

Thesis title

Analysis of the Energy Transition through Electrification Scenarios in the Ecuadorian
Shrimp Farming Sector

Subtitle

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Abstract

The shrimp sector in Ecuador is the second most important in the country and has begun a process of energy transition through the electrification of its operations, moving from the use of diesel for pumping water and aerating the farming ponds, towards the connection to the electrical grid. This energy transition leads to investments in infrastructure and generates an impact on different variables of the sector, such as its productivity, exports, greenhouse gas emissions, social impacts, among others. This study develops a methodology to analyze the energy transition of the sector through electrification scenarios.

In Chapter 1, an introduction to the study to be carried out and the motivation are presented. Chapter 2 shows a review of the literature on the energy transition and the energy situation of the country and the shrimp farming sector. Chapter 3 establishes the scenario analysis framework, as well as proposes the use of the Energy Transition Index as inspiration to analyze the energy transition of the shrimp farming sector. Chapter 4 indicates the methodology to carry out the specific analysis and evaluation. Chapter 5 develops the nine established dimensions of the energy transition applied to the sector. Chapter 6 highlights the critical findings, and finally, in Chapter 7 the conclusions, recommendations and limitations of the study are provided.

Keywords: Energy transition; electrification; shrimp farming; Ecuador; scenario analysis; energy matrix; CO₂ emissions; environment; industrial sector analysis

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List of Abbreviations

CAF	Development Bank of Latin America
CO ₂	Carbon dioxide
ETI	Energy Transition Index
Ha.	Hectare
IDB	Inter-American Development Bank
kTons	Thousand metric tons
kW	Kilowatt
kWh	Kilowatt-hour
lb	Pounds
MW	Megawatt
SDGs	Sustainable Development Goals
USD	United States Dollar

1. Introduction

Energy transition refers to a significant long-term structural change in an energy system. The energy transition that is being experienced today arises from the need to mitigate climate change and global warming with the objective to maintain the planet's temperature within a maximum increase of 1.5°C with respect to pre-industrial levels under the Paris Agreement. To achieve this goal, it is necessary to reduce greenhouse gas emissions towards global carbon neutrality by 2050 implementing different actions, among which the shift from fossil fuels to renewable energies stands out. (IRENA, 2022).

Ecuador is a signatory country of the Paris agreement and is currently implementing policies to achieve carbon neutrality. Its energy production has a high penetration of renewables, with a 77.3% share of hydroelectric power in 2020 (Ministry of Energy and Non-Renewable Natural Resources, 2021). But when analyzing in more detail the complete energy situation of the country, the information of its energy matrix does not consider self-generation systems isolated from the electrical grid. An outstanding example of this situation is found in the shrimp farming sector, that uses diesel engines to pump water and aerate shrimp ponds to oxygenate the production processes instead of using electric motors due to the lack of electrical interconnection, which generates high environmental pollution.

The shrimp farming sector is the second most important in Ecuador, after the oil industry. Ecuador became in recent years the world's largest producer of shrimp, with a national production one million metric tons in 2021, which represents a participation in value of 21.8% of the total world production of 4.56 million metric tons in the same year (SeaFoodSource, 2022). Of this production, Ecuador exports 848,000 metric tons, representing a total value of 5,323.3 million US dollars, 19.9% of the country's total exports (Central Bank of Ecuador, 2022). The shrimp industry generates direct employment for 260,000 people (Calderón, 2020).

To support the development and competitiveness of the shrimp farming sector, Ecuador subsidizes diesel with a fix price of USD 1.57 per gallon on July 2022 (Lasso, 2022), while the real cost of diesel in the country was USD 3.15 per gallon during the same period (El Comercio, 2022). This subsidy represents an impact on

the finances of the Ecuadorian economy, which may be unsustainable in the medium and long term.

In Ecuador there are approximately 215,300 hectares of shrimp farms, and it is estimated that less of 2% of the shrimp farms are electrified through their interconnection to the national grid (Ministry of Energy and Non-Renewable Natural Resources, 2022a), while the others shrimp farms use diesel. For electrification to be of interest to shrimp farms, the Ecuadorian government has determined a special electricity tariff exclusively for the industry, but that is still not enough incentive to motivate a fast transition due to the high investment in capital costs and the lack of commitment of the government in the construction of electrical infrastructure, considering that the shrimp farms are located far from the electrical grid, or the nearest interconnection point do not have the capacity to supply all the power needed.

The Ecuadorian government has launched a plan for the energy transition of the shrimp farming sector, which consists of an investment in electrical infrastructure of USD 306 million through loans from the Inter-American Development Bank (IDB), the Development Bank of Latin America (CAF), and a counterpart from the own country to expand the electricity distribution network and reach 56,411 hectares of shrimp farms in the next years, although the electrification of the other remaining hectares will still be pending.

It is estimated that for each hectare of shrimp farming, 870 gallons of diesel are used per year, which generates emissions into the atmosphere of approximately 8.77 tons of CO₂ per hectare per year (Ministry of Energy and Non-Renewable Natural Resources, 2021b), and also this industrial process generates other hazardous waste such as the use of lubricants and filters, as well as high-intensity noise.

The Ecuadorian government seeks with the energy transition of the shrimp farming through electrification a solution that provides sustainability, increasing the competitiveness and production efficiency of the sector, generating economic benefits, positive social impacts, and a reduction in the country's CO₂ emissions.

For these reasons, it is decided to carry out this study that examines the energy transition of the shrimp sector through electrification, with an analysis of scenarios, since there are currently no complete studies that include a wide vision of the total

energy transition of the sector, and this can support the Ecuadorian government and stakeholders of the sector to define new and realistic policies that favor the industry. This study can also be used from an academic point of view to be applied to other industries in different countries that generate an impact in reducing emissions and dependence on fossil fuels.

To structure this study, first the current information available on the energy transition and the shrimp farming sector in Ecuador is outlined. Secondly, a conceptual model and methodology is defined for specific electrification scenarios. Thirdly, the scenarios are calculated and examined within the defined framework, resulting in a broad perspective of vision of the energy transition of the sector through the electrification. Fourthly, an analysis and discussion of the results is presented. Finally, a conclusion of the research is obtained.

2. Literature Review

The literature review will focus on giving us a compilation of sources referring to the different perspectives of energy transition, the evolution of Ecuador's energy matrix in recent years, the current situation of the shrimp sector in the country, along with its emissions and its electrification plan established by the government, to finally conclude the uncover gap on which this study will be based.

2.1. Energy Transition

Energy transition has had different meanings throughout history, and this study highlights the definition made by the European Commission which can represent a general summary of the whole concept: "*Energy transition is a long-term structural change in an energy system aimed to develop a secure, affordable and climate-friendly energy system better able to manage and balance dynamic patterns of energy supply and demand*" (European Commission, 2019).

The World Energy Transitions Outlook 2022 (IRENA, 2022) presents a pathway to limit the rise in global temperatures by 2050 to 1.5°C above pre-industrial levels, by the agreement to pursue efforts to achieve that goal made by the signatories to the United Nations Convention on Climate Change in Paris in 2015. The proposed pathway positions electrification and energy efficiency as key drivers to the energy transition, leading all end users towards decarbonization, and requires an

enormous change in how societies produce and consume energy. The pathway results in a reduction of 36.9 gigatons of annual CO₂ emissions by 2050, and can be achieved through six technological avenues, as shown in Figure 1, and described below:

- Significant increases in generation and direct uses of renewables-based electricity.
- Substantial improvements in energy efficiency.
- The electrification of end-use sectors (e.g. electric vehicles and heat pumps).
- Clean hydrogen and its derivatives.
- Bioenergy coupled with carbon capture and storage.
- Last-mile use of carbon capture and storage.

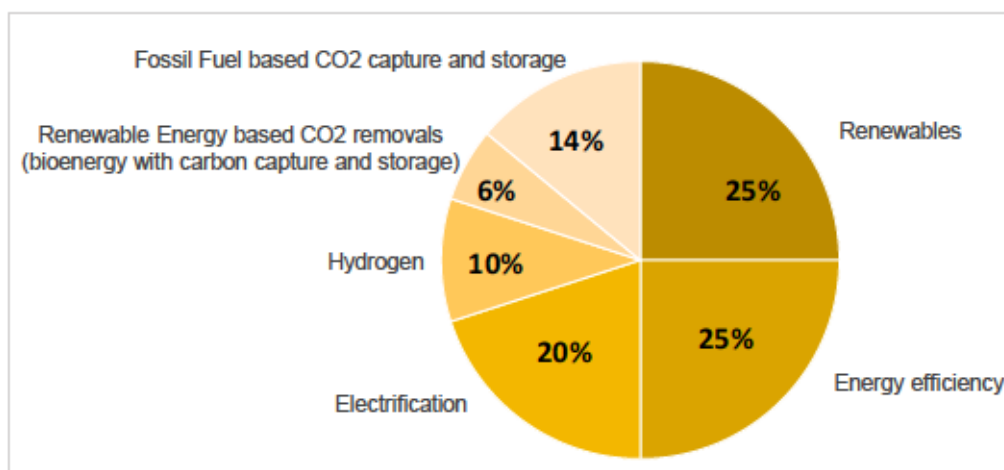


Figure 1. Reducing emissions by 2050 through six technological avenues

Source: World Energy Transitions Outlook 2022 (IRENA, 2022)

Some key conclusions of the World Energy Transitions Outlook 2022 (IRENA, 2022) are that end-use decarbonization needs to be given greater priority to reduce reliance on fossil fuels in industry, transport, and domestic heating; renewables-based electricity is now the cheapest power option in most regions; and, despite some progress, the energy transition is far from being on track and radical actions are needed to change its current trajectory.

A complete and updated compilation of the most relevant explanations and studies on energy transition was carried out in a research article by Smart Edward (2022), of which the following features of the energy transition are highlighted to take them into account in the study.

Main conceptual views on energy transition

- "Energy transition refers to a long-term structural change in energy systems".
- "Energy transition is a transition towards a low-carbon economy or greener energy system".

Characteristics of energy transitions

- "Energy transitions are rarely complete, meaning that they are complex processes that usually occur over a long period".
- "Energy transitions are paradoxical, meaning that the energy systems are made up of durable infrastructure networks with high investment costs in technologies and resources, they nonetheless change over time".
- "Energy transition and social-political changes are inherently interwoven".
- "Energy transitions are related to socio-environmental movements".
- "Energy transitions are parts of the political ecology systems".

Contexts in which energy transition should be analyzed

- "Economical context: Affordability of energy, with welfare and freedom".
- "Geopolitical context: Availability of energy, with political interdependence, territorial integrity, and respect for nature".
- "Social context: Acceptability of energy, with respect for nature".
- "Environmental context: Sustainability of energy, with equity and justice".
- "Philosophical context: Human-nature unity, with collective well-being".

Perspectives of sociotechnical landscapes of energy transition

- "Interim energy transition: When there are governmental green energy policies but without public support and acceptance".
- "Deliberated energy transition: When energy end-users impulse sustainable development transition without governmental policies".

- "Transformative energy transition: This is a hybrid of the first and second views, where sustainable energy is driven by government policy and public actions".

Main drivers of energy transition

- "Costs and benefits of using energy resources, for example, are motivated by attenuating import energy dependency, or by the need to expand the energy infrastructure".
- "Risk of climate and environmental degradation".

These features describe the holistic meaning of the energy transition, which will be considered when analyzing the energy sector environment of the country and how the Ecuadorian government has raised its energy policy toward the shrimp farming sector.

2.2. Ecuador energy matrix evolution

Ecuador's energy matrix has had an important evolution in recent years, increasing its demand from 20,382 GWh in 2010 to 31,449 GWh in 2020, representing a growth of 54.5% as indicated in the National Energy Balance (Ministry of Energy and Non-Renewable Natural Resources, 2021). The energy supply had a contribution of 77.3% from hydroelectricity, 20.1% from thermal energy, and 1.8% from other sources (wind, biomass, solar, and interconnection), as is shown in Figure 2. It should be noted that the country's maximum demand in August 2021 was 3,960 MW, according to the Agency for the Regulation and Control of Energy and Non-Renewable Natural Resources (2021).

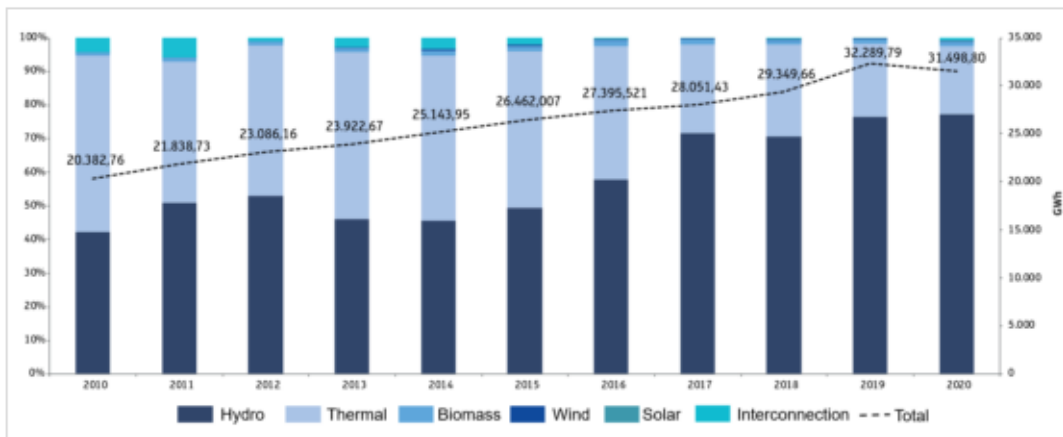


Figure 2. Energy matrix evolution of different sources of energy

Source: Ministry of Energy and Non-Renewable Natural Resources (2021a)

Ecuador has a policy of moving from a state dependent on fossil fuels toward renewable energy, implementing energy policies for the development of hydroelectric energy together with solar, wind, and biomass. The main problem of Ecuador's energy transition is its political instability and its inability to implement its plans through the existing legal framework (Morales & Morales, 2020). This vision seems to be changing, because in 2021 the Ecuadorian government launched an aggressive investment plan in the energy sector through tenders and private contracts for 25 years to increase non-conventional renewable energy by 500 MW and in parallel a thermal combined cycle working with natural gas including the importation of liquefied natural gas with a total power of 400 MW, to increase power in times on dry seasons and, which will support the increase in energy of intermittent sources and will support the rising energy demand for the next years.

The National Energy Balance (Ministry of Energy and Non-Renewable Natural Resources, 2021) also refers to the country's total greenhouse gas emissions, indicating that during the period from 2010 to 2020 there was a reduction from 35,152 kton CO₂ to a value of 34,076 kton CO₂.

2.2.1. Ecuador as a signature of the Paris Agreement

Ecuador was one of the countries that established the Paris agreement at COP21 in December 2015 intending to limit global warming to well below 2°C, preferably 1.5°C compared to pre-industrial levels. With the signing of this agreement, Ecuador commits to reduce its greenhouse gas emissions to achieve a carbon-

neutral planet by the year 2050, and for this, it must establish climate action measures in the short, medium, and long term, and update them every five years. years in documents called Nationally Determined Contributions (NDC).

The National Determined Contributions of Ecuador include an unconditional goal of reducing its greenhouse gas emissions by 9% for the energy, industrial processes, agriculture, and waste sectors by 2025, and conditionally to receive financial international support, this goal can be increased by 20.9%. Ecuador's goals also include the reduction of associated flaring gas and power generation with liquefied natural gas to replace the use of diesel (Republic of Ecuador, 2019).

Ecuador also ratified its commitment to the Sustainable Development Goals (SDGs) with the United Nations and declared the 2030 Agenda as a Public Policy of the National Government (United Nations, 2022). Within the 17 sustainable development goals, the agreements that stand out are:

- SDG 7: Affordable and non-polluting energy, which guarantees access to safe, sustainable, and modern energy for all, which has variables such as access to electricity in the population, CO₂ emissions per total electricity produced, and participation of renewable energies in the energy matrix.
- SDG 13: Climate action, which seeks to adopt urgent measures to combat climate change and its effects, which includes variables such as CO₂ emissions from the combustion of fossil fuels.

2.2.2. Energy transition in Ecuador

According to IRENA et al. (2022), Ecuador has several instruments to promote energy development, energy transition, and climate action. With the creation of the Ministry of Energy and Non-Renewable Natural Resources, the National Energy Plan 2050 project began, which seeks the development of energy, economics, social and environmental through scenarios, as shown in Figure 3. The National Energy Plan 2050 will establish cost and medium-term plans for the energy sector aimed at meeting the United Nations sustainable development goals (SDGs).

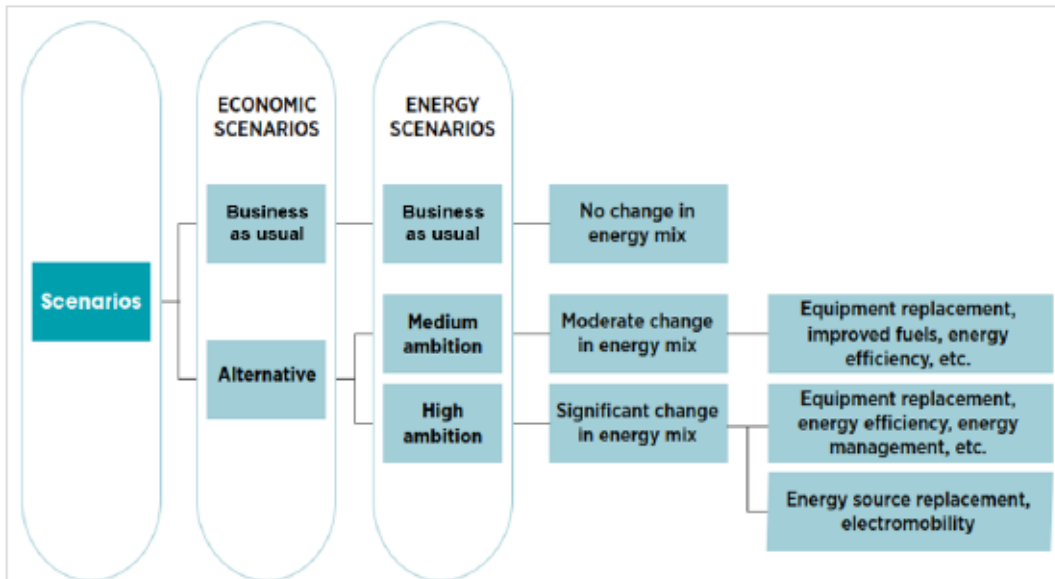


Figure 3. Proposed scenarios for Ecuador's National Energy Plan 2050

Source: IRENA et al. (2022)

As additional information, Golla & Gerke (2018) presented the first complete and sustainable energy transition study for Ecuador in 2018, revealing that the country's renewable energy potential is 103 GW and that with only 60 GW of non-conventional renewable energy installation, it would be possible to reach a 100% renewable energy matrix without relying on fossil fuels, along with the use of Power-to-X technology as a backup. This transition could be carried out in a period of 10 to 15 years, creating 100,000 qualified jobs and achieving carbon neutrality. The study concluded that the proposal of a 100% renewable matrix is economically possible.

2.3. Current situation of shrimp farming in Ecuador

The shrimp sector is the second most important industry in Ecuador after the oil sector, with a total value of 5,323 million USD in 2021 representing 19.9% of the country's exports (Central Bank of Ecuador, 2022). Ecuador's shrimp industry is the largest in the world shrimp market, reaching a production of one million metric tons in 2021, representing 22% of the global production of 4.56 million metric tons (SeaFoodSource, 2022). Of the total production amount of shrimp of Ecuador, 84% is for export and the remaining 16% is for domestic consumption. Shrimp production has shown an annual growth of 16% since 2015, as shown in Figure 4.

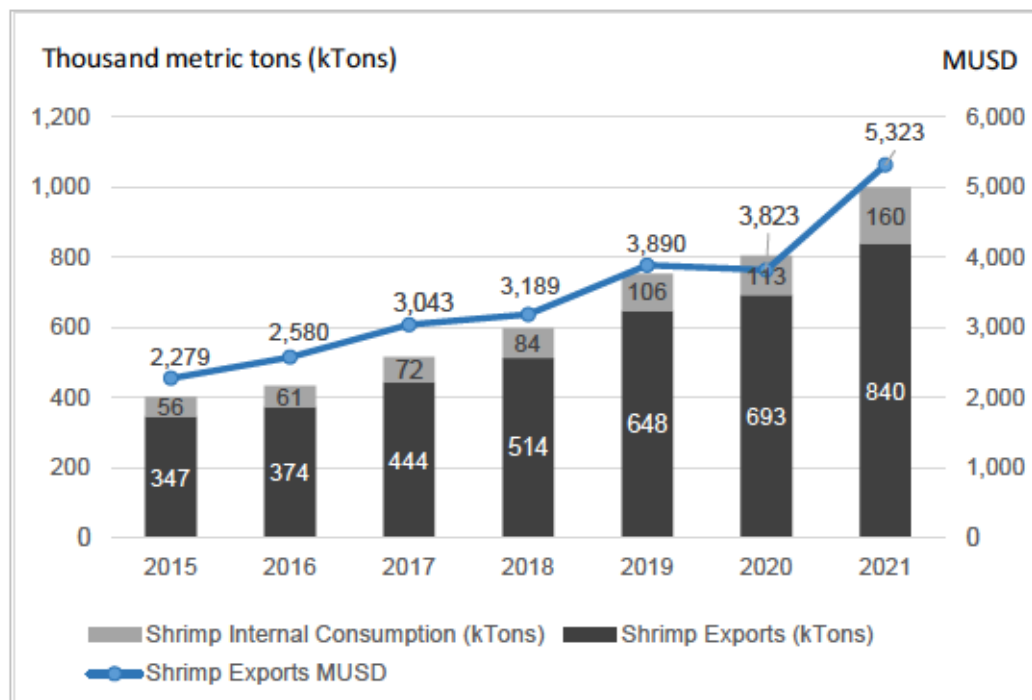


Figure 4. Shrimp production and exports 2015 - 2021

Adapted from: OikoData (2022) and Central Bank of Ecuador (2022)

In 2021, Ecuador had approximately 215,300 hectares for shrimp farming (National Electricity Corporation CNEL, 2022), with which can be calculated the average annual production per hectare during that year.

- Average Shrimp annual production 2021: 10,240 lb/Ha/year
- Average Shrimp annual production 2021: 4,645 kg/Ha/year

It is estimated that by 2020 the shrimp sector provides direct employment to 260,000 people in the country (Calderón, 2020) of a total of 2,634,000 people employed in the agriculture, livestock, hunting, forestry and fishing sectors (Cámara de Industrias y Producción, 2022).

The shrimp sale prices achieved a value of 6,500 USD/Ton in Ecuador, while in the international market the price was 32,980 USD/Ton in March 2022, almost 5 times higher, due to the increase of the transportation tariff, oil prices, and a higher demand of shrimp in the world (Oikodata, 2022).

2.3.1. Shrimp farming production process

Shrimp production begins with the preparation of the land and carrying out civil works for the construction of ponds and stabilization of walls. The shrimp larva receives a maturation treatment through a process of raceways or nurseries, which consists of adaptation in smaller ponds with control of parameters such as PH, salinity, temperature, oxygen, bacteria, etc. Subsequently, the post-larvae are cultured for rearing and fattening in the ponds, for 90 and 120 days, depending on the desired size of shrimp. The cultivation of the post-larvae requires a change of water through pumps and the use of aeration systems, depending on the production density of the shrimp farming system, which guarantees adequate levels of oxygen for the survival of the shrimp. Finally, the harvest is done manually or with harvesters, which must collect the shrimp without causing damage either by handling or stress (Pesantez et al., 2021). There are three types of shrimp farming systems that are implemented in Ecuador (FAO, 2022):

a) Extensive shrimp farming (low density)

This farming system uses natural ponds or built ponds with sizes greater than 20 hectares, with a low technological level and low-density production, using the natural productivity that allows savings in the consumption of balanced feed.

- Average densities: 10,000 to 15,000 shrimp larvae / hectare
- Average production: 600 lb/Ha/year

b) Semi-intensive shrimp farming (medium density)

Rustic ponds with dimensions from 2 to 20 hectares with a medium level of technology.

- Average densities: 15,000 - 120,000 shrimp larvae / hectare
- Average production: 1,000 – 5,000 lb/Ha/year

c) Intensive shrimp farming (high density)

Ponds with a size of 1 to 3 hectare, with or without plastic lining, with aeration systems. The technological level ranges from medium to high.

- Average densities: more than 120,000 shrimp larvae / hectare
- Average production: greater than 5,000 lb/Ha/year

Considering that the average production of the Ecuadorian shrimp industry is around 10,240 pounds per hectare per year, as calculated in chapter 2.3, this implies that there is a high impact of intensive shrimp farming in recent years.

The location of the shrimp farms is shown on the map in Figure 5, where it can be seen that they are mainly located in coastal areas with access to water.



Figure 5. Shrimp Farms Map

Source: Ministry of Energy and Non-Renewable Natural Resources (2022c)

2.3.2. Use of energy in shrimp farming

According to Pesantez et al. (2021), shrimp farming is an activity focused on obtaining the greatest amount of production using the least amount of resources, which leads to a high level of technification of the process to measure various parameters, within which the level of dissolved oxygen in water is the most important. Oxygen can be supplied by direct diffusion through the aeration process, or by photosynthesis using phytoplankton and algae that naturally generate

oxygen. The use of energy in a shrimp farm depends on its size and the type of system used: extensive, semi-intensive and, intensive. In intensive systems, small ponds are used and a high density of shrimp is stocked, so it is essential to use aeration equipment to maintain the oxygen level, and on the other hand in the extensive systems, pumping becomes more relevant since much more water needs to be pumped to fill the ponds, which implies a higher energy consumption.

The replacement of diesel engines with electric motors in the aeration and pumping systems has several advantages:

- Reduction of polluting emissions.
- Reduction of risks of spills of polluting liquids.
- The transport and logistics of diesel are avoided
- Does not require much maintenance.
- It can be remotely operated.
- Lower operating expenses.
- More efficiency in the use of energy.

Estimating an average electricity consumption of a shrimp farm in Ecuador is a difficult task because there are no official statistics on this subject, also considering the great diversity of farming systems in the country. An updated good approximation technical study was conducted by Pesantez et al. (2021), indicating that the average energy consumption of a shrimp farm using an extensive system is 50 kWh/day/Ha, while in an intensive system the consumption is 249 kWh/day/Ha. If we consider that average sowing is 90 days and they are carried out 3.5 times a year, we have an average period of farm operation of 315 days/year, which would give us an annual energy consumption:

- Energy consumption – Extensive System: 15,750 kWh/Ha/year
- Energy consumption – Intensive System: 78,435 kWh/Ha/year

According to the energy study made by Pesantez et al. (2021), in Figure 6 is shown the energy demand per hectare per day in a shrimp farm utilizing an intensive and extensive system.

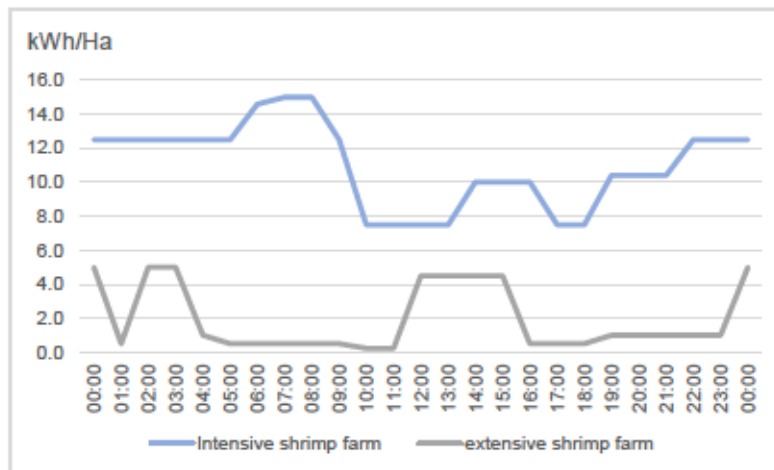


Figure 6. Daily power demand curve of extensive and intensives shrimp farms

Source: based on Pesantez et al. (2021)

To calculate a national average of energy consumption per hectare that encompasses all farming systems, the database of all the shrimp farms connected to the network during 2021 is going to be taken, which can be found in the “Shrimp Farming GeoPortal Web” of the Ministry of Energy and Non-Renewable Natural Resources (2022a), since they represent a random sample of the country and is the only available data at the moment. The details of this information are shown in Annex 1. The calculation of the average energy consumption result can be used for other projections later on:

- Total power of shrimp farms connected to the grid: 23,297 kW
- Energy consumption of shrimp farms connected to the grid: 77,205,884 kWh/year
- National average power demand per hectare: 6.67 kW/Ha (calculated in chapter 2.5.1)
- Total hectares connected to the grid: 3,492 Ha
- Estimated energy consumption of a shrimp farm: 22,109 kWh/Ha/year

To promote the development of the shrimp sector, the government implemented for several years a subsidy on the price of diesel exclusively for shrimp farming, which has been increasing over time, reaching a value of 1.57 USD per gallon by July 2022, while the average price for diesel in South America on the same date is 3.87 USD per gallon (El Universo, 2022). In 2017, with the launch of the electrification plan for the shrimp sector, to encourage the energy transition and

after a technical study, the government calculated an electricity tariff of 65 USD per kWh (Ministry of Energy and Non-Renewable Natural Resources, 2019b). This electricity tariff remains in force until July 2022, while the average national electricity rate is 92 USD per kWh during the same period (Ministry of Energy and Non-Renewable Natural Resources, 2022b).

To determine that electricity tariff for the shrimp farming industry, the Ministry of Energy and Non-Renewable Natural Resources together with the consulting company Delta carried out a study in 2017 in the first electrified shrimp farm in the country, Aquamar. The Aquamar shrimp farm is located in the Naranjal canton, province of Guayas, and the project consisted of the replacement of the consumption of diesel with electricity with an investment of approximately 4,830,000 USD, mainly in electrical infrastructure. In this study, it was determined that the subsidized price of the diesel in 2017, which was 0.87 USD per gallon (almost half of the 2022 subsidized diesel price), is at the break-even point to make the investment viable with an electricity tariff of 65 USD per kWh. Since it was expected that the diesel subsidy would be eliminated little by little in the following years, this electricity tariff would encourage the acceleration of the energy transition, together with an investment program in electrical networks carried out by the government with the support of financing from international organizations.

The Aquamar electrification project, constructed by the company GSP Group (2017), consisted of the electrification of 80% of its shrimp production ponds, covering approximately 470 hectares. Some pictures of the project are shown in Figure 7. The project obtained the following results:

- Increased shrimp production by 76% from 3,400 pounds of shrimp per hectare to 6,000 pounds per hectare.
- Elimination of the consumption of 870,000 gallons of diesel per year.
- The emission of 8,800 tons of CO₂ per year into the atmosphere was avoided.
- 50% decrease in the intensity of noise produced by diesel engines.
- Avoids the generation of hazardous waste: 8,000 liters of used lubricant, and 570 kg of used filters.
- Efficient pumping made it possible to save 40% of energy.
- Reduced cultivation time by 20%.

The investment ratios obtained from this first case of a shrimp farm electrification project implemented in Ecuador were the following:

- Electrical infrastructure: from 1,000 USD to 6,000 USD per hectare.
- Electric aeration systems: Up to 3,500 USD per hectare.
- Electric pumping: From 540 to 1,600 USD per hectare.
- Electrified automatic feeding system: Up to 3,500 USD per hectare.



Figure 7. First electrified pumps (right) and aerators (left) in Ecuador
Source: Cámara Nacional de Acuicultura (2017)

2.4. CO₂ emissions of shrimp farms

One of the first detailed studies on the amount of CO₂ emissions from a shrimp farm was carried out in 2017 by the company GPS Group (2017) in the Aquamar shrimp farm, as shown in the previous chapter. The result of this study projected by the Ecuadorian government was presented in the event “Tripartite agreement for the electrification of the shrimp sector” (Ministry of Energy and Non-Renewable Natural Resources, 2021b), where the estimation for 100,000 hectares was made, with the following results:

- Emissions of 100,000 Ha. using diesel: 877,000 Ton CO₂/year

With this value, the ratio of CO₂ emissions per hectare per year can be calculated and will be considered in future calculations, since it is the official information handled by the government.

- Average CO₂ Emissions: 8.77 Ton CO₂/Ha/year

As another reference, there is another study regarding emissions that was made by Pinargote (2021), who conducted a research of equivalent CO₂ emissions from shrimp farming throughout the province of Esmeraldas, Ecuador, considering only water pumping with diesel and without aeration, with the following result:

- Diesel Pumps average CO₂ Emissions in Esmeraldas (Pinargote, 2021):
0.779464481 Kg CO₂ eq / kg shrimp

Considering that the average production of shrimp is 4,645 kg shrimp/Ha/year as established in chapter 2.3, the average CO₂ eq emissions of this study can be calculated:

- Diesel pumps average CO₂ Emissions in Esmeraldas (Pinargote, 2021):
3.62 Ton CO₂ eq /Ha/year

It is interesting how the values use by the Ministry of Energy and Non-Renewable Natural Resources (2021b) are more than twice the values from Pinargote (2021), which is expected because the government also considers in its calculation the aeration process, and the shrimp farming system is more energy intensive on the national average.

2.5. Shrimp Sector Electrification Plan

To start the transformation of the energy matrix of the shrimp farming sector, the government of Ecuador decided to implement in 2017 the "Electrification Plan for the Shrimp Sector" prepared by the Ministry of Energy and Non-Renewable Natural Resources (2019a), with the main objective of removing as a source of energy for shrimp farming the use of fossil fuels such as diesel, and instead use electricity from hydroelectric plants and non-conventional renewables from the country's electrical grid.

With electrification, high production levels and other benefits can be obtained, reaching and maintaining optimal levels of oxygenation of the water in the ponds where millions of shrimp larvae grow, a process that is currently achieved through a water recirculation pump and water aerators, both coupled to diesel combustion engines, which would be replaced with the electrification plan with high-efficiency electric motors.

The new electrical energy demand of the electrified shrimp farms can vary from 3 kVA to 15 kVA per hectare, depending on the type of shrimp farming system that

is implemented (extensive, semi-intensive, or intensive). For the planning process, the National Electricity Corporation CNEL, responsible for the distribution and sale of electricity in the areas where the shrimp farms are located, estimates an average demand of around 7 kVA per hectare.

The investment that must be made to provide electrical service to shrimp farms depends largely on the proximity to existing networks and the load to be installed. For this situation CNEL must build and integrate infrastructure of electrical networks, transmission lines, distribution, and electrical substations, estimating a new demand of approximately 500 MVA for the initial electrification. The energy supply must be guaranteed from the National Transmission System through the Electric Corporation of Ecuador (CELEC), the governmental entity responsible for the generation and transmission of energy in the country.

The latest update of the electrification plan for the shrimp sector was shown in the General Plan for Business, Expansion and Investment 2022 (National Electricity Corporation CNEL, 2022). This plan indicates that the number of shrimp farms to be electrified add up to a total of 56,411 hectares, representing 26 percent of the country's total shrimp hectares. The execution of the plan will imply a new electrical power demand of 376 MW, according to Table 1, where the power estimation is shown per province.

Province	Total Shrimps farms (Ha)	Electrification plan		
		Shrimp farms		Demand
	(Ha)	(Ha)	% of total	MW
Guayas	132,100	30,488	23%	203
El Oro	41,600	8,500	20%	57
Manabí	19,900	7,607	38%	51
Esmeraldas	14,600	6,216	43%	41
Santa Elena	7,100	3,600	51%	24
	215,300	56,411	26%	376

Table 1. Power Demand of the Shrimp Sector Electrification Plan

Source: Adapted from National Electricity Corporation CNEL (2022)

Calculating with the information shown in Table 1, an updated power demand ratio per hectare can be obtained:

- Power demand ratio of a Shrimp Farm: 6.67 kW/Ha.

2.5.1. Financing of the Shrimp Sector Electrification Plan

To finance the Shrimp Sector Electrification Plan, the government has requested a loan from the Inter-American Development Bank, which was signed in 2020 and has a component called the National Plan for Energy Efficiency of Ecuador (PLANEE) which includes part of the financing of the shrimp sector for an amount of 106.32 million USD and its implementation has started in 2022. In parallel, the subscription of additional financing with the Development Bank of Latin America has been in process since 2019 to reinforce the power lines for the electrification of the aquaculture sector, for a total amount of 200 million USD, but which has not yet been approved. The electrification is expected to have a direct positive impact on the productive capacity of the sector of at least 25%, and accordingly the same amount on the exports growth (National Electricity Corporation CNEL, 2022).

2.6. Research question

The research studies carried out so far related to the energy situation of the shrimp farming sector in Ecuador are only focused on specific topics. Some examples of these studies are related to the analysis of the shrimp exports, use of photovoltaic systems, efficiency of the power pumps and aerators, electrification of one shrimp farm, estimation of CO₂ emissions of one shrimp farm, among others.

There is a gap in the studies that do not consider a complete vision of the energy transition of the shrimp farming sector, so it is necessary to project the challenges and strategies that should be considered for the establishment of public policies and infrastructure and support projects in the medium and long term for this sector that is of great importance in the country.

The present study has the objective to show the impact of the energy transition that is already being implemented, to give an answer to the main research question:

What would be the energy transition results and challenges for the Ecuadorian shrimp farming sector through its electrification?

After the problem raised and considering the actions that the Ecuadorian government is taking for the electrification of shrimp farms by increasing transmission and distribution lines, and with the country's plans to increase hydro, wind and photovoltaic renewable generation in its energy matrix, the hypothesis is

that several economic, social and environmental benefits were expected from the energy transition process of the sector.

The main objective of this research is to generate a comprehensive approach that analyzes and measures the main variables that would be considered in the energy transition of the shrimp farming sector focused on the electrification program planned by the government. It is to particularly find an answer to:

- Does the energy transition of the shrimp farming sector will allow a **reduction in the consumption of subsidized diesel**?
- What would be the **impact of the energy transition on exports and productivity**?
- What will be the **difference between the diesel subsidy and the electricity subsidy**?
- How the **energy transition affects CO₂ emissions** in the sector?
- What are the **challenges** of the energy transition through electrification in **infrastructure, new energy demand, and the energy matrix** of the sector?

3. Conceptual model

The conceptual model that has been selected for the evaluation of the research gap will be the scenario analysis, in accordance with the recommendation made by Jordan & Turmpenny (2015) in the book *The Tools of Policy Formulation* where is indicated that the scenario analysis is the recommended tool to have the vision on different futures and pathways of a policy formulation.

Jordan & Turmpenny (2015) also present other tools that can be used to make a policy formulation study, for example, the use of surveys, statistical reports, expert evidence, brainstorming, cost-benefit analysis, risk assessment, time-series analysis, Delphi technique, computer simulation, among others. These additional tools can give another vision of the energy transition, but they are focused on other objectives, such as the articulation of the problem, the search for future and past trends, and the comparison of different alternatives. In the case of this study, as the policy of the electrification of the shrimp farming sector is already established and initiated, the scenario analysis tool is the one that best fits to carry out the research.

The proposed scenario analysis will consider the percentage of electrified hectares in the country as a variable to be measured, since the government is executing a plan with a goal of electrifying certain hectares as an initial phase. Given this situation, it is desired to have a comprehensive and comparative future vision of the following scenarios:

- **Scenario 0: Shrimp farming sector without electrification.**

This scenario represents the starting point of the energy transition. Despite the fact that public policies towards the electrification of shrimp farms began some years ago, albeit very slowly and with few results with less than 2% of the shrimp farms electrified as of June 2022 (Ministry of Energy and Non-Renewable Natural Resources, 2022a), it is considered necessary to measure this scenario in order to have a vision of the opportunity cost of not reaching the planned goals.

- **Scenario 1: Shrimp farming sector with the current electrification plan fulfilled (56,411 of 215,300 hectares).**

This scenario represents the government's goal in terms of the energy transition of the sector, in which it is necessary to deepen the analysis and results that will be achieved with its implementation to determine the impact of this strategy.

- **Scenario 2: Shrimp farming sector with complete electrification (215,300 hectares).**

As the ultimate goal, the government's vision is to achieve the electrification of the entire sector, although achieving it may seem utopian, it is necessary to know the impact it would have if it is implemented, to see the whole potential of the energy transition of the sector through electrification. The results of this scenario could help generate new policy strategies and programs that encourage its development.

Comparing these scenarios in the framework analysis of the energy transition can give us a complete vision of the impact of the electrification policy in the economy and environment of the country.

According to Kosow & Gaßner (2008), scenario is defined by many authors as a description of a possible future situation including paths of development which may lead to that future situation. A scenario describes the development, the dynamics and the moving forces from which a specific conceptual future results, with the aim

to generate orientation regarding future developments through an observation of certain relevant key factors. The authors indicate that there are three things to be notices in the scenario analysis process:

- A scenario is not a comprehensive image of the future, meaning that in the process various factors are deliberately included and other excluded, placing the focus of attention on certain interesting aspects by means of a future-oriented involvement with specific area of study.
- The selection and combination of key factors with regard to a future time horizon is a construct, which means that certain factors are deliberately taken to be relevant or are ignored, and some assumptions have to be taken by the study according by the data available. The scenario does not represent future as a whole, but rather as a possible, future-oriented construct of certain key factors.
- Such scenario-construct is based on an assumption about how the future might one day look, and is an indicative of comprehensive mental outlines and models of the future.

To determine the framework that will be used to measure, compare and analyze the proposed three scenarios, it was found among other methodologies that one of the first institutions to measure the energy transition of countries considering various perspectives was the World Economic Forum (2022a) through the Energy Transition Index.

The Energy Transition Index – ETI – has benchmarked energy transition evolution of the countries during the last decade and is used as a reference in various studies. Correspondingly, the countries are familiarized with this methodology to establish new policies related to the energy transition that can improve their score compared to global standards, and likewise the framework could be adapted to the situation of an industrial sector. The Energy Transition Index framework is shown in Figure 8 and is divided in two parts: system performance imperatives and transition readiness enablers.

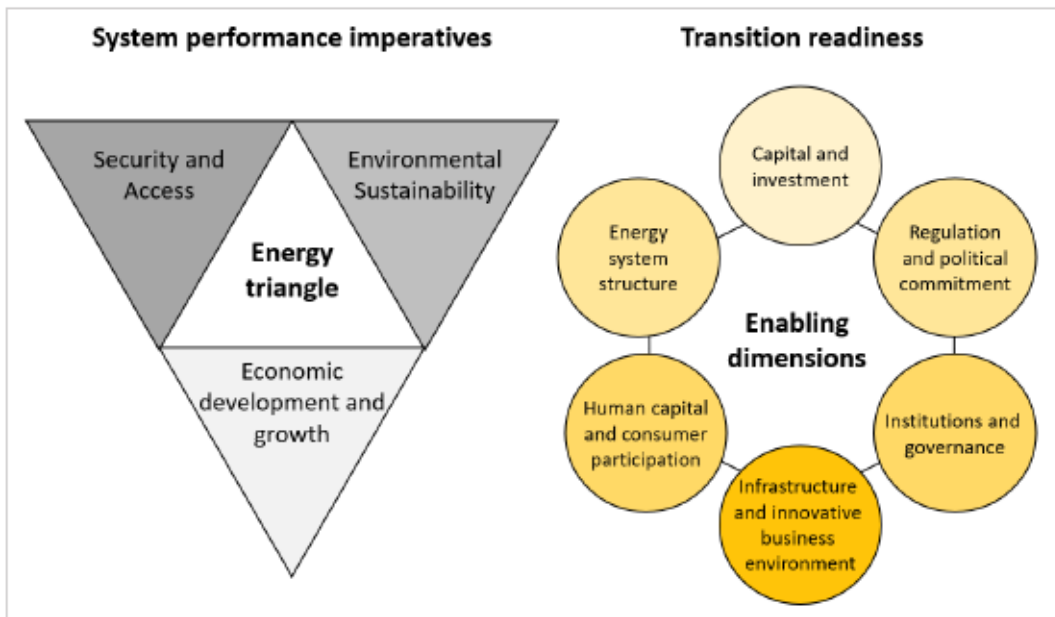


Figure 8. The Energy Transition Index framework
Source: World Economic Forum (2022a)

a) **System performance imperatives**

Also known as the Energy Triangle, assesses the performance of an energy system across three fundamental dimensions, with their respective measurement variables (Singh et al. 2019):

i) **Economic development and growth**

This dimension tracks the implications of competitiveness, investment attraction and the affordability of a country's energy sector. According to the World Economic Forum (2021), during the last decade the global average of this dimension has been practically flat due to the great challenge of decoupling economic growth from energy demand and consumption.

Measured variables: "Affordability, industry competitiveness, fossil fuel subsidies, cost of externalities and GDP contribution".

ii) **Energy security and access**

This dimension measures the availability of a system to supply energy at an uninterrupted and affordable price, dealing with timely investments in line with economic developments and environmental needs and focusing on the ability of the energy system to react promptly to sudden changes in

the supply-demand balance, ensuring energy access for all users (IEA, 2022)

Measured variables: "Energy access, quality of supply and security of supply".

iii) Environmental sustainability

This dimension tries to measure the impact of the activities and policies carried out by countries with the environment, and if this interaction is carried out in a responsible manner without compromising future generations to cover current needs. One way to measure this impact is through the reduction of greenhouse gas emissions.

Measured variables: "Air pollution, energy intensity, carbon intensity, carbon emissions per capita".

b) Transition readiness enablers

It is necessary to see the energy transition beyond the limits of a single energy system given the interconnection with other local and global systems, thus generating social, economic and environmental impacts in an interrelated manner. It is for this reason that this framework has determined six enabling dimensions of the energy transition with their respective measurement variables (Singh et al. 2019):

iv) Capital and investment

Access to credit is an enabler of the energy transition, which is booming worldwide but its promotion and use in renewable energies and electrical structure, as well as in new technologies such as carbon storage and capture, still need to be increased.

Measured variables: "Ability to invest, access to capital, recent investment into energy efficiency and recent investment into renewables".

v) Energy system structure

To achieve the energy transition goals, it is necessary to invest to change the energy system through an adaptation of the country's energy matrix towards a renewable capacity and generation focused on the goal of carbon neutrality.

Measured variables: "Energy demand growth, electricity energy mix and fossil fuel dependency".

vi) Human capital and consumer participation

Investment in education towards new technologies and infrastructure related to the energy transition and renewable energies are essential, which will also generate new, more specialized jobs.

Measured variables: "Quality of education and jobs in renewable energy sector".

vii) Infrastructure and innovative business environment

The development of infrastructure for business growth in a country is a basic enabler to achieve greater productivity and promote the energy transition that also generates competitiveness; therefore, it is also necessary to implement measures that develop innovation in the energy sector.

Measured variables: "Trade logistics, transportation infrastructure, availability of technology and innovative business environment".

viii) Institutions and governance

Governance and credibility in a country's institutions is necessary to establish long-term energy transition policies, as well as to maintain stable country finances and regulation.

Measured variables: "Transparency and political stability, Rule of law and stable finances".

ix) Regulation and political commitment

The government's commitment to the energy transition is elementary, and becomes a reality through public policies, regulation and goal setting, in accordance with international agreements towards the reduction of the country's emissions.

Measured variables: "Commitment to international agreements, stable policy and regulation to support energy efficiency, renewables and access".

The performance of Ecuador in the Energy Transition Index (ETI) in the last 10 years it has been improving, going from an initial ETI score of 57.2 in 2012 to an ETI score of 60.88 in 2021, as shown in Figure 9, from which we highlight that the performance of the system is very well positioned, higher than the world average, but its readiness towards the energy transition still has deficiencies, and is below the world average.

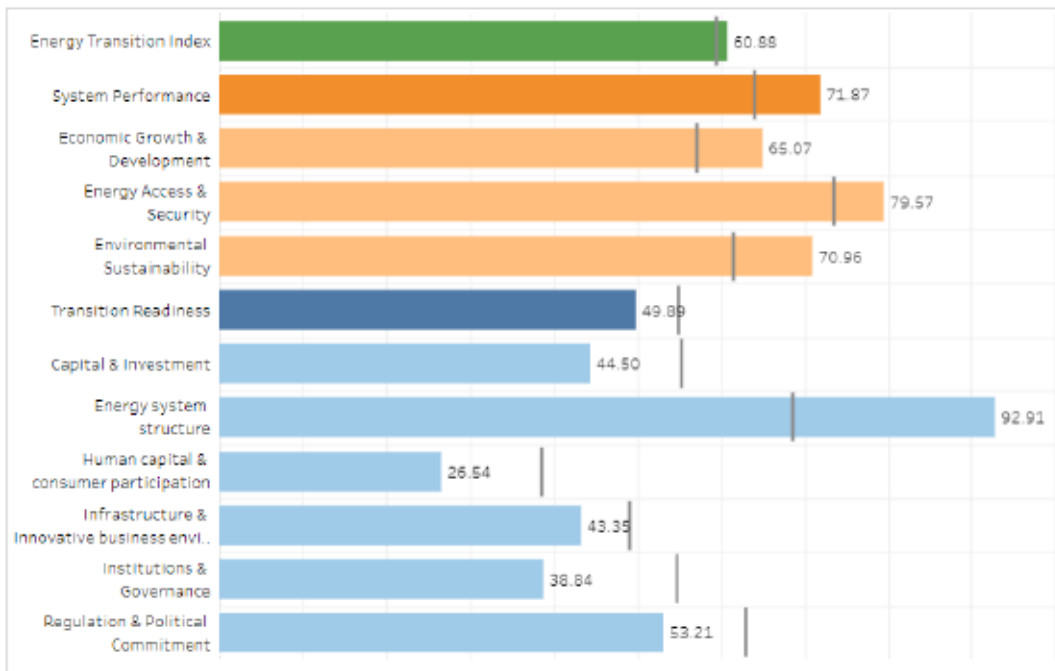


Figure 9. Ecuador ETI 2021, sub-indices and dimension scores
Source: World Economic Forum (2022b)

As the Energy Transition Index Framework has been designed to evaluate the performance of the energy transition of countries, this study will try to adapt the framework to the industrial sector with a view to measuring the three proposed scenarios and to serve as an analysis for public policy decision-makers and stakeholders in the sector. to continue promoting the path towards the energy transition focused on the goal of carbon neutrality.

4. Methodology

As mentioned in the previous section, the objective of this study is not to measure the Energy Transition Index for the Ecuadorian shrimp industry, since this index has been created to evaluate countries and reflects their current status by measuring their system performance and its readiness to face the energy transition compared to other countries, making a benchmark.

In the present case, the variables used in the Energy Transition Index will be used as a guide and inspiration to determine how each of the nine dimensions applied to the Ecuadorian shrimp sector will be analyzed, which will be proposed based on

the information available or that can be calculated. Where applicable, the projection of the variables established for the three scenarios defined for the study will be used.

By implementing this methodology, an attempt will be made to establish what the results and challenges of the energy transition of the Ecuadorian shrimp sector will be. Below is how the nine dimensions will be developed for this study.

i) Economic growth and development

Variables to be measured: Shrimp production, exports, diesel consumption, subsidy swift from diesel to electricity. All variables estimated for the three scenarios.

ii) Security and Access

Variables to be measured: Power demand, Energy demand. Both variables estimated for the three scenarios.

iii) Environmental sustainability

Variable to be measured: CO₂ emissions, estimated for the three scenarios.

iv) Capital and investment

Variable to be measured: Investment required by the shrimp farms for electrification, estimated for the three scenarios.

v) Energy system structure

Variable to be measured: Energy matrix of the shrimp farming sector, estimated for the three scenarios.

vi) Human capital and consumer participation

Analysis and description of the dimension on its current situation and the challenges towards the energy transition.

vii) Infrastructure and innovative business environment

Analysis and description of the dimension on its current situation and the challenges towards the energy transition.

viii) Institutions and governance

Analysis and description of the dimension on its current situation and the challenges towards the energy transition.

ix) Regulation and political commitment

Analysis and description of the dimension on its current situation and the challenges towards the energy transition.

The projection of scenarios when applied will be carried out with the information available from official government sources, from studies carried out by academic institutions, universities and consulting companies. The objective is through these calculations can serve as a reference to establish realistic public policies to enhance the energy transition of the shrimp farming sector and considering the challenges to achieve a complete decarbonization of the sector, which will bring competitive advantages to the industry, and economic and social benefits to the country.

5. Findings

After conducting a research for available and accessible information in Ecuador from government institutions, aquaculture associations, studies carried out by engineering and consulting companies and various works developing specific topics on productivity, efficiency, environmental impact and energy applications for the shrimp farming sector in Ecuador, this chapter will try to elaborate the main results from the point of view of the proposed scenarios focused on the nine dimensions established in the methodology. These findings will allow a synthesis that reflects the projected energy transition of the shrimp farming sector through electrification and its benefit and impact on the economy, environment and society.

It should be noted that due to the nature of the nine established dimensions and the information found, only the estimation of electrification scenarios will be used for the first five dimensions, while for the last four dimensions (human capital, infrastructure and innovative business environment, institutions and governance, and regulation and political commitment), only a general analysis will be carried out of their current situation and the challenges these dimension will face towards the energy transition through electrification.

5.1. Economic growth and development

To establish the economic growth and development dimension at the industrial level applied to the shrimp farming sector, it will be determined for the three proposed scenarios how electrification will impact productivity and exports, how much the use of fossil fuels will be reduced in the production process and how it will affect the change from a subsidized fuel to a subsidized source of electricity,

taking into account the current fuel cost and estimating a future variation of that cost.

5.1.1. Productivity and Exports

Based on the study carried out by the Ministry of Energy and Non-Renewable Natural Resources (2017), it is estimated that productivity only due to the change in electrification technology will increase by a minimum of 25%, which would imply that national production could rise from one million metric tons per year in scenario 0, up to 1.065 million metric tons per year in scenario 1 upon completion of the current electrification plan, and with a potential to reach a production of 1.25 million metric tons per year if all shrimps farms are electrified. This would imply an increase in the value of exports starting in scenario 0 from 5,323 million USD, to 5,672 million USD for scenario 1 and 6,654 Mio USD for scenario 2, as can be seen in Figure 10. It should be noted that it is very likely that production could increase even more because the projected electrification only considers changing the current technology from diesel combustion to an electric one, but with the availability of electricity at an affordable price, it is possible to invest in new aeration technology and feeding automation.

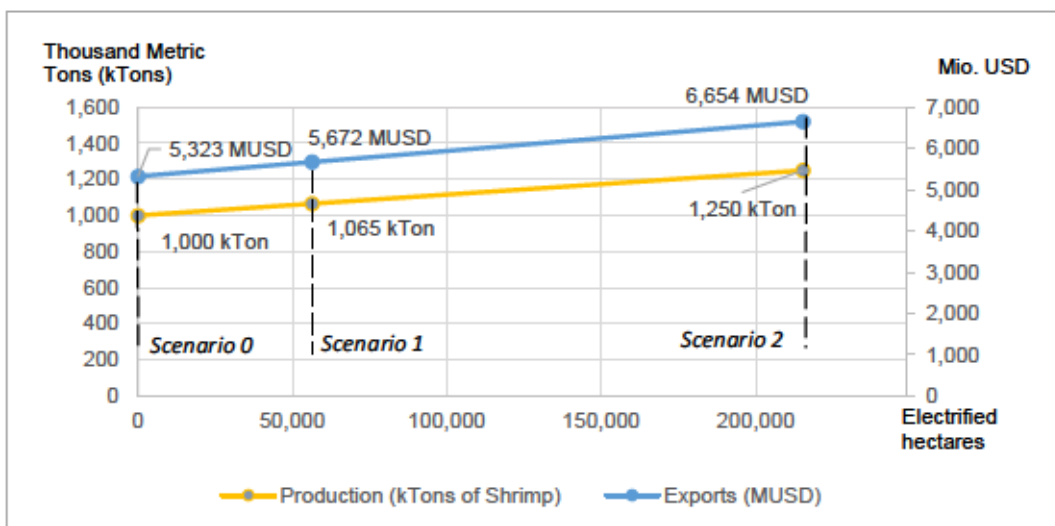


Figure 10. Projection of production and exports for each scenario

Source: Prepared by the author

5.1.2. Reduction in the use of fossil fuels

According to the Ministry of Energy and Non-Renewable Natural Resources (2021b), the average diesel consumption in Ecuador of 100,000 hectares is 87 million gallons of diesel per year, which is equivalent to:

- Diesel consumption per Hectare: 870 gallons/Ha/year

With this information it can be estimated the results on the decrease in diesel consumption within the three proposed scenarios in Figure 11, where it can be seen that for scenario 0, fuel consumption without any electrification is approximately 187.3 million gallons per year, in scenario 1 this volume is reduced to 138.2 million gallons per year and in scenario 2 the shrimp farming sector would stop consuming diesel considering that all of them would be electrified.

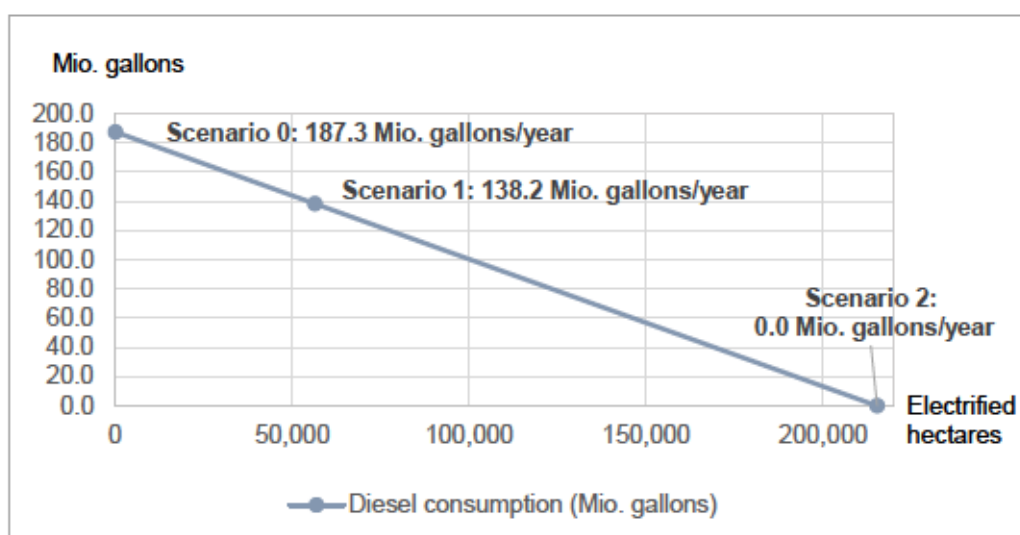


Figure 11. Projection of Diesel Consumption

Source: Calculated by the author

5.1.3. Switch from subsidized fuels to subsidized electricity

As indicated in chapter 2.3.2, the subsidized price of diesel for the shrimp industry is officially at 1.57 USD per gallon in July 2022. To evaluate the opportunity cost, this value will be compared to the diesel importation cost, which according to El Comercio (2022) for July 2022 was on average 3.15 USD per gallon. With these

values the diesel subsidy per non-electrified hectares can be calculated, considering also the previous shown ratio of diesel consumption.

- Diesel subsidy (August 2022): $3.15 - 1.57 = 1.58$ USD/gallon
- Diesel consumption per Hectare: 870 gallons/Ha/year (chapter 5.1.2)
- Diesel subsidy per non-electrified hectare: 1,374.60 USD/Ha/year

It is understood that the international price of diesel fluctuates with certain periodicity, but for the purpose of this study we will make an analysis of a variation of +/- 25% of the current international importation cost.

On the other hand, is known that the subsidized electricity price of the shrimp industry is 65 USD/MWh (Ministry of Energy and Non-Renewable Natural Resources, 2019b), while the national average is 92 USD/MWh (Ministry of Energy and Non-Renewable Natural Resources, 2022b), and the consumption per electrified hectare is in average 22,109 kWh per hectare per year, as calculated in chapter 2.3.2. With this information we can conclude the following ratios:

- Electricity subsidy (July 2022): 27 USD/MWh
- Electricity subsidy per electrified hectare: $27 \text{ USD/MWh} * 22.109 \text{ MWh/Ha/year} = 596.9 \text{ USD/Ha/year}$

As an additional note, it is not conclusive that the price of 92 USD/MWh is the real cost of the electrical grid. It is possible that this national rate is also subsidized, but since we do not have statistical data on the subject, is going to be consider this price for our evaluation. With the ratios shown above, in a scenario 0 without electrification, the government subsidy would be 296 million USD per year, while in scenario 1 the net subsidy would be 252.2 million USD per year and in scenario 2 when a total electrification of the sector is reached, it only applies the electricity price subsidy, that achieve 128.5 million USD per year, as shown in Figure 12. It is interesting to see in this graphic that if diesel import cost decreases by 25%, the economic benefit of electrification is reduced.

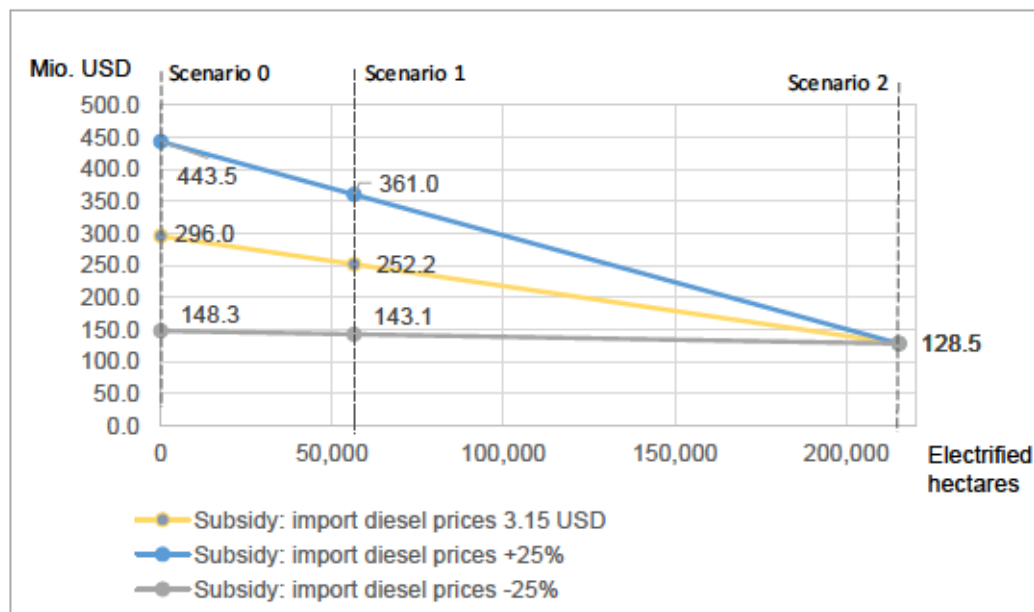


Figure 12. Total diesel and electricity subsidy per scenario

Source: Prepared by the author

5.2. Security and Access

Security and access to energy is of the utmost importance for an industry, since if there is no reliability or affordability in energy, this can affect its competitiveness and productivity. In the case of Ecuador, the subsidy for electricity and diesel means that the industry and all end users have access to energy resources at better prices than neighboring countries, but it generates a huge cost for the state.

Currently, most shrimp companies do not have access to the electrical grid, due to the lack of distribution and transmission networks, and also due to the lack of power capacity of the current substations and networks to supply the demand of these companies. It is important to emphasize that Ecuador having an energy matrix with a component of 77% of its energy generation made by hydroelectric energy, in dry seasons (without rains) a supply problem is generated that must be covered with diesel thermal generation.

To try to go into the dimension of access and energy security in detail, we will estimate the demand for electrical power that the shrimp sector would require and this demand will serve as a reference for the country's electricity generation and transmission investment plans.

As previously calculated in chapter 2.3.2, the power and energy demand of the shrimp sector is estimated at an average of 6.67 kW/Ha in power and 22,109 kWh/Ha/year in energy. With these values, the demand that the sector will require for the three scenarios proposed in shown in Figure 13, with values of 376 MW with 1,247 GWh for scenario 1 and 1,436 with 4,756 GWh for scenario 2. It is impressive to see in this analysis that if the electrification of the entire sector were carried out (scenario 2), the power demand of 1,436 MW would represent an increase of 36% of the country's maximum demand of approximately 3,960 MW by the year 2021 (Agency for the Regulation and Control of Energy and Non-Renewable Natural Resources, 2021).

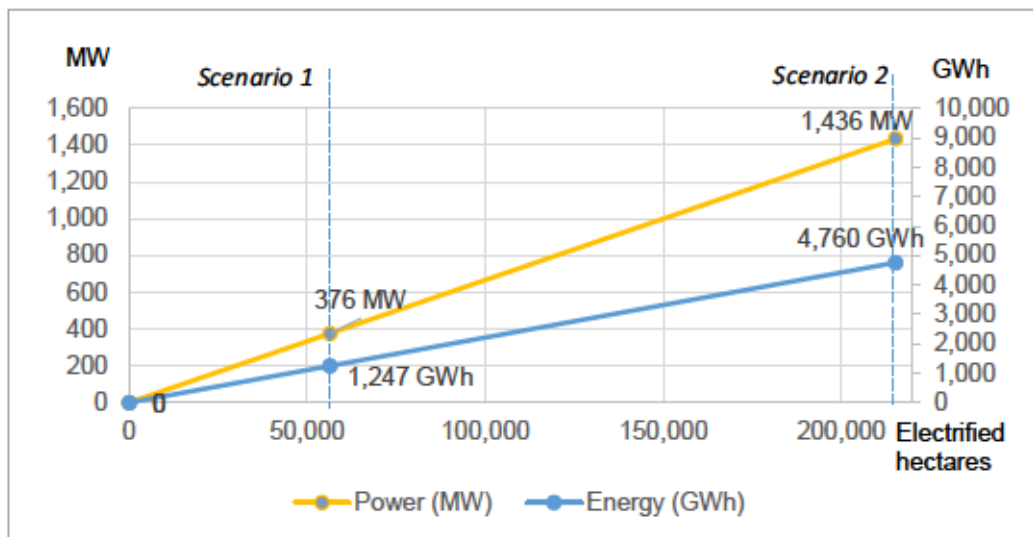


Figure 13. Power and Energy demand for proposed scenarios

Source: Prepared by the author

It is also important to highlight that this demand for power and energy generates its peaks and valleys at certain times of the day, so the system must be prepared to assimilate these fluctuations, as can be seen in the Figure 14 obtained from the Electricity Master Plan of Ecuador 2018 (Ministry of Energy and Non-Renewable Natural Resources, 2019b), as pumping and aeration depend on tides and types of farming systems.

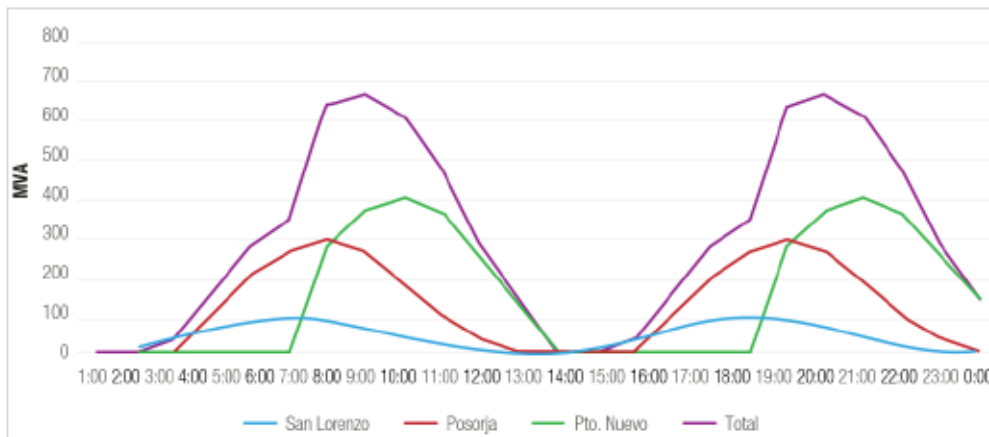


Figure 14. Daily shrimp farm power demand curve per province

Source: Ministry of Energy and Non-Renewable Natural Resources (2019b)

5.3. Environmental sustainability

Environmental sustainability refers to the relationship that one has with the environment and how this relationship can be carried out in a harmonious way without affecting it, which can be achieved by efficiently managing natural resources and carrying out productive activities efficiently, thus allowing its preservation. to the coming generations. One way to measure this progress towards sustainability is through the measurement and reduction of the carbon footprint of the production processes, and this is what we will apply in the case of the shrimp farming activity which, through the transition planned energy company, expects to reduce its emissions from the use of diesel in its processes, to use electricity from the grid. It must be considered that the generation of energy that arrives through the electrical grid also generates greenhouse gases, consequently the measurement of emissions via this energy transition process must also consider these grid values.

To calculate the average emissions with which the energy from the electrical network arrives, we will use the statistics carried out by the National Electricity Operator CENACE (2021) in its report "CO₂ Emission Factor of the National Interconnected System of Ecuador 2020", where it informs of the emissions made by electricity generation annually, which is shown in Table 2, where the grid emissions ratio per kWh was also calculated:

	2018	2019	2020
Annual Power Generation (GWh)	24,738	27,482	26,924
Emissions (kTon CO₂)	2,747	1,928	1,547
Grid emissions ratio (Kg CO₂ / kWh)	0.111	0.070	0.057

Table 2. Calculation of grid emission in Ecuador

Source: Prepared by the author based on information from National Electricity Operator CENACE (2021)

It is interesting how in just two years the network emissions ratio was reduced by almost half, thanks to the effects of the policy of increasing the penetration of hydroelectric energy in the energy matrix, and also considering a little the effect of the pandemic that took place in that year, where the electricity consumption of the country decreased in a small proportion.

To calculate how many emissions should be considered in an electrified hectare of shrimp farm, the value of the grid measurements for the year 2020 will be taken and the estimated average electricity consumption of the same, previously calculated, will be used.

- Estimated energy consumption of a shrimp farm: 22,109 kWh/Ha/year
- Estimated Grid Emission ratio: 0.057 kg CO₂ / kWh
- Estimated emission of electrified hectare: 1.26 Ton CO₂/Ha/year

For our calculation of emissions in the three proposed scenarios, we will use the estimation of emissions from diesel shrimp farms that was calculated in chapter 2.4. for a value of 8.77 Ton CO₂/Ha/year. The results of the analysis are shown in Figure 15.

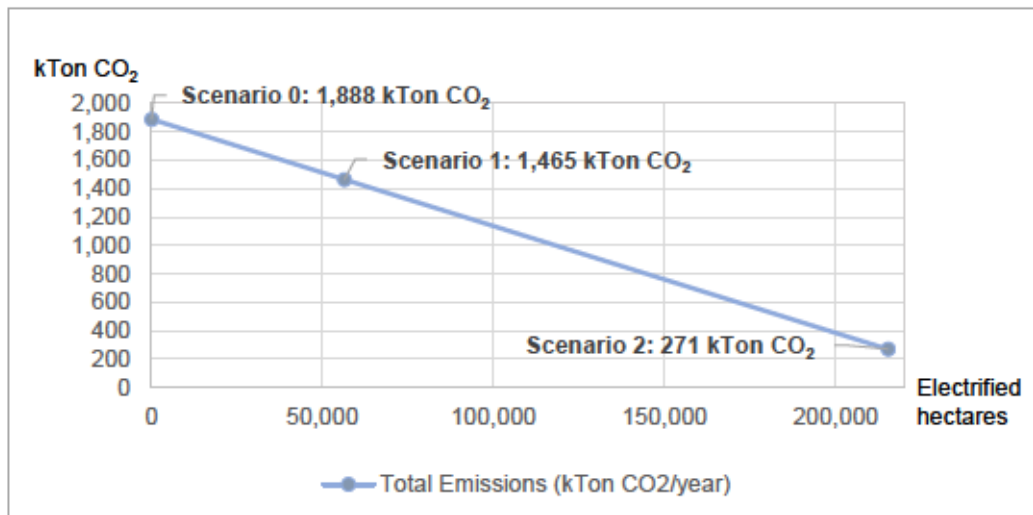


Figure 15. Projected CO₂ emissions per year for scenario

Source: Prepared by the author

With this analysis, it can be concluded that electrification generates a high reduction in CO₂ emissions in shrimp farms, decreasing from 1,888 kTon CO₂/year in scenario 0 without electrification, to 1,465 kTon CO₂/year in scenario 1 with the government electrification plan implemented, with the future potential to decrease to a value of 271 kTon CO₂/year in scenario 2 if the electrification of the entire sector is completed.

Considering that the total country's emission in 2020 was 34,076 kton CO₂ (Ministry of Energy and Non-Renewable Natural Resources, 2021), the impact of the scenario 1 will be a reduction of 423 kTon CO₂/year, equivalent of 1.24% of the country's emissions, and in scenario 2 the impact will be a reduction of 1,617 kTon, equivalent of 4.75% of the country's estimated emissions if the national electrical grid CO₂ emissions ratio remain constant despite the increase of the shrimp farms new power demand.

5.4. Capital and investment

Access to capital by the government for the development of energy generation, transmission and distribution infrastructure for the shrimp sector is essential to chart the path towards the energy transition. As discussed in chapter 2.5.1, the Ecuadorian government launched the electrification plan for the shrimp sector that proposes to electrify 56,411 hectares of shrimp farms, a goal that is called scenario

1 in this study, and estimated that investment in electrical infrastructure was around 306.32 million dollars estimated in 2017. As of July 2022, it has only been able to obtain financing for 35% of the required budget, which has delayed the entire investment plan and consequently the electrification, which after 5 years of launch of the plan, only less than 2% of the country's hectares have been electrified (Ministry of Energy and Non-Renewable Natural Resources, 2022a).

It is necessary for the country to obtain advice and international support to obtain financing that is not only for the electrical infrastructure of the country, but also to finance the change of the energy matrix within the shrimp farms, since the estimated investment is very high. Taking as an example the study carried out by GPS Group (2017) in the Aquamar shrimp farm, the investment shown in chapter 2.2.2. results:

- Investment in electrical infrastructure, electric aeration system, electric pumping and electric feeding system: up to 14,600 USD per hectare

In an average shrimp farm there are 70 hectares, which would result in an investment of up to 1.02 million USD, an amount that could be very difficult to reach and finance by a shrimp farm company with its own resources. This issue can be addressed through public financing policies with government loans that could be paid via the electricity tariff, or other mechanisms. It could be estimated that the investment in infrastructure of the shrimp farms companies for the proposed scenarios is:

- Shrimp farms companies own investment in Scenario 0 (0 Ha): 0 Mio. USD
- Shrimp farms companies own investment in Scenario 1 (56,411 Shrimp Ha electrified): Up to 823 Mio. USD
- Shrimp farms companies own investment in Scenario 2 (215,300 Ha electrified): Up to 3,143 Mio. USD

5.5. Energy system structure

The dimension of the composition of the structure of the energy system of shrimp farming is also important because it indicates how dependent the sector is by energy source, mainly it marks the dependence on fossil fuels (diesel, natural gas and coal) and which would be the goals of the government to change this

composition towards a more renewable matrix. For this study, we will carry out a projection by scenario showing the shrimp matrix dependent 100% on diesel in scenario 0 towards a transition reflected in the energy matrix of the electrical network in scenarios 1 and 2, as shown in Figure 16.

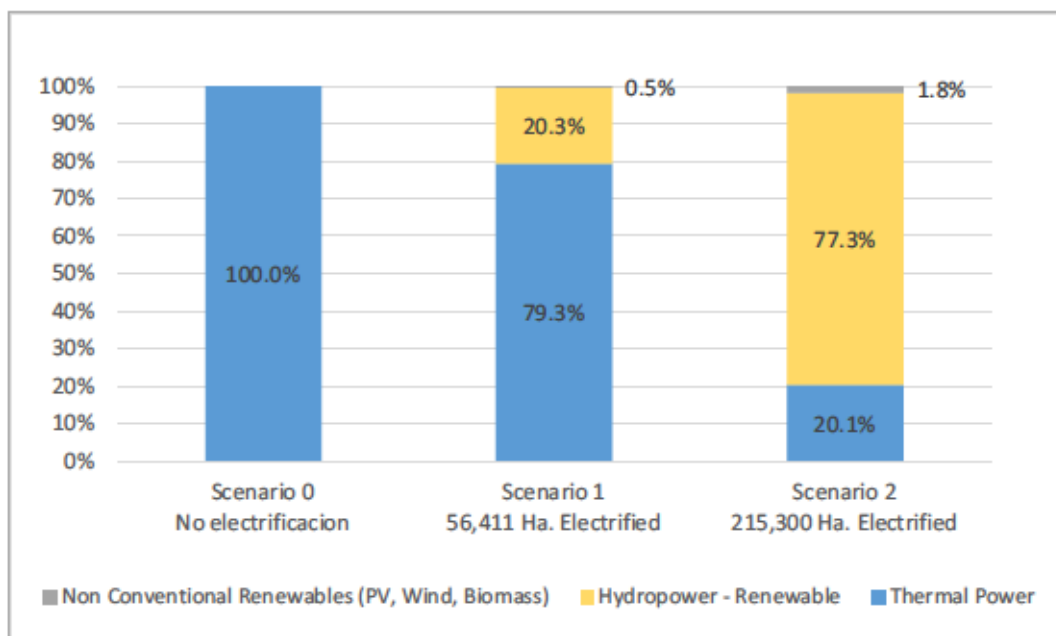


Figure 16. Energy matrix estimation for scenario for shrimp farming sector
Source: Calculated based on information from Ministry of Energy and Non-Renewable Natural Resources (2021a)

This analysis indicates that if the Ecuadorian government complies with its initial electrification plan for 56,411 hectares, as proposed in scenario 1, the energy matrix of the shrimp farming sector would consist of 79.3% thermal energy, 20.3% hydroelectric energy and 0.5% non-conventional renewable energy. In the future case that consists in the implementation of the electrification process for the entire shrimp sector in the country and maintaining the same national energy matrix, the values would change in scenario 2 to 20.1% thermal energy, 77.3% hydroelectric energy and 1.8% non-renewable energy conventional.

It must be taken into consideration that these data would only apply if the country's energy matrix remains at the same proportion of generation, and this is something that the Ecuadorian government seeks to change with the launch of non-

conventional renewable energy auctions in the coming years, as mentioned in chapter 2.2. with the new auction of 500 MW for photovoltaic, wind and biomass. If the auction is executed, the new generation capacity should come into operation from the year 2025, making a more renewable national energy matrix and also impacting the estimated CO₂ emissions of all the industrial sectors that are electrified with interconnection to the national grid.

5.6. Human capital

This is the dimension of which less information is told about the shrimp sector in the available media. Ecuador, being the main producer and exporter of shrimp in the world, has the need to train and develop its human capital. As previously indicated, the shrimp sector employs 260,000 people (Calderón, 2020), which generates greater challenges in terms of technology education, since there is a lot of difference between operating a shrimp farm that operates with diesel engines, and a shrimp farm that is technified and automated. There will be greater challenges on the part of the government and the education institutions in establishing the bases to continue developing this industry.

To measure this dimension, the same value that the Energy Transition Index has evaluated for the country in the year 2021 can be used, because it reflects the situation of the entire country, which also affects the shrimp sector. The result of the ETI index for Ecuador for the Human Capital dimension was a rating of 26.54%, while the world average is at 38.47%, therefore there is still a large gap to cover and overcome to be in the global competitive average and in this way to be able to generate greater added value and quality of life for the population and workers directly related to this sector.

One of the studies carried out on human capital for the shrimp sector was carried out by Álava (2018) in the Ecuadorian province of Manabí, in which, through a statistical process of surveys applied to heads and managers of human resources of shrimp companies in the study area. The result obtained of the survey was that the experience and the technical profile are the most valued characteristics in the people of the organization, being the production manager the most complex and balanced profile, since he must combine technical training and leadership, while biologists and laboratory technicians they are the most fundamental since their profile supports the genetic strengthening of the shrimp and the detection of pests

or infections. In the same study it was reflected that the technical modernization of the shrimp sector would not imply the massive substitution of workers, on the contrary, the trend is towards preserving the personnel and promoting their technical training.

5.7. Infrastructure and innovative business environment

In the dimension of infrastructure and innovative business environment, it creates a challenge for the shrimp farming sector, since Ecuador has the possibility of being a benchmark in other countries in the efficient production of shrimp. The electrical infrastructure, as is known, is a pending issue for the government that is already on the way to resolving it, albeit slowly. In the case of infrastructure for exports, the demand and expectations of producers and the international market are currently being met, despite the logistical problems resulting from the war between Ukraine and Russia, global inflation and logistics costs.

Within the field of innovation, for example, there are public and private initiatives that seek to certify shrimp that have zero emissions, this should be internationally recognized and will generate a competitive advantage that could even increase the price of the product according to the consumer. Ecuador has generated benchmarks in packaging mechanisms, frozen food exports, and has achieved international quality certifications, this is carried out mainly by large companies, but through development policies it could be replicated in medium and small companies with the support of the government.

According to Connect (2021), the Ecuadorian shrimp industry demands innovation in its production process, but it is technologically limited, with only six registered patents in the entire sector, mainly related to the prevention of viral and bacterial pathologies. The same author established in its research that the main issues demanded by the shrimp sector are:

- Feed and nutrition: There is a need to increase the productivity and efficiency of aquaculture by creating sustainable sources of protein with sustainable and scalable supplies of quality alternative ingredients.
- Process control and optimization: To increase local productivity it is necessary to reduce the demand for supplies and resources, which is achieved by optimizing industrial processes. Similarly, disease control is

key in the industry, since on average 40% of shrimp production is lost because of it.

- Reduction of environmental impact: Clean technologies, waste and effluent treatment, as well as the recovery of resources and the creation of new products based on a circular economy approach, contribute to the reduction of environmental impact.
- Shrimp farming techniques: Much of the country's shrimp is produced in shrimp farms. It is important to innovate about new cultivation techniques and methodologies that could innovate this sector, for example using renewable energy

In the case of electrical infrastructure, for the execution of the Electrification Plan for the Shrimp sector (scenario 1), the state plans to invest in substations, transmission lines at 138 kV and 69 kV, and medium voltage distribution networks at 13.8 kV (Ministry of Energy and Non-Renewable Natural Resources, 2019a).

5.8. Institutions and governance

To evaluate this dimension, we will also refer to the Energy Transition Index, which indicates that Ecuador had a rating of 38.84% while the world average is 54.56%, so it could be said that the institutionality and governance in the country is deficient.

The country, having a dollarized economy, presents advantages to investors and exporters since it has not been affected by the devaluation of the currency suffered by other countries in the same region, such as Argentina, Chile and Ecuador.

But there is a very great political instability in the country, despite the fact that it has benefited from the high international prices of oil, which is its main source of income, during the year 2022 many strikes and work stoppages were generated throughout the country due to the attempt to try to eliminate the subsidy for fossil fuels and electricity, which generates a large expense for the state, and where the president was at risk of being vacated. The stoppages were promoted mainly by carriers and indigenous communities, which finally led the government to stabilize fuel prices for a period of time.

5.9. Regulation and political commitment

The evaluation carried out by the World Economic Forum qualifies this dimension for Ecuador with a value of 53.21% compared to 62.83%, which is measured as a world average, so there is still a gap to cover to improve regulation and the country's political commitment towards an energy transition.

Specifically, for the shrimp sector, the "Shrimp Sector Electrification Plan" was established in 2017, which seeks to electrify 56,411 hectares of shrimp farms, which as of July 2022 still does not have full financing. According to the National Electricity Corporation CNEL (2022), various projects are being implemented in the country, such as the Project to Advance the Change of the Ecuadorian Energy Matrix, the Program for the Modernization and Renovation of the Ecuadorian Electric System, and the Program for Reinforcement of Electrical Distribution Networks for the Aquaculture sector.

Despite the projects that are being carried out, the shrimp sector demands a faster change in the energy matrix, for which it is trying to use other mechanisms, such as the execution of exceptional electrical interconnection projects based on article 33 of the General Regulations of the Organic Law of the Electric Power Public Service, which indicates that, exceptionally, when the Electric Company cannot meet the requests for electrification of the aquaculture and agricultural sectors, they may finance and build the distribution works, through agreements of public-private association (National Electricity Corporation CNEL, 2022). Based on this regulatory framework, several shrimp farms that are interested in the interconnection and have the financial capacity to carry out the works have started the procedures. In total, within this regulatory framework, a total of 14,883 hectares of shrimp farms have requested the approval of their projects for a total of 206 MW, of which only 4,612 hectares have obtained approval. The total amount of investment for all the projects referred to in these private investment agreements amounts to 19.6 million USD.

6. Analysis and Discussion

After carrying out an evaluation of the nine dimensions proposed by the World Economic Forum applied to the energy transition analysis in the shrimp farming sector of Ecuador, it is possible to realize the great challenges that electrifying the entire sector would entail. Only the additional power demand of the electrified shrimp farms could imply a 36% increase in the power demand of the country, which should also consider that the demand would fluctuate during the day, since generally the operation of the water pumps used by the shrimp farms depend on the tides.

Building the entire electrical infrastructure to supply the demand of the shrimp farming sector with new power plant for approximately 1,436 MW would be a very high investment, and it should also be considered that it could be higher since, given the boom in the Ecuadorian shrimp industry, there are several new shrimp farm projects that are being under development for the following years.

An important indicator that also stands out from the study is the reduction of greenhouse gas emissions, since changing the energy matrix of the shrimp sector from diesel to electric would reduce its emissions from approximately 1,888 kTon of CO₂ per year, to a value of 271 kTon of CO₂ per year, which is equivalent to a 85.6% reduction, considering that the country's generation matrix remains in the same proportion. This would benefit the government in meeting its emission reduction targets for the country, contributing with the reduction of approximately 4.75% in the scenario 2 of the total electrification of the shrimp farming sector.

In relation to subsidies, it is interesting to note that transfer diesel subsidies to electricity generation subsidies is economically convenient for the state when diesel import prices are high, as is the current situation. In the long term, it is a convenient policy since it not only generates accessibility and security of energy to this high-priority sector of the country, being the largest in non-traditional exports and being the first producer in the world, it is necessary to provide energy stability and quality, which promotes greater productivity in the face of increasingly growing global demand. It would be necessary to analyze whether this subsidy can be considered as dumping internationally, or if it is serving to fictitiously lower prices of the final product, which would mean that international consumers will benefit

from the subsidized spending carried out by the state, which is not sustainable in the long term.

One recommendation for the Ecuadorian government is to periodically measure the energy matrix not only of the shrimp sector but of the main industrial sectors in the country, to set short, medium and long-term goals in terms of energy transition and request support from international organizations to meet its outlined objectives, within the framework of compliance with its National Development Objectives (NDCs) and its Sustainable Development Goals (SDGs).

From the study is highlighted that in order to carry out the energy transition, it is not only necessary to carry out energy generation and transmission infrastructure by the state but also investment by shrimp companies to change their internal technology by investing in efficient electric motors and internal distribution networks, for which support needs to be established with financing policies that could be included in the electricity rate, which for example could also include distributed generation projects with the use of photovoltaic energy.

It is important to indicate that all these calculations are being made with approximate values based on the current situation of the shrimp sector in terms of productivity, energy consumption, and amount of greenhouse gas emissions, among others, which have been carried out by various specialists and institutions and should be taken as an academic document, which can help the government and the shrimp sector to delve into the specific studies that are required to support the achievement of an adequate energy transition in the sector.

The benefits of the energy transition of the shrimp sector through electrification are highly beneficial for the economy and environment of Ecuador, since it increases its productivity, with this the competitiveness of the final product, improves efficiency of production processes and will generate demand for more specialized human capital that will result in an indirect increase in formal educational institutions and will generate an environment of innovation that could also lead to exporting technology and experience to other countries. These goals that the energy transition entails will generate savings in subsidies to the government, removing dependence on the international price of diesel, and will support the country's energy policy in reducing greenhouse gas emissions, benefiting the Ecuadorian environment.

7. Conclusions

The energy transition of countries and industries is a necessity to avoid climate change and stay within the goal established in the Paris agreement of a maximum increase in global temperature of 1.5°C.

This study confirms that one of the proposed measures of the energy transition for decarbonization proposed by IRENA (2022) through the electrification of end-use sectors, is achieved in the case of the Ecuadorian shrimp farming sector since as it was verified, the equivalent emissions from the electrical network are much lower than self-generation with diesel systems.

Regarding the features of the energy transition summarized by Smart Edward (2022), the research made on the shrimp industry sector coincides with the theory, since it entails a long-term structural change in this energy system towards a greener one, the process is complex and takes a long time and the investment costs of the energy transition are very high and imply infrastructure that is durable over time. Correspondingly, the energy transition is influenced by political, social and environmental changes, in this particular case to provide support to one of the country's main industries that helps improve its society and the economy with the creation of more jobs and the increase of the exports. In parallel, the energy transition reduces emissions and fulfills the country's international commitments towards carbon neutrality.

Another conclusion is based on the fact that although the country's peak power demand in August 2021 was 3,960 MW (Agency for the Regulation and Control of Energy and Non-Renewable Natural Resources, 2021), if an electrification plan is developed for all the shrimp farming sector, as shown in the proposed scenario 2, the Ecuadorian government will need an additional power generation of 1,436 MW, which should be generated with technology that does not produce more emissions than the current energy matrix to maintain its decarbonization goals.

It is also confirmed that within the tools proposed by Jordan & Turnpenny (2015), scenario analysis can be used to have a vision of different futures and pathways, as was demonstrated with the three scenarios determined in this study for the shrimp farming sector.

With the energy transition of the shrimp farming sector planed by the Ecuadorian government, there is the potential to increase the shrimp production by 25%,

increasing also exports in the same proportion. The use of fossil fuels would be reduced with a potential of 187.3 million gallons of diesel per year, and government subsidies would decrease. This transition would increase the security and accessibility of energy in production processes.

The total electrification of the shrimp farming sector could also provide a reduction in emissions of 1,617 kTon CO₂, which represents 4.75% of the country's total estimated emissions in 2020.

The contribution of this study to the literature reviewed is based on creating and applying a new methodology to measure and plan an energy transition public policy based on nine dimensions that are widely used globally to measure the transition of countries. The results of the study confirm that the energy transition through electrification proposed by the government reduces greenhouse gas emissions in the industry, although the change from a diesel subsidy to an electricity subsidy does not necessarily lead to savings in the Ecuadorian government budget, since it depends on the cost of diesel, which is affected worldwide, and the cost of electricity, which depends largely on fossil fuels and investment in new generation projects.

Another contribution is based on the use of scenarios based on the number of companies that are affected by the energy transition, as in our case, which is measured in the number of electrified hectares. This methodology can serve as motivation to create new energy transition scenarios in industries, such as the use of renewable energies or other self-generation technologies, measured in a certain percentage of companies in a country, with which new scenarios can be compared and their validity validated. impact on the nine dimensions raised.

This research is expected to serve as a potential contribution to the Ecuadorian shrimp sector, to visualize the holistic benefits that can be achieved with the energy transition through electrification, and create a framework towards the energy transition for other industrial sectors in the country and the world.

7.1. Limitations and recommendations

It should be considered that this study is only a projection of scenarios based on what can be observed and measured in the current situation of the shrimp farming sector of Ecuador with the information available, which can change over time with

the variation in the price of raw materials, renewable energies, the political and social situation, among others.

The present investigation is also an academic study that presents a particular vision of the sector, which could be analyzed from different perspectives, for example, instead of analyzing it considering the transition of the sector towards electrification, it could be carried out towards distributed generation or the use of energies. renewables with batteries for their operations.

We recommend taking the methodology developed in this study to deepen with more variables of measures. This methodology can also be used as a reference towards the energy transition of other industries. A vision that could also be recommended is the creation of an index, such as the Energy Transition Index (ETI), but applied to measure the industrial sectors of a country, which serves as a benchmark among them.

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Annex 1. Calculation of average energy consumption in shrimp farms

Shrimp Farm connected to the grid	Power demand (kW)	Avg. monthly Energy Consumption (kWh/month)	
VIAFARA POLO JAMES	702	143,932	
EMPRESA AQUASHRIMPS S A	154	53,079	
AGUAMARINA COMPANIA ANONIMA	673	93,646	
BELLITEC S.A.	557	123,438	
AQUA TECH SOCIEDAD ANONIMA	445	69,304	
CAMACIEL S.A.	299	32,443	
CUEVA YANGUA ANGEL BOLIVAR	266	99,845	
ERAZO SANCHEZ LUIS MIGUEL	583	93,090	
JARCELMAR CIA LTDA	658	117,669	
LANGOSTINO S A LANCONOR	1767	424,767	
LIGFA S.A.	409	42,467	
PESQUERA MARYCIELO CIA LTDA	554	118,058	
RUIZ CABRERA KLEVER YOVANNY	458	119,095	
SEMBRIOS BELLA MAR S A SAMBELMAR	340	75,803	
FINCACUA SA	378	152,600	
PISCICOLA MALMALSAECON SA	728	160,533	
PRODUMAR S.A.	952	508,667	
AGROPECURIA AQUA CAMARON AGROSEACOM	120	41,733	
ANGARSHRIMP S.A	273	100,095	
CAMARONERA SUPRACAMARON ECUADOR	641	231,482	
DELICAMARONERA S.A.	610	199,034	
EXPORCAMBRIT S.A	4215	756,816	
GREENTRAILCORP S. A.	731	416,855	
INDUSTRIAL PESQUERA SANTA PRISCILA	944	338,420	
INLAFA, S.A.	208	53,821	
MENIER S.A	143	47,344	
MENIER S.A	131	43,224	
QUIMANSERVI S. A.	174	38,664	
QUIMANSERVI S.A.	250	58,200	
TECNOTEMPE S.A.	501	174,918	
CAMARONERA SAN JOSE S.A. SANJOCAMAR	104	54,949	
CULTIVOS MARINOS CULMARINSA S.A.	409	21,462	
EMPACADORA GRUPO GRANMAR	319	153,342	
GENETICA MARINA DEL ECUADOR S.A. (GENEMAR)	149	28,824	
INDUSTRIAL PESQUERA SANTA PRISCILA S.A.	123	39,600	
INDUSTRIAL PESQUERA SANTA PRISCILA S.A.	263	80,850	
INDUSTRIAL PESQUERA SANTA PRISCILA S.A.	281	119,952	
INDUSTRIAL PESQUERA SANTA PRISCILA S.A.	734	295,344	
LUTHORCORP S.A.	487	162,288	
MACROBIO S.A.	357	195,650	
PRODUCTOS MARINOS OMARS	361	119,700	
PROMARISCO S.A.	148	26,852	
TEXCUMAR S.A.	256	132,762	
DIVACCI	442	73,208	
	23,297	6,433,824	kWh/month
		77,205,884	kWh/year

Table 3. Energy and power consumption of shrimp farms connected to the grid

Source: Ministry of Energy and Non-Renewable Natural Resources (2022a)

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