ECUADOR'S ENERGY SECTOR:
PAST, PRESENT, & POTENTIAL FUTURE

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INTERNATIONAL SUSTAINABLE DEVELOPMENT (SUST 3701)

Spring 2020

STOCKTON UNIVERSITY

ENVIRONMENTAL SCIENCE AND GEOLOGY PROGRAM

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Abstract:

Ecuador has access to a great variety of energy resources due to its geographical location and geological conditions, ranging from high amounts of solar radiation to large oil reserves. These oil reserves have shaped much of Ecuador's past in terms of the development of its energy sector. In recent years, the country has made a shift to include significantly higher amounts of renewables into its energy portfolio. Through domestic and international investment, hydroelectricity now accounts for the majority of all power produced on the mainland. The Galapagos Islands still remain largely dependent on imported diesel for its power plants, but the number of renewable installations is increasing. However, newly identified issues with Ecuador's hydroelectric facilities may lead to increase in other renewable alternatives, mainly in terms of wind, solar, and geothermal power.

Introduction:

The modern energy industries of the world have historically been reliant on the use of carbon-based fossil fuels as the primary fuel source for electricity generation. This reliance has led to an ever-increasing amount of greenhouse gas emissions and numerous environmental issues. These issues are now being compounded by the pursuit of better standards of livings in developing nations, particularly in Asia, and the expansion of their individual energy sectors. As a result of this, worldwide energy consumption is expected to increase by approximately 50% from 2018 to 2050. Historically industrial sectors have represented the majority of international energy consumption, but the residential and commercial sectors have drastically expanded their consumption in recent years to meet the new standards of living. Increasingly higher energy

consumption will present many major environmental concerns should it be meet with increases in fossil fuel-based generation. However, according to the U.S. Energy Information Administration, the small growth expected in fossil fuel energy is predicted to be outstripped by the growth of renewable energy sources, which will become the most dominant primary sources of energy by 2050. These trends are driven by growing governmental awareness of the environmental issues that continued greenhouse gas emissions are causing and increasing financial viability of renewable energy sources when compared to traditional fuel sources (US Energy Information Administration, 2019 + Dudley, December 13, 2018). The growing energy sector of Ecuador perhaps best represents these larger international trends and provides an idea of what a renewable energy future may look like. This paper will be examining the various energy resources of Ecuador as well as the past, present, and possible future states of the Ecuadorian energy sector.

Ecuador's Natural and Geological Resources:

Despite being a small developing nation on the western coast of South America, Ecuador is home to a variety of geological/geographical features that greatly benefit its energy sector. Ecuador's territory can be differentiated into four unique areas, which are the Galapagos Island, the Pacific coastal lowlands, the Andes Mountains, and the Amazon. The Amazon region is home to Ecuador's largest oil fields, which have seen widescale exploitation by foreign companies and the Ecuadorian government since the mid 1900's. The coastal lowlands surrounding the port city of Guayaquil are also rich in natural gas deposits. In total, these are estimated to hold the country's fossil fuel reserves of 8.83 billion barrels of oil and 11 billion cubic meters of natural gas (Alves, June 19, 2019 + Natural Resources and Energy, n.d + Peláez-Samaniego, April 11, 2007). In

addition to the reserves of the lowlands and Amazon, a 2017 report published in volume 109 of *Renewable Energy,* found that the Andes had the most potential for wind energy. The Andes mountains contained the areas with the best access to wind currents, current infrastructure, population centers, and unrestricted land (Villacreses, March 23, 2017).

Additionally, there are other resources that Ecuador is able to access that are not bound to the specific regions in the country. A defining characteristic of Ecuador is its location on along several tectonic plates and the Equator, resulting in high levels of geological activity and solar radiation. As a result, solar farms and geothermal power plants are viable in large swathes of the country. The largest resource that Ecuador has access to however is the vast number of rivers and streams that exist within the country. Referred to as the, "Water Capital of the World", these water resources gives the country the ability to generate large amounts of hydroelectricity through the use of dams (Terry, December 15, 2007).

The History of Ecuador's Energy Sector:

Although possessing a wide range of energy resources, the poor economic conditions and restrictive terrain of Ecuador had a limiting effect on the country's electrification. While the United States had constructed its first commercial power plant in the 1880's, Ecuador would not see widescale commercial electrification until the mid-1900's. Small-scale hydroelectric plants had been constructed in several areas of the country starting in the 1890's, but they were isolated from each other and covered small service areas. These plants were most often used for industrial purposes, such as providing power to gold mines in the "El Oro" province in 1924. By the 1950's, these plants were consolidated into a series a municipality owned utility companies, but they still

only provided electricity to approximately 17% of the country. This number would only begin to expand in 1961 with the establishment of the Ecuadorian Institute fort Electrification, or INECEL, under the First Master Plan for Electricity. Under this plan, INECEL would have complete control of Ecuador's energy sector, being responsible for all regulation, setting tariffs and rates, and construction of new power plants. During its operation, INECEL would construct Ecuador's largest hydroelectric facility at the time with a rated capacity of 1075 Megawatts. Around the time INECEL was expanding Ecuador's energy infrastructure, the Ecuadorian government and foreign oil companies had discovered the large oil reserves in the eastern Amazon regions. The Texaco-Gulf oil company was given permission to begin extraction in 1967 and oil pipelines were quickly built to bring the extracted crude oil to the three coastal refineries Ecuador operated. By 1972, the oil output of these fields was 29 million barrels.

With Ecuador's vast oil and hydroelectric resources under the management of the Ministry of Energy and Mines and INECEL, its installed energy capacity steadily grew. By 1980, 226 Megawatts of hydroelectric energy and 856 Megawatts of thermal energy were installed. The amount of hydroelectric capacity would surpass thermoelectric capacity by 1990 and drastically increased the difference between the two until 1997, when thermal capacity grew beyond hydroelectric. This shift was influenced by the dissolvement of INECEL in 1996 and the opening of Ecuador's energy sector to private investors. From this point, the differences in installed capacity between the two energy sources remained negligible. There were a total of twelve utility companies operating within Ecuador by 2006, with only four focusing on continued hydroelectric development. The other eight utilities solely operated thermoelectric energy plants due to the cheaper costs of facility construction. The amount of traditional renewable power sources, such as wind and solar, remained nearly non-existent during this time. Despite its significant build up,

the energy sector began to struggle meeting its full demand in 1999, requiring the importation of energy from surrounding countries. However, the electrification process had been wildly successful and 83% of the population had access to electricity in 2004 (Peláez-Samaniego, April 11, 2007 + Natural Resources and Energy, n.d).

The Modern Energy Sector:

Oil extraction in Ecuador would continue to expand well into the 21st century, with production reaching all-time highs. The oil industry would come to dominate the Ecuadorian economy due to the sheer amount of oil being produced and the demand from both domestic and international sources. This excessive influence was strengthened by a sharp rise in oil prices in the between the early 2000's and late 2010's, helping cement crude oil as the top export for Ecuador. Oil's dominance would crumble shortly after this high point as prices once again shifted and plummeted. At the same time as this economic shift, oil production began to plateau and international scrutiny on the negative environmental consequences of fossil consumption was rising (Ecuador Crude Oil: Exports, n.d). As a result of these conditions, Ecuador began to shift its energy sector away from its dependence on fossil fuel energy. In 2009, the Plan for Good Living was put forth by the Ecuadorian government to shift investment from thermoelectric power plants to hydroelectric facilities. This plan called for the construction of eight new hydroelectric dams that would be able to meet 90% of the country's energy needs. Six of these dams would be financed by the Ecuadorian government and various financial institutions, such as the International Monetary Fund. The largest of these dams is the Molino dam, with a rated capacity of 1,075

Megawatts, and the smallest is the Mazar-Dudas dam, with a rated capacity of 21 Megawatts (Ecuador, May 2017).

The other two dams that were constructed under the Plan of Good Living are unique from the others as they are the largest in the country and were financed primarily by China and its Exim Bank. The Coca Coda Sinclair dam and associated power plant is the largest hydroelectric facility in Ecuador, with a rated capacity of 1,500 Megawatts, and provides 30% of Ecuador's total power needs. Another 13% of the country's power needs are met by the Sopladora dams, located on the Paute River in the south-east of Ecuador. The Sopladora dam works in tandem with the Molino dam as part of the Hydropaute cascade scheme, where the Sopladora dam is located downstream from Molino dam. This scheme allows the Sopladora dam to maintain high levels of generation in periods of low river flow by increasing the amount of water released by the Molino dam. These dams were financed by China instead of Ecuador due to a debt-for-oil agreement between the two countries. As part of this agreement, Ecuador must export certain quotas of oil to China while also allowing Chinese companies to invest in energy projects within Ecuador (US Energy Information Administration, October 5, 2017). Despite being financed by Chinese companies, all power facilities are managed by the Electric Corporation of Ecuador, or CELEC. With construction of these new hydroelectric facilities, Ecuador was able to reach approximately 60 to 70% of its total power needs with hydroelectricity. This is a dramatic increase from the 44% that was met in the early 2000's, but still below the desired 90% put forth by the Plan of Good Living (Ecuador, May 2017).

In order to make up for the power deficit left by hydroelectric expansion, Ecuador has begun to invest more in other sources of renewable energy. Wind farms have seen minor investment in the continental territories of Ecuador. Viability studies have shown that the best

locations for these farms are in the Andes region of the country based on a variety of factors, such as wind speed, land availability, and overall sustainability (Villacreses, March 23, 2017). The largest of these farms began construction in 2012 in the Loja province, with eleven 1.5 Megawatt turbines being installed originally and additional 30 turbines planned to be installed at a later date. The original 11 turbines present in this farm supplied 25% of the provinces total power consumption and the installation of the new turbines would raise this percentage to between 45 and 60% (Sanchez, August 27, 2012). In the coastal provinces, the power production of solar farms have been shown to outcompete the production of offshore wind turbines, leading to increased interest in solar for these areas. The first solar farm in Ecuador was constructed in 2013 and was relatively small, only consisting of 4,160 panels and covering 3.5 hectares (First Photovoltaic Solar Power Plant in Ecuador, February 4, 2013). The success of this solar farm and the wind turbines in the Andes has spurred the Ecuadorian government to seek foreign investment so that a 200-Megawatt solar farm and a 110-Megawatt wind farm could be constructed in the Manabí province. These energy sources would help alleviate issues related to potential drops in power production that occur during dry seasons in Ecuador. This plant is expected to meet 22% of the provinces power demand and represents a serious increase in solar and winds presence in the Ecuadorian energy sector (Martin, July 31, 2019).

In addition to solar and wind, Ecuador has begun to tap into the impressive amount of geothermal power resources that can be found through out its territories. Geothermal power plants operate by using the natural heat of the Earth to turn pumped in water or existing groundwater into steam to turn steam turbines, much like traditional thermoelectric plants. Currently, the only direct use of geothermal power present in Ecuador is for water heating and small-scale heat pumps. However, the Ecuadorian government has begun exploratory drilling in the Andes to determine

the feasibility of constructing utility-scale geothermal power plants. The first of these drillings occurred in the Chachimbiro prospect during 2017. This geothermal well was able to reach temperatures close to 225 degrees Celsius at a depth of 1,978 meters, which is relatively shallow for the average utility-scale well. Another ten prospects were planned in 2010 along with the one in Chachimbiro and currently four of these have received the funding they need to begin exploration. Three of these wells will be high temperature wells similar to the Chachimbiro well, and the last one will be a shallower low temperature well. The remaining six wells are waiting for funding to become available and more studies must be conducted before any power plants begin construction (Beate, n.d).

In order to distribute the power generated by the many new facilities that the Ecuadorian government and other investors have constructed, the existing energy grid was expanded greatly. CELEC oversaw the construction of 2,000 kilometers of new transmission lines and an additional 600 kilometers of high voltage transmission lines. Four new substations were also constructed near major population centers to better improve the power reliability in those areas (Ecuador, May 2017).

Energy in the Galapagos Islands:

While the Ecuadorian government has invested heavily in renewable energy sources in its mainland territories, investment in the Galapagos Islands has been slow. In 2009, the government declared that they would be working towards meeting all of the islands' energy needs with renewable sources. The protected nature of the islands has resulted in development being slowed in order to ensure that development does not disturb the environment and the many species found

there. However, progress has been steadily been made in expanding renewables on the islands, mainly in the forms of solar and wind generation. The first wind-based power plant was established on San Cristobal in 2007 and consisted of three wind turbines and a number of smaller solar panel systems, producing approximately 31% of the island's total power needs (Galápagos San Cristóbal Island Wind Park, n.d). Independent, small-scale solar generation is also present on the majority of the inhabited islands but is usually reserved for larger properties like the Baltra Island airport and Charles Darwin Research Centers. The most successful project to date is a newly constructed solar and biodiesel plant located on Isabela Island. This plant was built in 2016 through the cooperation of the Ecuadorian government, the Elecgalapagos utility, and the German engineering conglomerate Siemens. Beginning generation in 2018, this plant has an average of 114 Megawatt-hours each month from solar panels and reduced the amount of diesel used by 42 tons (Hybrid power plant for the Galápagos Islands, n.d). Despite these successes, the energy sector in the Galapagos Islands still remains dominated by traditional thermoelectric plants that utilize diesel fuel shipped in from the mainland.

The Future of Ecuador's Energy Sector:

Although the many hydroelectric plants Ecuador has constructed have allowed it to limit the amount of fossil fuel generation, there have been a variety of problems associated with their implementation as well. Hydroelectric dams have a history of causing environmental issues associated with the creation of reservoirs and construction. The reservoirs required to allow dams to operate at 100% capacity are known to cause massive habitat and land loss for both the people and species that once lived in the surrounding areas. Additionally, the emissions that these dams

are supposed to offset by replacing fossil fuels may also be generated by the reservoirs, as underwater decomposition in the reservoir causes the release of greenhouse gases (Environmental Impacts of Hydroelectric Power, March 5, 2013). In terms of construction, the hydroelectric dams constructed by China in Ecuador have come under increasing scrutiny. The Coca Coda Sinclair dam in particular has been experiencing severe structural failure in the form of hundreds of exterior cracks, with many more estimated to exist underneath the concrete exterior. The failure of this dam would be catastrophic for the surrounding areas, but further assessment and repairs could cost upwards of one billion dollars (Casey, December 24, 2018).

Given the Ecuadorian government's desire to reach 90 to 100% renewable generation and the replacement of all of its thermoelectric generation capacity and the issues present with its hydroelectric systems, it is likely that the country will begin to shift its investments into other renewable sources. Overall, wind and solar power plants are much cheaper to construct and operate than hydroelectric facilities and do not represent a potential disaster if they should fail. Under the current system, expansions in these areas could help the country fully divest itself from thermoelectric generation if the hydroelectric facilities were kept in operation or they could begin to replace hydroelectricity as the main form of generation. This would require the creation of energy storage solutions to counteract the intermittent power generation that plagues solar and wind. The smaller hydroelectric dams could be repurposed to serve as energy storage by utilizing the techniques of pumped hydroelectric storage. This involves pumping water to higher altitudes when power generation is greater than normal and holding it there until power is needed. When demand increases, this stored water can be released back downhill, generating additional electricity through operating turbines.

The promising results of geothermal testing in the Andes could also contribute greatly in the expansion of geothermal power generation as funding becomes available. The most distinguishing characteristic of geothermal power is its superb ability to act a baseload power source, as these facilities are known to produces a consistent amount of power at all times of the day. This fact would allow geothermal facilities to work well with other renewables like solar in wind to provide for both baseload of many of Ecuador's provinces and the increased demands at certain times of the year. However, it is also likely that these facilities will be largely constrained to the mainland, despite the excellent conditions in the Galapagos Islands. This is largely due to the strict regulations in the islands and the difficultly of assessing the potential environmental impacts of geothermal power generation in the Galapagos (Beate, n.d).

Conclusion:

The modern Ecuadorian energy industry has come a long way from its fossil fuel-dominated beginnings and is now well on its way to achieving the desired goal of 90% renewable generation. This miraculous shift has been powered by advances in hydroelectric infrastructure and massive investments from both domestic and international sources, despite complications in recent years. Other sources of renewable power have also proven themselves to be indispensable in lowering reliance on fossil fuel usage and generating significant portions of the country's power needs. Ecuador has proven itself to be a leader in global pursuit of renewable power generation and can serve as an exemplary model for other developing nations seeking environmentally friendly energy independence.

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