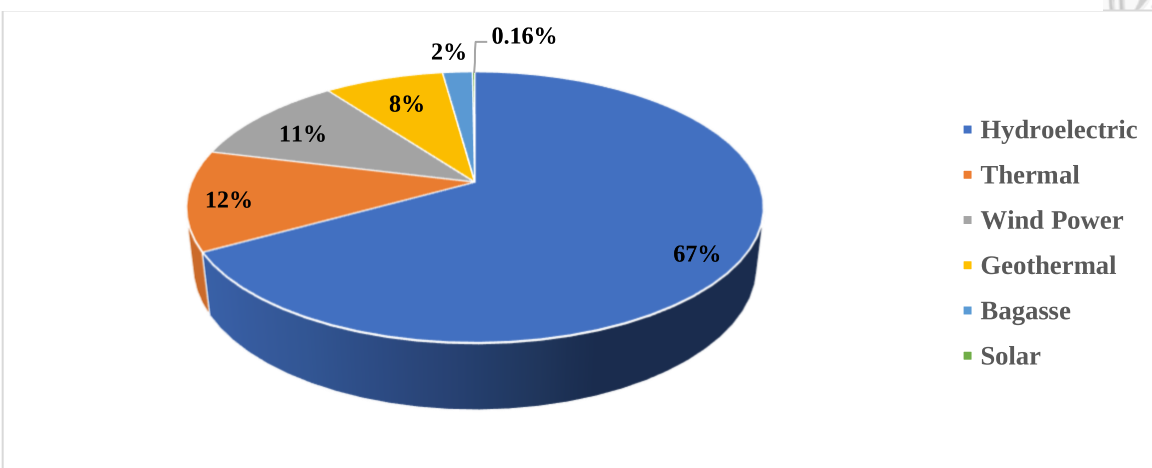
Figure 5

Costa Rican Electric Grid by Source Type (2021)



From "Informe Ejecutivo del Plan de Expansion de la Generación 2022 – 2040," by Instituto Costarricense De Electricidad Gerencia De Electricidad, 2023, (https://www.grupoice.com/wps/wcm/connect/741c8397-09f0-4109-a444-bed598cb7440/Plan+de+Expansión+de+la+Generación+2022-2040.pdf?MOD=AJPERES&CVID=osLqnZB).

Additionally, ICE owns 68% of the power stations, 18% belong to private contractors (10% operate under a BOT model (build-operate-transfer)), and other electricity distribution companies own 14%. The interaction between ICE and private energy generators is based on ICE's monopoly over Costa Rica's electricity supply; the private sector can only offer renewable energy projects up to 50MW and must sell this energy to the state (Skowron et al., 2020).

Even though electric generation in Costa Rica has been almost entirely generated from renewable sources, thermal power generation (coal, fossil fuel) is still a part of electricity generation in Costa Rica. That happened because thermal power generation provides crucial backup for the rest of the grid production in times of critical hydrologic events such as droughts, floods, and earthquakes, among others (Instituto Costarricense de Electricidad, 2023; Instituto Costarricense de Electricidad, 2015a).

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The Instituto Costarricense de Electricidad Gerencia de Electricidad (2023) reports that in 1994 extreme drought caused thermal power generation to reach its all-time highest of 17.4 % of total electricity generation. This massive increase was mitigated with the introduction of geothermal and wind power in 1996, which in conjunction with favorable hydrologic conditions, caused, from 1996 to 2006, virtual independence from thermal energy. Moreover, the period leading up to 2014 was characterized by low-flowing rivers, which led to an increase in the use of thermal electric generation. Therefore, since 2015, a higher capacity of renewable energy was introduced, and imports from the regional electric market and favorable climactic conditions have limited fossil fuels powered electricity use to below 2%; the system was able to generate 12,540 GWh, which were produced according to the following distribution, ICE (66%), private contractors (21%), and electricity distribution companies (13%). Of the total electric generation, 74% was produced from hydroelectric power, 13% from wind power, 13% geothermal, 0.07% solar power, 0.54% bagasse, and 0.02% thermal (Instituto Costarricense de Electricidad, 2023).

4.3. Costa Rica's Renewable Energy Projects and their Funding Sources

As discussed in previous sections, green energy projects are funded through public and private investment, and Costa Rica is no exception.

4.3.1. Funding Sources

Thus, what are the financial policy incentives that Costa Rica has experienced to develop its renewable energy system? Carbon taxes are among the most common ways to fund renewable energy transition. However, Costa Rica does not have an explicit Carbon Tax in line with the IPCC Carbon Tax or the United Nations model for carbon taxing (OECD, 2022b). Costa Rica's carbon taxing method is to levy fuel taxes directly. Costa Rica passed

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law No. 8114 on July 2001 and updated it in November 2007. In the law, fuels derived from hydrocarbon are levied a unique tax that is updated quarterly and should not exceed a 3% variation (La Asamblea Legislativa de la República de Costa Rica, 2007). The tax is managed and administered via the Dirección General de Tributación (the national institution in charge of taxes in the country). Moreover, the tax is destined for the following programs or entities: 29% to Consejo Nacional de Vialidad (CONAVI, Road Maintenance), 3.5% to environment services managed by Fondo Nacional de Financiamiento Forestal (National Fund for Forestry Financing), 0.1% to agricultural services managed by Ministerio de Agricultura y Ganadería (Ministry of Agriculture and Livestock), 1% for the upkeep and reconstruction of the Costa Rican Road network managed by the Universidad de Costa Rica (University of Costa Rica) (La Asamblea Legislativa de la República de Costa Rica, 2007). The Ministry of Finance administers the remaining 67% at its discretion but has not explicitly disclosed the destiny of these funds.

The latest tax percentage for fuels set under public decree "Decreto 44005-H, published in El Alcance N° and 81 a La Gaceta N°79 del 08 de mayo de 2023" adjusts the tax for fuels as follows: 37% for unleaded fuels, 24% for diesel, 25% for jet fuel, 24% for aviation gasoline, 13% for kerosene and LPG holds steady at ¢24 colones (US$ 0.04 at May 20th exchange rate (Banco Central de Costa Rica, 2023) for the next six years for LPG (Autoridad Reguladora De Los Servicios Públicos, 2023).

As Haites (2018) discussed, levying direct or indirect taxes on fossil fuels has different intentions and purposes. In the case of Costa Rica, as mentioned above, 33% of the taxes collected from fossil fuels are destined for agricultural, environmental, road maintenance, and building purposes. The use of the remaining 67% is not disclosed, but it can be supposed that it is used to finance government expenditure and its projects. Change in Costa Rica is

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policy-driven, and more importantly, it is driven by the national commitment to stop climate change and secure a sustainable society, not stimulated by taxes. Throughout history, different administrations have seen environmental policies as key to Costa Rica's development. Proof of this is the Decarbonization Plan set up to exceed the SDGs and seen as the correct step forward to meet Costa Rica's needs for the future.

During its initial stages, ICE's production of energy and creation of power plants was solely financed by the government and Costa Rica's central bank. With time ICE was allowed to borrow from international financial institutions and emit bonds to fund its operations. As a member of the OECD (25 May 2021), Costa Rica is recommended to follow economic policy and incentives that create a transition from a linear economy to a circular economy for the different productive sectors such as agriculture, transportation, and electricity generation (UNA Comunica, 2022). Therefore, Costa Rica's financial industry has started emitting green bonds to face the high costs of transitioning to a circular economy and achieving the National Decarbonization Plan. These bonds are meant to finance the Sustainable Development Goals (SDGs), among which is renewable energy. The bonds can be emitted by the government, public institutions, and private or public enterprises, among others (UNA Comunica, 2022). ICE is the second entity to issue green bonds valued at USD 30 billion (Futuris Consulting S.A., 2021; UNA Comunica, 2022). The bonds will be used to finance renewable energy projects. This step was also emulated by other companies that will finance solar farms, biomass plants, and carbon-neutral certification projects with green bonds (UNA Comunica, 2022).

Another of Costa Rica's targets is to electrify its transportation system, which will significantly reduce greenhouse gases as the transportation sector is the most significant source of emissions. Intending to reduce emissions and improve efficiency, the Costa Rican

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government passed a law that not only creates tax exemptions in imports and duties for electric vehicles spare parts and batteries but also creates incentives for building charging stations, special parking permits, unrestricted circulation, among others (La Asamblea Legislativa de la República de Costa Rica, 2018).

4.3.2. Costa Rica's Renewable Energy Projects

Costa Rica has been steadily developing its renewable energy market by implementing and developing various renewable projects: hydropower, geothermal, wind power, solar, and biopower. Electricity generation and distribution in Costa Rica is under the monopoly control of the Costa Rican Institute of Electricity (ICE), with the participation of other public institutions, private companies, and co-ops authorized by law to generate and sell electricity (International Trade Administration, 2022).

ICE runs 68% of the plants, while 18% are under contract agreements with independent power producers (10% using BOT contracts). The remaining 14% belongs to the distributor companies of electricity (Instituto Costarricense de Electricidad, 2023).

In this sense, the projects developed in Costa Rica for green energy have generated almost 100% of the electricity in the last years. Out of the total generation in 2021 of 12,540 GWh., ICE contributed 66%, using ICE's plants owned by itself and 21% from plants under contracts with independent producers. The rest of the energy generated came from distribution companies (Instituto Costarricense de Electricidad, 2023).

Particularly, electricity distribution and commercialization it is under the control of eight public companies, including ICE and its subsidiary Compañía Nacional de Fuerza y Luz (CNFL), two local city companies, Empresa de Servicios Públicos de Heredia (ESPH) and Junta Administrativa del Servicio Eléctrico de Cartago (JASEC), and the rural

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electrification cooperatives of Guanacaste, San Carlos, Los Santos y Alfaro Ruíz (COOPEGUANACASTE, COOPELESCA, COOPESANTOS, and COOPEALFARO, respectively) (Instituto Costarricense de Electricidad, 2023).

The electricity generation system includes projects of varied sizes, whose installed capacity and electricity generation vary per the size of the plants. The most significant projects come from hydropower, geothermal, and wind power sources. The electric park of Costa Rica comprises more than 444 installed plants (Instituto Costarricense de Electricidad, 2015a). In this sense, the plants sampled are among the ones with significant installed capacity.

There is no identical funding format across all renewable energy projects in Costa Rica. The sampled projects are financed by one or a combination of the four primary funding sources: The Costa Rican Government, International Aid and Grants, and Private Investment and Public-Private Partnerships.

4.3.3. Hydropower

Hydropower generation represents the highest portion of the renewable energy generated in Costa Rica. This kind of renewable energy is listed as one of Costa Rica's natural resources. At the moment of this research, the following three hydroelectric projects are the most repetitive ones.

Reventazón plant: It is located in the river of the same name, 8 km southwest of Siquirres city, Limón province. The plant takes advantage of the energy potential of the river (120-265 meters above sea level). It is one of the largest installed capacity plants in Costa Rica, with 305.5 MW and an annual production of 1,572.8 GWh (Instituto Costarricense de Electricidad, 2022). It is estimated that the plant benefits 525,000 homes. The funding came

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from a mix of private and public resources to cover the total cost of US$1,379 million: US$152.5 million from the ICE, US$97.8 million from the Inter-American Development Bank, US$468.7 million from a syndicated loan-Costa Rica National Bank, Banco Popular, Bancredito- and US$435 million from IFC-World Bank and the Inter-American Development Bank (Alfaro, 2015). The Central American Bank for Economic Integration provided US$225 million to fund the project. The plant covers 9.15% of national demand (Banco Centroamericano de Integración Económica, 2023). The plant received the international Blue Planet Prize due to the best practices during its construction. Moreover, the plant is classified as an environmentally sustainable case for its practices to protect natural resources (Castro, 2019).

Angostura: With a total capacity of 172 MW, it is a reservoir-based project located in Cartago province, on the Reventazón river/basin. It began commercial operation in 2000 (Power Technology, 2023). The total cost of the project was US$307.2 million, funded by the Central American Bank for Economic Integration (US$73.3 million), European Investment Bank (US$11 million), Inter-American Development Bank (US$159 million), and the ICE (US$64 million.) (La Nación, 1998).

Corobicí: The plant is in Santa Rosa, Guanacaste. Corobicí installed capacity accounts for 174 MW. The cost of the construction is not publicly available. After its single phase was completed, the project got commissioned in 1982. Mitsubishi Heavy Industries was selected as the turbine supplier (Power Technology, 2021). Moreover, the plant is vital, providing an essential source of electricity to the national electric system.

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4.3.4. Wind power

Currently, most of the wind power plants in Costa Rica are in Guanacaste. There are 17 plants in Costa Rica (Lopez, 2019). The energy generated from wind sources is the second most important in the country after hydroelectric energy (Garza, 2019). The largest plants include the Planta Eólica Guanacaste (PEG), Orosi, and Chiripa.

Planta Eólica Guanacaste: is located at Cantón de Bagaces, Guanacaste (Celsia, n.d.). Upon completion, the wind farm was expected to have a capacity of 49.5 MW. PEG was expected to start operation in 2009 (renewableenergyworldcontentteam, 2008). No financial information on the total cost of the farm is electronically available.

Orosí: Citi Bank and US Ex-Im Bank granted a loan of US$45.5 million to import 25 turbines as a central part of the farm. The developer of the project was Globeleq Mesoamerica Energy. The wind farm has a capacity of 50 MW and started operations in 2014 (REVE, 2014). The total cost of the investment is not available.

Chiripa: Connected to the national system in 2014, it has a total installed capacity of 49.5 MW. It is located at Tilará, Guanacaste. 65% of the ownership is under the control of ACCIONA, and 35% belongs to Grupo Econoenergia, both private entities. The total investment for the plant was US$125 million, and its clean energy can cover 80,000 houses (acciona, n.d.).

4.3.5. Geothermal

Renewable energy production based on geothermal sources is produced in the Miravalles and Pailas fields.

Miravalles field: Started operations in 1994, is in Guanacaste and includes four plants predominantly: Miravalles I, Miravalles II, Miravalles III, and Miravalles V for a total

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installed capacity of 165.5MW (Instituto Costarricense de Electricidad, n.d.). Among the previous, the largest ones are Miravalles I and Miravalles II, which have an installed capacity of 55MW each. The monthly energy produced can cover the needs of 283,000 residential consumers (Instituto Costarricense de Electricidad, 2015b). A Japanese ODA loan was granted in December 1985 for around US$66 million – or 13,500 million Yen- to start the development of the Miravalles geothermal field (Japan International Cooperation Agency, 2017).

The Pailas systems: It includes two plants, Pailas I (2011) and Pailas II (2019), each of them has an installed capacity of 55MW (Instituto Costarricense de Electricidad, n.d.). Pailas I was commissioned to the Central American Bank for Economic Integration. At the same time, Pailas II used loans from the European Investment Bank, the Japanese International Cooperation Agency, and funds from the ICE. The total cost of Pailas II was US$366 million, including an additional cost of US$41 million (Think Geoenergy, 2019).

The most recent project is the Borinquen geothermal field. It is expected to start operation in 2023. The project received loans from the Inter-American Development Bank, the Japanese International Cooperation Agency-JICA (US$240 million), and ICE (Presidencia Costa Rica, 2017). The total investment for the construction is not available at the moment of the research.

4.4. Benefits of Renewable Energy in Costa Rica

The literature review describes multiple socioeconomic benefits for the population of the countries which transition to renewable energy, but what are some of the tangible socioeconomic benefits that Costa Rica is experiencing from engaging in the transition to renewable energy? Some of the socioeconomic benefits that Costa Rica and its population

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enjoy include access to affordable and clean energy, reversing deforestation, and payment for environmental service-PES program.

- **Access to affordable and clean energy**: As per Paredes (2015), ICE announced a reduction of 10 percent in electricity prices in 2015. The previous was possible because of the available amount of clean energy derived from renewable energy and the possibility of importing cheaper energy from neighboring countries through SIEPAC. Additionally, in 2019, almost 99 percent of the energy in Costa Rica came from renewable energy (1.16 percent came from backup plants that used fossil fuels). By 2018 the total population of Costa Rica was estimated at 5.05 million people; 79 percent lived in urban areas, while 20 percent lived in rural areas. Because of the amount of energy produced from renewable sources, 100 percent of all households have access to electricity generated from renewable sources. (Young, n.d.). Moreover, the 2020 Sustainable Development Report of Costa Rica estimates that 93.5 percent of the country's total population uses clean cooking fuels and cooking technologies that contribute to reducing greenhouse gas emissions (Sustainable Development Report, 2020). Access to affordable and clean energy boosts economic activity and allows households to perform their daily activities (studying and cooking, among others).
- **The tropical country that has reversed deforestation**: As per Lewis (2020), between 1970 and 1980, Costa Rica had one of the highest deforestation rates in Latin America. The Costa Rican government and the citizens joined efforts to reverse the previous. Nowadays, Costa Rica can proudly state that in addition

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to totally reversing deforestation, the country has built an ecotourism trademark that, in 2019 alone, generated almost US$4 billion in revenue, accounting for more than 8 percent of the GDP and generating nearly 200,000 jobs in the country.

- **Payment for Environmental Service-PES**: As per Rodríguez (2022), the government introduced the program to pay farmers to protect watersheds, conserve biodiversity or capture carbon dioxide. Most of the funding for this program comes from fuel taxes. Moreover, in 2020, in recognition of capturing 14.7 million tons of carbon dioxide between 2014-12015, US$54 million from the Green Climate Fund. In the same year, the country agreed with the World Bank a deal of US$60 million. The success of the PES program has led the government to think about creating a marine PES that would pay the coastal population to protect the ocean. Farmers get an extra income for preserving the forest, which in turn helps maintain the country's hydro sources.

The literature points out more benefits related to the transition to renewable energy. Unfortunately, the available data about Costa Rica does not create a clear connection between other benefits and the transition to renewable energy, which is recommended to be covered in future research.

4.5. The Future of Renewable Energy in Costa Rica

Since 1884 when the first 25 lamps powered by hydropower were installed in San José, the capital of Costa Rica, the country has been steadily working on different renewable energy projects that are helping the country to achieve an environmentally friendly status and thus being closer to achieve the goal of having an environmentally sustainable country.

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Costa Rica is considered one of the top 9 Green Energy Countries worldwide, with Costa Rica ranking third (Howell, 2022). Although the country has a high production of renewable energy, almost 70 percent of the country's general energy still relies on the consumption of fossil fuels. The country's logistics and private transportation is dependent on fossil fuels. While their energy has been produced almost entirely from renewable sources for some time, backups are fossil fuel-based due to their availability and ease of use.

Plans to phase out the use of fossil fuels and the decarbonization plan include transitioning to new production technologies, reducing fossil fuel consumption where possible, and demand for efficient and low-emission transportation and machinery for logistic purposes, among other vital aspects that will be discussed in detail, in chapter 5, a section that will cover Costa Rica's plans to continue working toward consolidating a sustainable country.

The three major economic activities that still heavily rely on the consumption of fossil fuels are oil for transportation and heating processes and gas for domestic cooking (Howell, 2022). The fact that some economic activities keep relying on the consumption of fossil fuels is a typical pattern that can be observed in many other countries around the world.

The government of Costa Rica and its citizens are well aware that to become a decarbonized country, the Costa Rican industries will need to undergo a total transformation that will require a considerable investment of financial resources that will allow them to access technological resources that can be used to implement better practices that will lead to achieving a sustainable economy.

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4.5.1. Costa Rica's National Decarbonization Plan

In response to a request made by Mr. Carlos Alvarado Quesada, President of Costa Rica, the Minister of Environment and Energy, along with the country's most significant stakeholders, elaborated the National Decarbonization Plan. It provides a detailed strategic plan to complete the process of achieving the decarbonization of Costa Rica. The elaboration of it was financially supported by the German Cooperation through the Climate Action II Project and two programs belonging to the Inter-American Development Bank (IABD). It also received technical support from different international organizations such as the Climate Change Directorate, The Electrical Power and Energy Research Laboratory (EPERLab) of the School of Electrical Engineering of the University of Costa Rica (Inter-American Development Bank, Dirección de Cambio Climático, RAND Corporation, Universidad de Costa Rica, 2020).

On 20 September 2019, the Costa Rican Executive Government published an executive decree in the National Gazette that officialized the implementation and considerations of the "Plan de Decarbonización Compromiso del Gobierno del Bicentenario," which includes all activities and measurements that give support, promote, drive, and execute it (Diario Oficial La Gaceta, 2019). The executive decree highlights the urgent transition of the global economy towards a sustainable one and the importance of using natural resources sustainably to fulfill the commitments contracted under the 2030 Agenda for Sustainable Development and the Paris Agreement. Considering the previous, and after achieving an electric grid that is 95% free of emissions and over 52% of the whole country covered in forest, all Costa Rican sectors must support and facilitate the execution and achievement of their national project.

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The Decarbonization Plan by the Costa Rican Government (2019) aims to go beyond an environmental agenda; its primary goal is to transform Costa Rica's economy into a green economy (Gobierno de Costa Rica, 2019). This determination was taken in part because of the responsibilities adopted with the Paris Agreement and due to the presidential agenda of former Costa Rican President Carlos Alvarado Quesada. The Plan aims to reach zero or negative carbon emissions in the sectors where possible and reach the lowest levels where reaching zero is impossible.

The decarbonization plan was designed to be implemented in three stages:

1. **Foundations Stage**: It was executed between 2018-2022: As its name suggests, it aimed to set the basis for immediate impact actions, but most importantly, for substantive long-term transformation.
2. **Inflection Stage**: It is currently under execution. It was planned to be implemented between 2023 and 2030. This phase aims to create real change. It will create actual transformation; lower adoption barriers while considering and reaching agreements among the different government agencies and all involved stakeholders.
3. **Normalization of the change or mass deployment stage:** It is expected to happen from 2031 to 2050. The final stage of normalization of change or mass deployment is highly dependent on what the future will look like, yet, it can be predicted that old high emissions technology will be phased out in favor of more highly efficient technologies, the world as a whole has already transitioned to decarbonized technologies or will be more actively transitioning to them, and it will provide more significant opportunities to those who are already involved in the change.

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The Costa Rican Government has already designed and put into practice its Decarbonization Plan, which short, medium, and long-term goals started to be implemented in 2018 and are expected to be fully implemented by 2050. The Plan focuses on decarbonizing four main sectors of Costa Rica's economic activities: "Transport, Energy, Waste and Agriculture, Forestry and Other Land Uses also known by its English acronym AFOLU (Inter-American Development Bank, Dirección de Cambio Climático, RAND Corporation, Universidad de Costa Rica, 2020). Although the Plan focuses on those four different economic sectors, the main objective of the Costa Rican Decarbonization Plan is to transform the country's economy into a circular economy and thus eliminate fossil fuels use by 2050.

Among the four main sectors contemplated in the National Decarbonization Plan, ten axes are crucial to reduce greenhouse gas emissions and modernizing the Costa Rican economy to transform it into a sustainable and circular economy. It can be summarized as follows (Inter-American Development Bank, Dirección de Cambio Climático, RAND Corporation, Universidad de Costa Rica, 2020):

1. **Sustainable Transportation and Development**

- **Axis 1**: Development of a public transportation system that is safe and based on a scheme of renewable and efficient mobility. In 2050, the public transportation system will be the primary choice of transportation for everyone. By 2035, 70% of the public transportation fleet will have zero emissions, and the rapid train transportation system, which is currently under construction, will be completely electric.
- **Axis 2**: Transformation of light vehicles from fossil fuel into zero emissions renewable energy source for power. In 2050, 60% of all light vehicles will have zero

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emissions, with a higher percentage for commercial and state purposes. 100% of new light vehicle sales will be zero emissions. By 2035, 25% of vehicles will be electric, and by 2025 motorcycle-based deliveries will be stabilized and aimed to have zero emissions and be shared. The electric charging network will continue developing, and complementary zero-emission stations such as hydrogen will continue to be in development. As technology improves, business models and transportation will change to include aspects such as autonomous driving and shared vehicles.

- **Axis 3**: Freight Transportation will be encouraged to adopt zero-emissions technologies or as close as possible to zero emissions. By 2050, freight transportation will have decreased emissions by 20% compared to 2018 previous levels. By 2022, Costa Rica should have data on freight transportation emissions and implemented pilot programs with a smart-logistics approach to increase freight truck efficiency.

2. **Energy, Sustainable Construction, and Industry**

- **Axis 4**: Strengthen the electric grid with capacity, flexibility, and resiliency to supply renewable energy at a competitive cost. At the moment of doing this research, less than 30% of the energy used in transportation, residential, commercial, and industrial, among others, is electric. By 2030, the electric grid will operate entirely on renewable sources. The investment program for the evolution of the electric grid should guarantee a competitive price for end users. By 2050, renewable energy will become the primary energy source for these areas. Moreover, processes and protocols will be digitalized to provide a more efficient management approach across the national territory.

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- **Axis 5**: Construction should be carried out under the highest efficiency and low emissions standards. By 2050, all edifications should operate under low-emission standards. By 2030, all new constructions should be designed and constructed to follow and implement low emissions and resiliency.
- **Axis 6**: Modernization of the industrial sector through low or zero-emission technologies. By 2050, the industrial sector should have transitioned from energy sources to stop their production of emissions. By 2030, businesses and the industrial sector will have developed a cradle-to-grave model and strategy for their products, packaging, and uses to envision a circular economy.

3. **Waste Management**

- **Axis 7**: Development of a waste management system based on the principles of separation, reuse, revaluation, and final disposal with the highest efficiency and low emission of greenhouse gasses. By 2050, the country will have solutions for waste management issues based on recollection, separation, reuse, and disposal. By 2030, Costa Rica will have a citizen and business culture of less waste creation and successful-waste management.

4. **Agriculture – Change, Solutions, and Use of Land Based in Nature**

- **Axis 8**: Development of highly efficient agri-food systems that generate goods for export and local consumption with a low carbon footprint. By 2050, the most highly advanced agricultural technologies will be used so that agriculture can be carried out sustainably, resiliently, competitively, and with a low carbon footprint.

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- **<u>Axis 9</u>**: Strengthening the eco-competitive livestock model based on productive efficiency and low greenhouse gas emissions. By 2050, the livestock industry will use the most highly advanced technologies for livestock based on sustainability, competitivity, low emission, and resiliency to climate change.
- **<u>Axis 10</u>**: Strengthening of the urban, rural, and coastal land management systems that facilitate the protection of biodiversity, increase forest areas, and management of forest areas based on solutions derived from nature. By 2030, forest-covered areas will increase to 60% while also reverting the degradation of marine and land ecosystems.

The Costa Rican government acknowledges that to achieve this Plan, other steps need to be taken. Inclusion, gender equality, and human rights are cornerstones of improving its citizen's life. Moreover, Government institutions will need to modernize their digital operations to be more flexible and thus be able to face the following changes. Also, financial reform towards a green fiscal policy must consider economic valuation to contamination and decarbonization. In the same terms, the public and private funds will need to be funneled to materialize the plans. Finally, all the changes cannot happen if there is no plan in place for the jobs market that will provide opportunities and mitigation strategies for the sectors that will benefit or be affected the most. At the same time, working with end users and consumers, teachers, and students at all levels will help create a culture with initiatives and technologies that aim to transform Costa Rica.

4.5.2. Benefits and Costs of Implementing the National Decarbonization Plan

Costa Rica already provides all its electric production from renewable sources, albeit it has backup generators powered by fossil fuels. In addition, the energy sector in Costa Rica

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is reliant on fossil fuels. Around 70% of the energy sector uses gas and oil to power transportation and heating processes in the industry and for cooking (World Future Council, n.d.). Costa Rica has met their promises with action. The country has also been able to revert deforestation. On top, it possesses the world's 6% biodiversity, and it has developed a green image by developing the ecotourism industry, creating protected wildlife areas, and banning single-use plastics, among other measures (Smith E. , 2021). The country has been moving towards carbon neutrality for some time now, as an initiative from former Costa Rica President Alvarado (World Future Council, n.d.). This initiative culminated with the creation of the National Decarbonization Plan, which, if executed as planned, will transform Costa Rica into a carbon-neutral country by 2050.

The Benefits and Costs of Decarbonizing Costa Rica's Economy is a study prepared by the Inter-American Development Bank, RAND Corporation, Dirección de Cambio Climático, and the University of Costa Rica. It analyses the benefits and costs of decarbonizing Costa Rica's economy by 2050. Its benefits can be appreciated in terms of lowering emissions in both the public and private transportation sector, reduction of emissions resulting from agriculture and livestock activities, and making it carbon absorbing due to changes in land usage, waste management and recycling, energy-efficient buildings, and reduction in emission from the industrial sector (Groves et al., 2020).

The transportation sector is projected to significantly reduce emissions and provide discounted costs of US$ 24 billion and around US$ 13 billion in health, accidents, and congestion. These benefits are primarily due to transitioning to electric vehicles requiring less maintenance and operations, improved public transport system, and reduced private transportation. The main costs are derived from investments to improve and transform freight

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transportation and transition to an electric fleet for public and private transportation (Groves et al., 2020).

The study estimates that the building sector is projected to help reduce emissions by 42% through 2050, costing roughly US$ 2.4 billion in the same period and yielding US$ 1.8 billion in energy cost savings. Costs can be more accurately calculated once plans and details of the building inventory are available (Groves et al., 2020).

Reducing emissions in the industrial sector of the production of cement, reduce of emissions due to the use of industrial products such as refrigerants, and reduction of emissions related to the energy consumption of industrial processes, is projected to decline emissions by 21% with a cost of US$ 2.2 billion and yielding a benefit of reduced energy cost and increased productivity of US$ 4.3 billion (Groves et al., 2020).

The Waste Sector would decline its emissions by about 57% costing US$ 4.4 billion, and provide US$ 3.7 billion of value due to the use of treated wastewater, recycled materials, aesthetics, and health. Reducing emissions from waste, particularly industrial waste, would offset much of the cost of decarbonization due to the circular economy. Costs are related to creating processes that will deal with efficient waste management, such as recycling and collecting solid waste, capturing methane, composting, securing sanitation, sewage connection, and treatment (Groves et al., 2020).

Reducing the agricultural, livestock, and forestry sector emissions would yield US$ 3.1 billion yet yield US$ 25 billion in benefits. The most significant gain comes from the livestock industry through proper waste management and improvement in feeding and planting trees. Improvement in agricultural techniques and electrified machinery would further enhance the benefits. The costs are opportunity costs, as the land would be used for purposes other than timber, agriculture, and livestock (Groves et al., 2020).

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Chapter 5: Case Analysis

As previously discussed, transitioning to an economy derived from renewable energy is pivotal in mitigating climate change and achieving sustainable development goals. Costa Rica has consolidated itself as a global leader in renewable energy. The country has designed and executed an ambitious national plan to become carbon neutral by 2050.

This chapter is divided into three sections. First, a SWOT analysis was conducted to analyze the transition to renewable energy in Costa Rica and its socioeconomic benefits. Second, the SWOT analysis result and the previously discussed literature review are used to provide key findings about this unique case. Third, the limitations of the transition to renewable energy in Costa Rica and the execution of this research are presented.

5.1. Costa Rica's Renewable Energy SWOT Analysis

The following SWOT analysis will be conducted based on all the information discussed in previous chapters. This SWOT analysis is valuable to identify and evaluate the Strengths, Weaknesses, Opportunities, and Threats influencing the current and future scenarios of renewable energy in Costa Rica and distinguishing the critical internal and external factors that impact the growth and consolidation of renewable energy in Costa Rica. Figure 6 presents Costa Rica's energy SWOT analysis.

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Figure 6

Costa Rica's Renewable Energy SWOT Analysis

SWOT

Strengths	Weaknesses.	Opportunities	Threats
• ICE • Development of multiple renewable energy projects. • Country's Ecoturism trademark • Country's energy policy	• Overdependance on hydroelectric power. • Limited storage capacity • Lack of technical human resources.	• Diversification of its renewable energy portfolio. • Increasing regional integration • Green economy development	• Negative effects of climate change • National socioeconomic priorities • High investment cost • Worldwide uncertainty

A detailed explanation of each element of the SWOT analysis will be carried out to better understand the above SWOT analysis.

Strengths

- **ICE**: The state-owned vertically integrated entity that provides electricity and telecommunications to Costa Rica. Since its creation, ICE has been authorized to design policies and projects to ensure that electricity will be accessible to all the people in Costa Rica. ICE's well-designed policies have been fundamental to developing multiple renewable energy projects which facilitate Costa Rica's transition to renewable energy. ICE got the pioneer vision of using Costa Rica's

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renewable sources to start transitioning to renewables long before the dependency on fossil fuels created a global environmental crisis.

- **Development of multiple renewable energy projects**: Costa Rica has diverse renewable energy sources. In addition to hydro (the country's primary source of renewable energy), wind, solar, and geothermal are also available. The abundance of different renewable energy sources is the foundation for developing multiple renewable energy projects within the country. ICE has taken advantage of them to develop various renewable energy projects and produce enough renewable energy to supply its national demand and sell the surplus to the SIEPAC.
- **Country's ecotourism trademark**: Costa Rica has proven a solid commitment to protecting the environment by implementing multiple measures that secure a sustainable country for the benefit of all its citizens. Currently, the government is working toward reaching carbon neutrality by 2050. Securing a sustainable future has unified Costa Rican society to work towards developing different renewable energy projects. Developing these projects has required preserving forests and, thus, the national ecosystem. Facilitating the development of various renewable energy projects and initiatives contributing to sustainability has created the country's ecotourism trademark, which produces a revenue of US$4 billion that accounts for 8 percent of the country's GDP and secures 200,000 jobs for its citizens.
- **Country's renewable energy policy**: The country's national policies have been designed and implemented with a national well-being vision of creating a sustainable country. Nationalizing hydro sources for preservation and later using them to secure renewable energy access for all its citizens was one of the wisest decisions the

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government could make. Imposing taxes on fossil fuels to partially fund the PES program to incentivize forest preservation, as well as using part of those taxes to reinvest in road maintenance and creating green bonds that motivate investment in renewable energy, are among other of the significant decisions made by the Costa Rican government that continue contributing to the development and consolidation of transitioning to renewable energy production and consumption in the country.

Weaknesses

- **Overdependence on hydroelectric power**: Hydroelectric power generation represents 74 percent of the total energy produced from renewable sources in Costa Rica, making the national renewable energy sector vulnerable to inconsistent water availability, resulting from variable precipitation patterns resulting from the adverse effects of climate change. Scarce rainfalls and droughts represent a significant challenge to steadily generating hydroelectric power. Costa Rica experienced this phenomenon in the first quarter of 2019 when intense droughts created a deficit of seven percent in hydroelectric power generation compared to the same period in 2018 (Rodríguez, 2019).
- **Limited renewable energy storage system**: At the moment of this research, the infrastructure for renewable energy storage capacity in Costa Rica is still minimal. Proper storage capacity infrastructure limits the nation's ability to store surplus energy from peak generation periods. The lack of an appropriate system of storage represents a significant challenge to balancing supply and demand (Laugs, Benders, & Moll, 2020). The government and the key stakeholders in the renewable energy sector must develop a robust renewable energy storage system that allows the country to take

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advantage of its production capability for national consumption and explore the possibility of using the stored surplus to export it to other countries through SIEPAC.

- **Lack of technical human resources**: A training program must be designed to develop technical human resources to be inserted in the new job market created by implementing the National Decarbonization Plan. Otherwise, the success of the transition to renewable energy and its future sustainability could be jeopardized.

Opportunities

- **Diversification of Costa Rica's renewable energy portfolio**: As has been highlighted before, 74 percent of Costa Rica's renewable energy comes from hydroelectric power, but the country has a significant opportunity to diversify its energy matrix by investing in the development of other renewable energy sources such as solar and wind, the last one considerably compensated the shortage in hydro electrical generation in 2019 (Laugs, Benders, & Moll, 2020). Moreover, due to its nature, the country has the potential to expand its geothermal energy sector, which has the potential to generate 1,000 Megawatts. When this research was carried out, the power geothermal fields in Miravalles and Pailas had a total power generation of 262 Megawatts, being "the largest ones in Central America" (Think Geoenergy, 2021).
- **Green economy development**: Costa Rica's national plans to make its economic transition into a green economy represent an excellent opportunity to consolidate itself as a global leader in both renewable energy and sustainable development. The country can capitalize on its renewable energy resources. A green economy status can label the country as a desirable destination to attract direct foreign investment interested in sustainable practices; this will increase employment opportunities and

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technological advancements and thus enhances economic growth for the whole country. (The World Bank, 2012).

- **Regional renewable energy integration**: This unique integration model currently seeks to provide security and supply competitive prices to all 45 million inhabitants in the Central American Region, which allows them to have interconnected power grids and energy trades among the countries in the region. Costa Rica and the other countries in the Latin American and Caribbean region could benefit from the regional energy integration system. Such a system would increase collaboration among the countries in the LAC regions, promoting production cost-sharing and facilitating technological exchange among neighboring countries (World Bank Group, 2021), thus contributing to achieving zero carbon emissions while energy prices are accessible for all the population in that region.

Threats

- **Negative effects of climate change**: The entire world is vulnerable to the adverse effects of climate change, and Costa Rica is no exception to the previous. The country's renewable sector is susceptible to the impact of climate change and its adverse effects, such as droughts, extreme rainfalls, or any other extreme weather event due to its overdependence on hydropower. Any or all of the previous can negatively impact the country's renewable energy production system. This scenario stresses the importance of diversifying the renewable energy matrix of the country, which can help Costa Rica overcome this threat.
- **National socioeconomic priorities**: Any transformation requires an investment, and the investment amount positively relates to the desired level of transformation. A

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country's transition into producing and consuming renewable energy requires significant investment. Something that can be challenging for Costa Rica, even though it has a relatively high standard of living, is that it is still a developing country. In a country where financial resources must be well-invested to cope with national priorities such as health, education, and infrastructure, sustaining the development and expansion of renewable energy projects can be particularly challenging. Here lies the importance of a well-designed renewable energy policy and a well-executed strategic plan that helps to cope with the previous.

- **High investment cost**: It is well-known that modernization to achieve better practices, in this case, achieve sustainability, usually requires a high initial investment cost that can take quite a long time to reach the desired production stage and the expected return on investment. A high-scale project such as one country transitioning to producing and consuming one hundred percent renewable energy represents a high investment cost and an extended period to get a return from that investment. The previous may discourage private investors, mainly because it is a national industry that the Costa Rican government highly regulates through ICE, which is the largest stakeholder and thus the one who has the power to determine the different policies that govern the whole industry.
- **Worldwide uncertainty**: The dynamic of national and international markets can determine the success or failure of any industry. In this sense, the renewable energy sector of Costa Rica is subject to face uncertainties derived from international policy changes, international energy prices, and international market dynamics that can halt national or international investment that support the development of different

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renewable energy projects in the country (The World Bank, 2012). Additionally, Costa Rica does not own the technology used to produce renewable energy; thus, the price and supply of this technology are out of their control, which ultimately can determine the success of their plans.

Costa Rica can continue achieving its renewable energy goals to secure its sustainable transformation by taking advantage of its strengths, working on its weaknesses, capitalizing on its opportunities, and reducing its threats. A comprehensive approach that guarantees policy stability, technological advancements as well as capable technical human resources, and strategic investment are required for Costa Rica to facilitate the continuity and consolidation of the country's national plans and thus achieve sustainably in a country that only produces, distributes, and consumes one hundred percent renewable energy.

5.2. Case Findings

The literature reviewed assisted us in corroborating that human-caused climate change is an issue worsened by the contamination created by the long-term dependency on fossil fuels. Keeping in mind that the development of the world has derived from the energy created from fossil fuels, the cost of using fossil fuels has negatively impacted the natural environment. On the other hand, research suggested that a transition to renewable energy is a response that could palliate the negative impact of using fossil fuels. Renewables are an ideal alternative to mitigate climate change because, compared to fossil fuels, renewables can prevent the production of greenhouse gases and improve energy security in the long term.

While the cost of entering into the development, production, and distribution of renewables is high, the benefits of green energy on the long-term counterbalances, such as high costs because the cost of human-caused climate change is higher and must be reverted.

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Human-caused climate change has not only affected nature as a perception but, in actual practice, the raw materials required in the supply chain to produce all goods, thus creating higher prices, scarcity, and environmental calamities.

Moreover, the literature review proved that international organizations have made available economic resources for countries to develop and implement renewables. In this sense, Costa Rica has developed most of its green energy projects by using their own funds and from loans and funds provided by organizations such as the World Bank, BCIE, and the Japan International Cooperation Agency, among others.

Hence, financial resources, alternative sources to produce energy, and modern technology exist for countries to enter and implement renewable energy.

Even though the conception of renewable energy production in Costa Rica was a response to the inequality in energy distribution, Costa Rica had the vision to solve this problem using its abundant natural resources. The transition to renewable energy in Costa Rica was exacerbated by the global climate crisis, which threatens all living species on earth, and by the multiple international oil crisis that continuously increased the cost of production and distribution of energy derived from fossil fuels. This sequence of events marked a breakeven point that was a determinant for the Costa Rican government to transition to renewable energy, making it a national priority from which all its citizens have benefited.

ICE's creation and active role, which acts independently from politics, has been key in designing and implementing a national policy framework that stresses the country's well-being. This vision has given ICE the support of the private sector and most of the country's citizens. This consensus has been crucial to transitioning to renewable energy and implementing the National Decarbonization Plan to achieve a sustainable country and circular economy.

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Moreover, nationalizing hydro sources, reversing deforestation, and implementing different measures that secure the preservation of the national natural resources have led to the creation of a sustainable country internationally recognized for its incredible achievements in renewable energy and natural resources conservation.

The research demonstrated that the transition to renewables has brought various socioeconomic benefits for the country and its citizens, securing energy access for all the inhabitants of Costa Rica at an accessible price, building an ecotourism country trademark resulting from the preservation of the country's flora and fauna, which translate in a prosperous industry that contributes to the creation of jobs and also to increase Costa Rica's GDP.

Every country has unique socioeconomic, political, and environmental conditions; nevertheless, the pioneering case of Costa Rica demonstrates that well-designed national policies, paired with national support, lead all the citizens in a country to work toward reaching common national goals. The case can serve as a guide for all those countries planning to start their transition to renewable energies. Countries can learn valuable lessons about the pros and cons that Costa Rica has encountered in its transition process to renewable energy, which not only has contributed to reducing the negative side effects of the environment but has also brought about socioeconomic benefits to the country and its citizens.

5.3. Case Limitations

While conducting this research, the following limitations were encountered:

- Information availability: the financials for the renewable projects implemented in Costa Rica regarding loans, project cost, profits, etc., were not publicly available. The

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lack of public information related to the projects made it difficult to analyze the financial performance further to understand the feasibility of the projects.

- Geographical location: investigating renewable energy in Costa Rica could be enriched if the researcher were able to visit in situ some of the projects, interview a sample of the Costa Rican population to understand better their perspectives regarding their renewable energy system, as well as visit the governmental institutions in charge of the projects.
- Plans: some of the plans are in developing phases. The decarbonization plan is in the first year of the inflection stage, which is supposed to bring real change toward sustainability. Consequently, the success of the plan cannot be immediately verified.

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Chapter 6: Conclusions

After completing the investigation and analysis of Costa Rica's renewable energy, and based on the literature reviewed, it is accurate to conclude that Costa Rica's case is a model in the determination to transition to renewable energy.

As expressed in the literature review, most countries are considering renewable energy implementation as a response to mitigate the climate change observed by the continuous use of fossil fuels. Nevertheless, the implementation of renewables in Costa Rica derived from a national plan to manage the natural resources to secure energy for the country. In this sense, Costa Rica is not one of the countries that began its process by trying to minimize the climate change crisis. It is possible that when Costa Rica's government nationalized the water sources at the end of the 19^{th} Century, the first steps toward environmental conservation were unconsciously made. At that time, climate change was not a global issue, but Costa Rica started the path to renewable energy implementation. Therefore, the gap in the literature review covering renewable energy implementation is not as a response to climate change but as a national policy and competitive advantage of using natural resources.

At the same time, the researched questions could be answered during this research. It could be understood how Costa Rica implemented and shifted to renewable energy. The government of Costa Rica leveraged the abundance of water resources to secure energy production. As time passed and modern technologies appeared, Costa Rica stayed within its national agenda to produce energy. Costa Rica understood that using national resources in combination with financial funds from international organizations was feasible for hydroelectric projects to generate green energy. It is important to mention that the different governments of Costa Rica throughout its history have kept as a focus of interest and priority the development of the country.

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Additionally, it was verified that Costa Rica benefitted from the transition and implementation of renewable energy. Among the benefits found are access to affordable and clean energy, reversing deforestation, and payment for environmental service-PES program.

Moreover, a SWOT analysis examined Costa Rica's current renewable energy situation and potential future opportunities. Its result is the foundation to summarize this study's essential findings and recommendations.

Costa Rica successfully started its unique and extraordinary journey to transition to renewable energy by designing and implementing different policies and plans. Costa Rica has placed itself as a global leader in sustainable development. The position as a leader in renewable energy implementation is more praiseworthy because although Costa Rica has a relatively high standard of living, it is a small country with limited financial resources available to invest and develop new projects.

Costa Rica owns several renewable resources, including hydropower, geothermal, solar, and wind power. Those renewable sources are the foundation for developing multiple renewable energy projects. It is imperative to highlight that even though Costa Rica owns various renewable energy sources, which gives them a competitive advantage, that advantage is only helpful with the vital role that ICE has played during all this time.

Combining government policies through ICE, which has steadily developed and implemented its ambitious sustainable plans autonomously from the central government, plus the fact that most of Costa Rican society has backed up those policies, has been vital for adopting and implementing renewable energy and creating a permanent change in the country, a permanent change that will be achieved through the implementation of the National Decarbonization Plan. That combination is the most significant factor in the successful transition to renewable energy in Costa Rica. The country's remarkable achievement of a 98

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percent renewable energy share in electricity generation demonstrates Costa Rica's success in combining strategic planning and national commitment.

Moreover, Costa Rica can capitalize on its renewable energy policy and natural competitive advantage among other countries in the region to create a favorable environment that will attract direct foreign investment, facilitating the flow of financial resources that can be invested to train local human resources as well as to secure the well-development of current or future renewable energy projects. As a result, Costa Rica's economy might be dynamized by creating more job opportunities, which could increase household income and thus improve the well-being of all citizens in the country.

It is essential to maintain the strategic and coordinated collaboration between the stakeholders involved in this process to maintain the current level of success, such as the national government, the national private sector, the country's citizens, and international partners (such as international organizations that provide international aid or loans).

Currently, the country stands at a critical stage to further unlock its potential. The country should continue taking advantage of its natural competitive advantage in renewable sources and developing and implementing current and future renewable energy projects and practices to attain sustainability. If Costa Rica can do so, the country will continue leading the way in sustainable development in the Latin American and Caribbean region. The country should continue its current path in developing national policies that help cope with future challenges, overcome economic limitations, and, most importantly, achieve the already proposed goals.

The multiple accomplishments in transitioning to renewable energy can serve as an inspirational model for other nations that are about to embark or have already embarked on a greener and more sustainable future.

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Costa Rica still needs to overcome some challenges, yet without hesitation, it can be asserted that Costa Rica is on the right path to transition to renewable energy and, thus, securing a sustainable future.

6.1. Recommendations for Future Studies

The case of Costa Rica in renewable energy is a model to be followed. However, some recommendations can be made related to Costa Rica's green energy situation and for further studies.

It is strongly recommended that the Costa Rican government makes available collected data related to the implementation and transition to renewable energy. Making data publicly available is essential to smooth the evaluation process of transitioning to renewable energy and estimate its costs and financial benefits. At the same time, it will show the areas that require additional input to achieve the expected success in future projects. Likewise, transparency in the management of renewable energy projects could be assessed.

Also, Costa Rica must diversify its renewable energy matrix to reduce its vulnerability and dependence on hydropower. In this sense, geothermal renewable energy represents a good diversifying opportunity with a promising power generation capacity based on the natural resources of Costa Rica.

The government of Costa Rica should maintain and make available environmental impact studies to ensure natural resource conservation. The country owns 6 percent of the world's total biodiversity; therefore, the government should be cautious about the development and location of future renewable energy projects.

Costa Rica must continue developing technical partnerships with other countries implementing renewable energy. By doing so, an increase in efficiency, cost-effectiveness

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achievement, and improved energy distribution might be attained. Technological knowledge of renewable energy available in other countries should be a key focus for future renewable energy projects in Costa Rica to ensure the current benefits and energy diversification.

It is also recommended that the country solve its current limitations in energy storage infrastructure to effectively utilize the surplus of renewable energy produced during peak hours. Once storage challenges are solved, Costa Rica could confidently ensure a stable and resilient energy sector that will distribute energy to all its citizens. After domestic demand is fulfilled, any surplus of renewable energy in Costa Rica could be sold to other countries through the SIEPAC system to generate income.

For further studies, visiting the location of current renewable energy projects should be conducted to verify the state and situation of the projects. Interviewing the population that lives near the projects should be done to obtain the citizen's perspective on green projects and to evaluate whether the government considers the population's opinions.

Finally, Costa Rica's transition and implementation of renewable energy could be used by neighboring countries in the Central America region as a model to progress in the green energy sector. By having similar natural resources, the countries of Central America could leverage Costa Rica's knowledge and experience to pursue a path to green energy. Analyzing the similarities and differences between the countries of Central America and Costa Rica could become the framework for a green Central America region.

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Appendix

Climate Change Background

The United Kingdom Research and Innovation Agency, also known as UKRI, describes the most important scientific facts that drove political stakeholders around the world to get involved by developing and designing environmental initiatives and policies that will lead to both individual and joint actions to stop climate change and its devastated consequences for both Mother Earth and its inhabitants (UK Research and Innovation, n.d.). Climate Change is not something that happened overnight, but a succession of multiple events that started around eighty-three years ago and continue happening. Over the last century, the climate change crisis has steadily increased, becoming one of the most severe crises threatening all living species on Earth. Some documented events prove the alarming consequences of using fossil fuels.

Climate Change Milestone Events

Everything started in 1938 when an English steam engineer and inventor named Guy Callendar began collecting records from 147 weather stations across the world. After making multiple calculations by hand, he made an alarming discovery: global temperatures had risen 0.3 degrees Celsius over the previous 50 years. At that time, Doctor Callendar's insights confirmed that "Carbon dioxide-CO2 (one type of greenhouse gas) emissions that derived from industrial activity were responsible for global warming" (UK Research and Innovation, n.d.). However, his findings were ignored by other scientists who were completely skeptical to believe that human activities could be able to impact the environment and thus create climate change. Even though his research method was elementary, as time passed, it has been proven that his discoveries were exceptionally precise and aligned with current calculations.

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Then in 1985, a team of French and former Soviet scientists started extracting samples of Antarctic ice from the depths of the Antarctic Ocean. After analyzing them, they concluded that over time, there is a positive relationship between the increase in the level of atmospheric greenhouse gases and the increase in Antarctic temperature. At that moment, they also discovered that the current levels of carbon dioxide and methane in the atmosphere were the highest in the past 420,000 years. After analyzing a third Antarctic ice sample, scientists at the British Antarctic Survey found out that just before the beginning of the Industrial Revolution, the concentration of carbon dioxide was stable for a millennium, then it started rising. At that moment, the concentration was almost 50 percent higher than before the industrial revolution.

In 1985, Joe Farman, Brian Gardiner, and Jonathan Shanklin, three scientists from the British Antarctic Survey, discovered a hole in the ozone layer (a layer that "protects all life from the sun’s harmful ultraviolet radiation" (United States Environmental Protection Agency, 2021)) above Antarctica along with irregular low levels of ozone over the South Pole. They argued that a compound called chlorofluorocarbons (CFCs), used in aerosol cans and refrigerators, could cause such a detriment in ozone levels over the South Pole.

Ozone depletion and CFCs as the cornerstone led to the creation of a multilateral agreement and one of the past century's most successful global environmental policies, the Montreal Protocol (Maizland, 2022). The protocol regulates the production and consumption of about 100 human-caused chemicals known as ozone-depleting substances (ODS) and helps increase worldwide consciousness about climate change. It was adopted on 16 September 1987. The protocol was to be applied in different schedules for developed and developing countries. It has also set measurable commitments to be achieved. The treaty

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continues to be amended and adjusted according to new scientific, technical, and economic advances (UN Environment Programme, n.d.).

The United Nations Environment Programme (UNEP) and the World Meteorological Organization created the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC's principal mandate is to create a recommendation based on the science of climate change and the social and economic impacts of climate change (Intergovernmental Panel on Climate Change, n.d.).

Then, in 1992, US scientists Smith and Buddemeier (1992) discovered that due to CO_2 dissolution in the ocean, the ocean's water acidity level had increased, making it difficult for different ocean-living species (corals and animals) to build reefs. High acidity levels have interrupted a vital process of corals and all animals having shells and limited their absorption of calcium carbonate, which is vital for their skeletons' formation. Nevertheless, the catastrophe will not stop there. Ocean acidification is devastating for other sea animals, such as urchins, whose role in balancing and supplying nutrients to other sea organisms is in danger (Smith & Buddemeier, 1992).

The United Nations Framework Convention on Climate Change (UNFCCC) was the first treaty that advocated limiting greenhouse emissions to prevent climate change. It came into force in 1994 after being ratified by 197 countries. The previous shaped the pathway for the Kyoto Protocol, which advocates that industrialized countries must "limit and reduce greenhouse gas emissions following agreed individual targets" (UK Research and Innovation, n.d.).

In 2003, Europe faced an extreme heatwave beyond any previous record. According to the Met Office (2003), the National Meteorological Service for the United Kingdom, the heatwave caused the death of more than 20,000 people (from different causes such as heat

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stroke, dehydration, sunburn, air pollution, and drowning). The environment was also dying; the flow of rivers as well as the water levels of lakes, decreased to their lowest in the last 100 years. Low water levels created one of this century's worst water supply shortages. Multiple fires broke out in many European countries due to the destruction of more than 215,000 hectares of forest, which led to topsoil erosion and multiple continuous droughts. These drove a constant temperature increase, leading to the meltdown of snow and glaciers in the European Alps region. This horrible event led to the development of the scientific movement called Extreme Event Attribution, "researchers use an extreme weather event and use climate modeling to say whether the likelihood of the event happening would be the same in a world without climate change" (UK Research and Innovation, n.d.). This model has allowed scientists to confirm that there is a dangerous changing pattern in the weather that would not be happening with such intensity if climate change were not a real problem that is getting worse and worse over time.

By 2007, just four years after the previous weather event, the scientific community confirmed that the Artic and Antarctic regions were getting twofold warmer than the rest of Earth, causing accelerating melt of The Greenland ice sheet, some portions of the Artic ice sheet and the Artic Sea ice. Climate change was not only having an adverse effect on the weather, but it also started affecting entire ecosystems and their distinct species. Furthermore, for the first time, the scientific community warned the world about methane emissions (another greenhouse gas), which according to the UK Research and Innovation (n.d.), has "a warming effect approximately 20 times stronger than CO2. As seawater temperatures increase in the polar regions, methane bubbles could rise to the surface, causing even more warming in the atmosphere."

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The United Kingdom Climate Change Act was the first long-term-legally binding framework for tackling climate change. Approved and adopted in 2008, based on the previous scientific findings, it required governments " to set legally-binding 'Carbon Budgets'" (Climate Change Committee, n.d.). The United Kingdom committed itself to reducing greenhouse emissions by 80 percent by 2050 compared to 1990 levels (GOV.UK, 2019).

On 12 December 2015, during the United Nations Climate Change Conference (COP21), 196 countries adopted The Paris Agreement: a legally binding international treaty on climate change whose two main objectives are: "hold the increase in the global average temperature to well below 2°C above pre-industrial levels, and to limit the temperature increase to 1.5°C above pre-industrial levels". The Paris Agreement is a landmark in multilateral cooperation to tackle climate change. It entered into force on 4 November 2016 (United Nations Climate Change, n.d.).

Alternatives to Climate Change

In response to the environmental deterioration demonstrated during the history by the research mentioned above, worldwide institutions were founded, aiming not only to study the problem as well as its viable solutions but, most importantly, to develop different mechanisms that can lead to a sustainable and effective change such as economic instruments and green energy.

These economic instruments include carbon taxes, emissions trading systems, emission reduction credits purchases, energy efficiency subsidies, renewables, research and development, and fossil fuel subsidies (Dubash et al., 2022; United Nations Climate Change, n.d.). Over the past years, carbon taxes and pricing are words thrown a lot when climate change is discussed. However, that is not a flux or a simple fad. Dubash et al. (2022) state

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that over the past few years, these kinds of instruments and emissions trading systems have shown positive acceptance and efficacy in achieving low-cost emissions reduction.

A carbon tax is a surcharge on carbon dioxide or other greenhouse gases on specified emitters or products and is most commonly charged on fossil fuel usage, renewables, research and development, and fossil fuel subsidies (Dubash et al., 2022; United Nations Climate Change, n.d.). Carbon taxes are taxes or tax rates governments apply to each emission unit, usually considered as tons of CO_2. Carbon taxes do not guarantee a specific reduction level but set a price on carbon emissions, typically from fossil fuels, affecting a country's economy renewables, research and development, and fossil fuel subsidies (Dubash et al., 2022; The World Bank, n.d.; United Nations Climate Change, n.d.).

Haites (2018) explains that carbon taxes and tax rates must be readjusted frequently to maintain efficiency and account for economic factors such as inflation, increases in real income, technological change, and changes in fossil fuel prices. For example, if tax rates are heavily set on CO_2 emissions without considering changes in the price of fossil fuel, carbon taxes exacerbate the emissions problem. An increase in the price of natural gas (which emits less CO_2 than coal) might offset the cost differential of coal, including a carbon tax. Per Haites (2018), the tax rate can be adjusted in several ways. One way is for the tax rate to be equivalent to the approximate benefit of reducing greenhouse gases by a ton of CO_2. Another way is to set the tax rate based on economic modeling that produces a targeted emission reduction. Lastly, it is to set tax rates to achieve a desired level of revenue.

The World Bank (2022) reports that 68 carbon pricing instruments globally, including carbon taxes and emissions trading systems, are currently under operation. These have reached record highs in prices in the European Union, New Zealand, and South Korea for emission trading systems and as well record highs in other areas for carbon taxes. As a result,

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carbon tax revenue increased by 60% in 2021 to US$84 Billion. However, the World Bank (2022) warns that prices must increase more to meet the goals of the Paris Agreement. Currently, only 4% of emissions are covered under the carbon pricing scheme needed to achieve the goals for 2030 (The World Bank, 2022). Moreover, the World Bank (2022) acknowledges that carbon pricing instruments alone are not enough to curb emissions but need complementary tools that target broader issues of climate change and market failures to be more successful such as research and development, technology, infrastructure, removal of regulations, market incentives, sector-specific regulations, among others.

Another consideration is the social acceptance of carbon taxes and the political motivation to implement or avoid such measures. Politicians play an essential role in policy implementation, and pro-industry politicians are less likely to increase costs or levy taxes to satisfy their bases. Rhodes, Axsen, and Jaccard (2017) find solid social opposition to carbon taxes; however, voluntary measures and supply-focused regulations are favored. Opposition to carbon taxes is predominant in rural areas as well as from those who rely on personal vehicles for traveling to and from work. Rabe (2018) found that early adopters of carbon pricing policies might develop energy innovation technology and boost domestic energy sources.

Moreover, Rabe (2018) found that at various levels, states, regions, cities, municipalities, and districts in the United States and Canada have developed their own initiatives for carbon pricing, which might lead people to think that a systematic national approach is on the horizon. However, a systemic application has yet to be created after a decade of implementation. In the same period, the European Union rallied national support in 28 nations for applying cap and trade policies. In the United States, presidential support

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for carbon taxes has been used to collect revenue to fight deficits rather than actual concern for the environment.

As with any policy, support for its effectiveness must be gathered across the social spectrum. Society must come together to create actual change that might slow human-created climate change. Carbon taxes levied for other purposes rather than environmental will have minimal environmental effects.

The International Energy Agency (2023) reports that fossil fuels are on a rapid rise and reached over 1 trillion US$ for the first time in 2022. The IEA is calling for phasing out subsidies as they tend to manipulate markets and hinder the adoption of energy from renewable sources. Moreover, fossil fuel subsidies might increase emissions and reduce the effectiveness of mitigation efforts.

The second mechanism to tackle climate change is renewable energy. Renewables can be traced back to the discovery of fire by early humans. It took a while for humans to learn how to farm, control and wield the forces of nature. Even today, there is so much we do not know and cannot predict. We are leagues ahead of the early human that found a burning tree that had been struck by lightning or the early human that, through friction, sparked the first flame. History shows us that learning to wield and harness the forces of nature has brought great benefits and leaps in the evolution of human life. Green energy poses no threat or harms nature. We are currently facing the problem of how we will stop climate change, what technology we will use, whether these technologies are enough, and the future of these technologies. What is rarely considered is that green energy is nothing new and significant advancements have already been made. One of the earliest examples in written history is the story of Archimedes' concave glass (Constantinople's Proclus had a similar one) (Delyannis & El-Nashar, 2010). With the use of glass, Archimedes is purported to have focused the sun's

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energy into a set of pieces of glass that were placed in a concave shape and with-it focused sun rays, which produced extreme heat and set an enemy fleet on fire (Delyannis & El-Nashar, 2010). The analogy of the kid with the magnifying glass and the ants comes to mind. However, war is not the best way of harnessing nature's power for humanity's benefit.

Renewable Types

The basis for today's technology can be traced to hundreds if not thousands of years ago. For example, waterwheels can be traced in Europe around 200 BC, and while it might be a basic rustic tool for moving water from one place to another or a water-powered wheat mill, it served as the basis of the technology we used today (Project Solar, 2018). With this principle, the first hydroelectric plant with commercial and private customers was set up in Appleton, Wisconsin, in 1882 (Nester, 2015; Project Solar, 2018; The International Hydropower Association, n.d.; Ziegler, 2022). Hydroelectric power plants are widely used today, and in the case of Costa Rica, it is the primary energy source.

At the same time, Europe also recalls the Netherlands and its famed windmills, which were these giant monsters in the mind of Don Quixote (published in 1605). Windmills can be traced to the 1590s in Europe and, in a horizontal setup, in the Middle East and Central Asia around 635 A.D. (Nester, 2015; Project Solar, 2018). By the late 1800s and early 1900s, these same windmills coupled with wind turbines were used to generate electricity in the United States and Denmark (Nester, 2015; Project Solar, 2018; Ziegler, 2022). Today, the largest wind farm is in Gansu, China. While it is still under construction, by 2021, it had reached a capacity of 10GW, and when completed, it would reach 20GW from 7,000 wind turbines (Hansen, 2023).

The basis for modern solar panels was discovered in 1876 by William G. Adams when he demonstrated that illuminating a node of selenium and platinum had a photovoltaic effect

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and created electricity without any moving parts (Nester, 2015; Project Solar, 2018). The improvement of this technology caused in 1981-1982, the first large-scale solar plant, Solar One, was built in California in which 1,881 mirrors concentrated the sun's rays to create electricity via steam turbines (Nester, 2015; Project Solar, 2018; Ziegler, 2022). Although, for a long time, the role of solar power was marginal as the technology to harness the sun efficiently was not optimal, today, the use of solar power has been used increasingly, growing from globally installed 40GW photovoltaic capacity in 2010 to 580 GW in 2019 (Enel Green Power, n.d.). Moreover, the cost of producing electricity from solar plants has fallen by 82% in the last ten years (Enel Green Power, n.d.), giving higher yields per dollar invested.

Before the industrial revolution and the discovery of fossil fuels and coal, the world's energy came from wood, more precisely, burning wood for cooking, and heating, among others. That use of wood uses biomass energy. Biomass energy refers to the use of crops, organic waste, and other forms of biological materials that can be used to substitute fossil fuels (National Geographic, n.d.; Seidel, 2021). In recent history, biofuel such as ethanol has been used to power cars as early as the 1800s, and since then, it has been used as a substitute for fossil fuels to power cars in times of scarcity. In recent decades, Brazil and the United States have been the largest producers of ethanol derived from sugarcane and corn, respectively (Lehman & Eckley Selin, 2023; National Geographic, n.d.; Seidel, 2021). The second most widely used biofuel is biodiesel which is produced from soybean and oil palm (Lehman & Eckley Selin, 2023). The economic and environmental impact of biofuels is relative to their production process. While it is considered that biofuels are carbon neutral, corn grown for ethanol is harvested with diesel-powered machinery, so sugarcane ethanol or algae diesel might represent a more considerable gain in energy production (Lehman & Eckley Selin, 2023).

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Last, one of the least invested renewable sources is geothermal energy (IRENA & CPI, 2023). Geothermal energy has been used for about 10,000 years, with the first example of usage for cooking by early Native Americans (Conserve Energy Future, n.d.; Lund, n.d.). Moreover, different civilizations have documented the use of hot springs through the ages. The first modern example of harnessing the Earth's heat power to create energy or for industrial purposes can be found in Larderello, Italy, where it was used to extract borate compounds from hot springs (Conserve Energy Future, n.d.; Lund, n.d.). This industry led to the first geothermal energy plant for commercial purposes, with a capacity of 250GW, being founded in 1913 (Conserve Energy Future, n.d.; Lund, n.d.). By the 1960s, geothermal plants were commissioned in the United States and New Zealand. Compared to the Italian and American plants, New Zealand's geothermal plants use the process of wet steam (Lund, n.d.). This process consists of using superheated water and steam from geysers. Steam is used directly for power generation, while the superheated water is separated and flashed into steam to increase generation (Lund, n.d.). Today, wet steam plants are the world's predominant geothermal energy plants (Lund, n.d.). In addition to energy generation, geothermal energy is also used for heating houses and buildings through geothermal heat pumps, and it is also used directly for spas, swimming, and cooking, among others (Lund, n.d.).

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