ASSESSMENT OF THE DEVELOPMENT OF AN OFFSHORE WIND ENERGY PROJECT IN THE ARCHIPELAGO OF SAN ANDRES, PROVIDENCIA AND SANTA CATALINA FROM A COST-EFFICIENCY PERSPECTIVE

by
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EXECUTIVE SUMMARY

This report could have not been done without the knowledge gathered during the master’s degree in Energy Policy and Climate. In particular, this work leverages the knowledge gathered on courses related to wind energy policy, science and technology. First, wind energy policy is key for proper offshore energy management. It sets the foundations needed for the development of offshore wind energy projects and is also a key determinant to the success of this type of technology. It also determines the “game rules” that need to be followed to engage all the stakeholders and ensure a positive environmental and social outcome of a project.

Second, it is important to understand the science behind this technology to understand the key influencing variables for an offshore wind turbine's efficient functioning. In this sense, bathymetry and wind speed are the key variables that need to be taken into account for the proper deployment of the offshore wind technology. On one hand, bathymetry has a direct impact on the installation costs of the offshore wind project as the cost will increase as the depth increases. And on the other hand, wind speed determines the commercial feasibility of a project.

And third, the characteristics of wind turbines and the current state of this technology is important to understand as it also impacts the cost-efficiency of a project. In this sense, a more efficient and larger wind turbine may represent efficiency gains in terms of cost reductions and increased electricity generation compared to a smaller and less efficient one. To analyze the effect of the technology on the cost-efficiency of a project, it is crucial to understand the policy and science aspects associated to offshore wind energy.

Mentored by Gerard Alleng

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INTRODUCTION

The archipelago of San Andres, Providencia, and Santa Catalina is the only insular department of Colombia. This archipelago, which has a population of about 80 thousand people and an area of 52.2 square kilometers. The set of islands rely on fossil fuels to cover most of its energy demand and on subsidies from the Government for electricity generation. All these has high financial, economic and environmental costs associated.

Role of renewable energy sources for a sustainable development

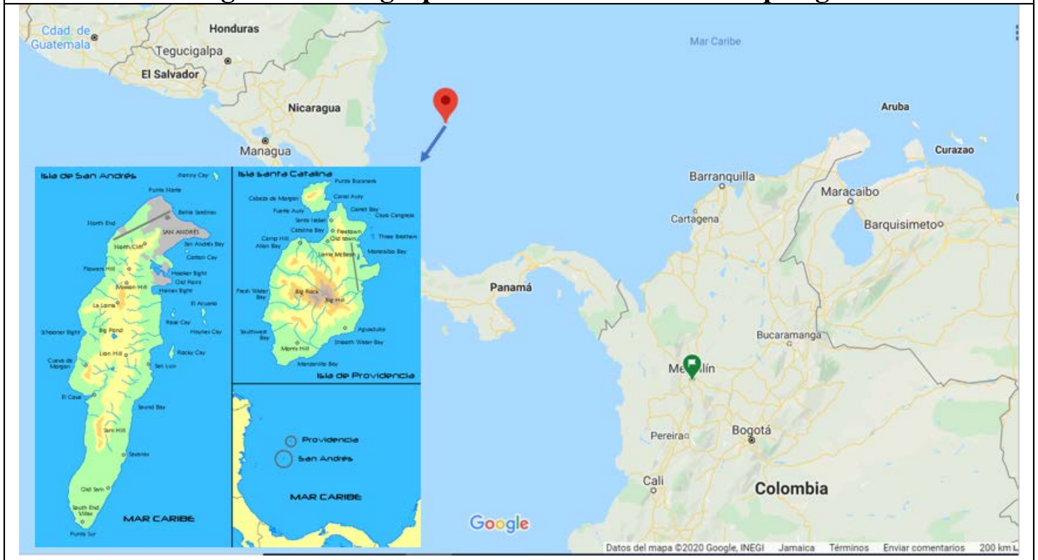
The industrial revolution evolved the way we do things as almost all daily activities require energy. To do so, we have relied mostly on fossil fuels to meet our energy needs. However, we are now starting to see the impacts of the overuse of these energy sources and are now requiring sustainable energy sources in order to mitigate climate change (IDB, 2016, p. 6).

Renewable energy sources can be utilized over and over again without exhausting them (IDB, 2016, 13-15). In addition, these sources could be a major contributor towards the energy consolidation for all countries as it can replace fossil fuels (or non-renewable energy sources) while reducing Greenhouse gas (GHG) emissions (Ganda et al., 2014) and/or help diversify the electricity matrix. Moreover, the deployment of these technologies has helped reduce the cost of the electricity bill in poor populations, as well as to create jobs in remote and poor areas (IDB, 2016, 13-15). Other indirect effects of the development of renewable energy projects include productivity improvements, job creation in other economic sectors, and the creation of tertiary services in the areas where these projects are developed.

The archipelago of San Andres, Providencia, and Santa Catalina

The Archipelago of San Andres, Providencia and Santa Catalina is a small set of islands composed of three large islands (San Andres, Providencia and Santa Catalina) and more than 20 keys. It is the only insular department (i.e. state) from Colombia (Figure 1). The archipelago is 775 kilometers northeast off the Atlantic coast of Colombia and about 220 kilometers from the west coast of Nicaragua. The set of islands has a total population of about 80 thousand people. It is the smallest department in Colombia in terms of area (52 square kilometers) and yet it is the most densely populated one with over 1.470 inhabitants per square kilometer.

Figure 1 – Geographical location of the Archipelago



Source: Google Maps. Wikipedia (https://es.wikipedia.org/wiki/Archivo:IslaSanAndresProvidencia.png).

From the three main islands, San Andres is the largest with an area of 27 square kilometers. It holds about 93 percent of the total population that lives in the archipelago. Providencia, the second largest, has an area of 7 kilometers square, and Santa Catalina is about one kilometer square (IDB, 2016, p. 17-20).

Electricity generation and demand

The archipelago is classified as a non-interconnected zone[1] (Figure 2) because it is not connected to the national electricity grid and supplies its energy needs mostly with fossil fuels like diesel (Figure 3). As a result, utility rates are approximately $0.26 per kilowatt-hour, which is slightly below the average for the Caribbean region which is $0.33 per kilowatt-hour (NREL, 2015). This price almost doubles the national interconnected grid's residential electricity tariff, which is $0.14 per kilowatt-hour (global petrol, n.d.). Greenhouse gas (GHG) emissions are about 134 thousand of CO2 equivalent every year and the fiscal burden that the archipelago represents to the country is about 40 percent (or about US$25 million) of the

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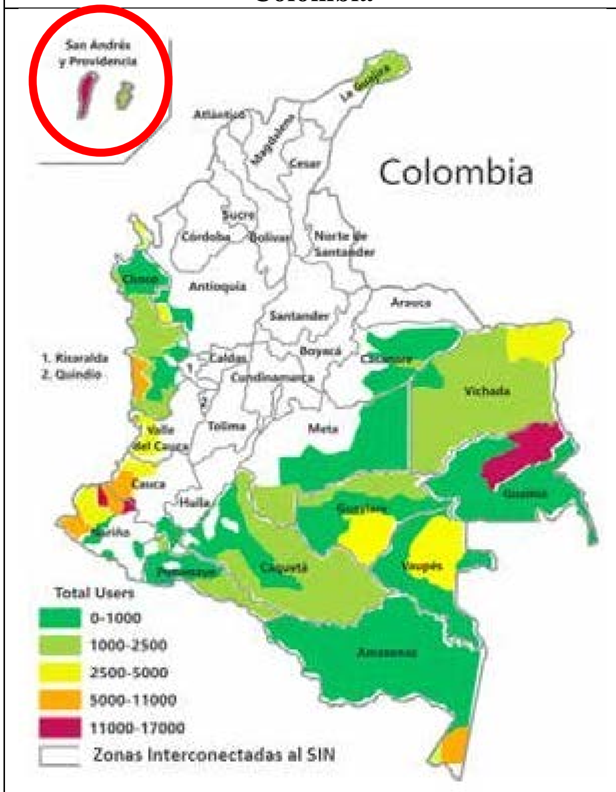
[1] Non-interconnected zones are areas that are located far from important consumer hubs, have high electricity tariffs due to the use of fossil fuels and the elevated transport costs, are characterized for having population with a reduced payment capacity, and also high fiscal costs due to the subsidies needed for the purchase of fossil fuel that is used for electricity generation (Law 855 of 2003).

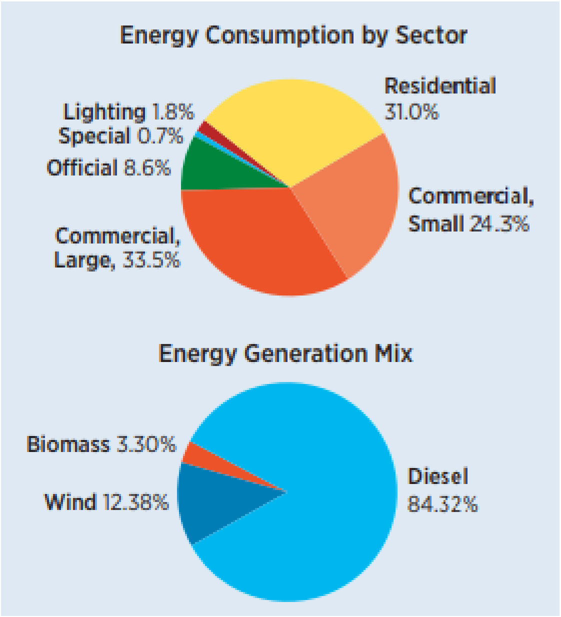
total subsidies provided by the national government to the fossil fuels used for electricity generation to non-interconnected zones every year (IDB, 2016, p. 17-20).

Figure 2 – Non-interconnected zones in Colombia



Source: Minminas, 2015

Figure 3 – Energy consumption and generation mix in the Archipelago



Source: NREL, 2015

There are over 19 thousand electricity users in the archipelago from which 90 percent are located in the main island of San Andres and the remaining 10 percent are in Providencia (IDB, 2016, p. 22-29). Annual electricity production is about 187.5 gigawatt-hour; the commercial sector accounts for over half (57.8 percent) of the energy consumption, residential represents 31 percent, and official, special and lighting the remaining 11.2 percent (Figure 3. NREL, 2015). The archipelago has universal coverage of the electricity service. Although it might sound odd, it is an important feature given that in many developing countries not everyone has access to electricity (from a utility company). On the downside, losses in the distribution of the electricity are around 24 percent, from which half is paid by the country.

The Energy Producing Society of San Andres and Providencia (SOPESA) is the utility company in charge of the generation, distribution and commercialization of the electricity service in the archipelago. San Andres has a total installed capacity of 83.6MW divided in 18 generation units that use diesel to generate about 200 GWh every year. In addition, San Andres has a 1MW waste-to-energy plant. On the other hand, the island of Providencia has a total installed capacity of 4.6MW divided in 4 generating units that also use diesel (IDB, 2016, p. 22-29).

The amount of electricity subsidized for low-income users in the archipelago is greater than in the continental territory of Colombia (UPME Resolution 18 1480 of 2012). In 2016, it was estimated by the Inter-American Bank that the archipelago received about U$100 million in subsidies in the between 2012 and 2016, which represented 40 percent of the total amount gave to the population in the form of subsidies for this matter (IDB, 2016, p. 22-29).

Given the current configuration of the electricity matrix, the high energy costs and GHG emissions, the high level of subsidies provided by the government to ensure the delivery of electricity to the inhabitants of the archipelago, and the expected growth in the demand, it is necessary to reevaluate the way energy sources are used to ensure the economic, environmental and social sustainability of the archipelago. To tackle these issues, renewable energy will play a key role in the coming years.

Offshore wind energy potential

The Mining and Energy Planning Unit (UPME) identified solar, wind, geothermal, and biomass as the most promising non-conventional renewable energy (NCRE) sources in Colombia (UPME, 2015, p. 24-33). For the Archipelago of San Andres, Providencia and Santa Catalina in particular, solar and wind were identified to have the largest potential. However, wind assessments refer (almost) exclusively to the archipelago's onshore wind energy potential which at the same time is hard to tap given the limitation of physical space in the island (NREL, 2015). On the other hand, offshore wind potential in the marine areas that belong to the archipelago falls within the commercially viable range. This, in addition to the current wind technology, allows for the development of an offshore wind energy project near the islands composing the archipelago.

This will contribute to a cleaner future for the archipelago and it could also help reduce electricity subsidies provided to low-income population. Recent offshore wind projects produced prices or costs that are considerably lower to the electricity tariff that the islanders currently pay. This will not only reduce the price paid by the final users but it will help abate 134 thousand tons of CO2 equivalent every year and reduce the U$25 million in subsidies that are given to the archipelago each year for the purchase of fossil fuels to generate electricity.

For a small set of islands that are overpopulated, accessing the portion of water that belongs to them for economic development is not a minor thing. This, added to the high cost of electricity due to their reliance on fossil fuels, opens the door for new and upcoming technologies like offshore energy sources. These include fixed and floating offshore wind, sea water air conditioning, ocean thermal energy conversion, wave energy, and tidal and ocean current energy. To complement the Government's efforts to reduce GHG emissions, as well as the cost of electricity for the final users, this paper intends to assess the feasibility of developing an offshore wind energy project in the archipelago of San Andres, Providencia and Santa Catalina by estimating the Levelized Cost of Electricity using the most recent offshore wind energy technology and costs associated, and taking into account the archipelago's offshore wind energy potential and bathymetry.

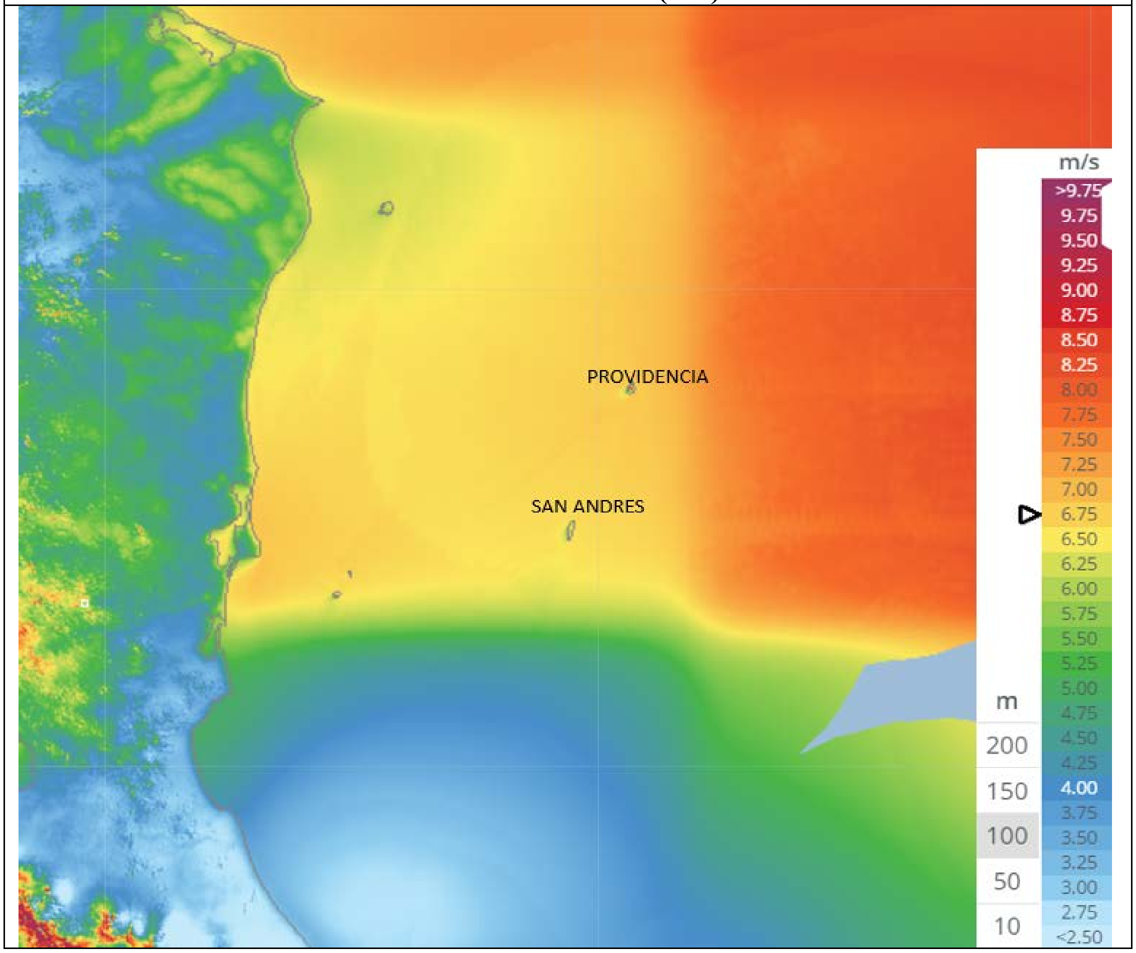
METHODS

This work focuses on the calculation of the LCOE for an offshore wind farm near the Archipelago of San Andres, Providencia and Santa Catalina in Colombia. To do so, it was necessary to first assess the wind energy potential and bathymetry near the archipelago to identify the feasibility of the wind farm from a technical perspective. Then, the LCOE approach is applied to estimate the revenue needed to cover the costs associated to the offshore wind farm.

Wind energy potential near the archipelago

The Global Wind Atlas is a free tool developed by the Technical University of Denmark and the World Bank Group that contains information on wind speed for all the regions in the world. It was developed to help policymakers and investors to identify high-wind speed areas, mostly for onshore wind power generation (Global Wind Atlas, n.d.). Although it is primarily a source of information for onshore wind data, it also has an offshore coverage of up to 200km from the shore. The database is based on the ERA5 reanalysis which has proven to be close enough to real wind speeds in non-mountainous areas (Jourdier, 2020). In this sense, this database will be enough given that this analysis is the first exercise made in the archipelago to understand the wind energy potential of the area and a preliminary assessment of the LCOE to determine the feasibility of building an offshore wind plant near the archipelago.

Figure 4 – Offshore wind speed map near the archipelago of San Andres, Providencia and Santa Catalina(m/s)



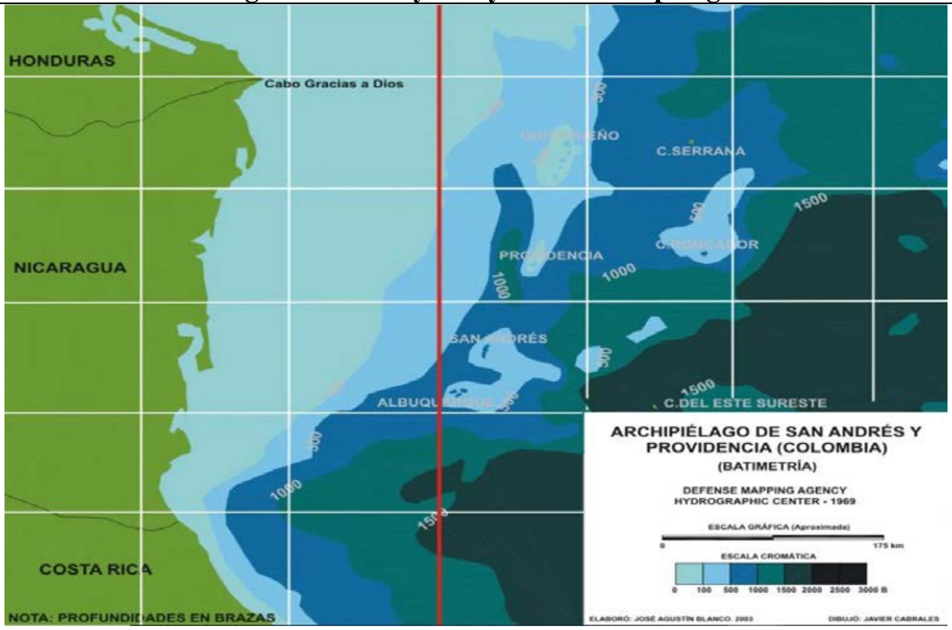
Source: Global Wind Atlas. (n.d.). Taken from: https://globalwindatlas.info/

From the image above it is possible to identify that average wind speeds near the islands of San Andres and Providencia, the most populated islands from the archipelago, are between 6.50 and 6.75 meters per second (Figure 4). This is very important as average annual wind speeds over 6.5 meters per second at 80-meter height are within the commercially viable range (University of Michigan, 2020). In fact, areas are considered "good places" where wind speed is at least 4 meters per second for small wind turbines and 5.8 meters per second for utility-scale turbines (EIA, 2020). Moreover, the wind speed range is above the cut-in speed at which a typical turbine starts generating electricity which is around 4 meters per second (AWEA, n.d.).

Bathymetry

Once the energy potential is verified, it is also key to verify the bathymetry near the islands. The bathymetry in this context refers to the distance from the sea level to the ocean floor at which the wind turbine was installed. The most recent technology advancements have been allowed turbines to be installed in depths close to 60 meters, although the great majority of wind turbines have been installed at depths below 40 meters (IRENA, 2020).

Figure 5 – Bathymetry of the archipelago



Source: Blanco, Jose. (n.d.).

The archipelago's bathymetry shows that water depth near the shore is between 100 and 500 meters in near San Andres, and between 0 and 100 meters near Providencia (Figure 5). This discards the area near San Andres for the installation of fixed offshore wind turbines given the current state of the fixed offshore wind technology. However, the installation of floating wind platforms in this area could be an option to explore as it has been done in other parts of the world, although cost is still a challenge. Providencia, on the other hand, opens the option for the development of an offshore wind farm.

LCOE AND WACC CALCULATION

The Levelized Cost of Electricity (LCOE) gives the average revenue needed to cover all the associated costs of constructing, operating and maintaining a renewable energy plant throughout its lifetime (EIA, 2020, p. 1-2). In this case, the LCOE is calculated to give an estimate of the minimum revenue amount required to cover all the costs associated to an offshore wind energy plant built in the Archipelago of San Andres, Providencia and Santa Catalina. This will provide a reference on the cost of the electricity produced with an offshore wind energy plant at which the technology will be competitive given the current cost structure of electricity in the archipelago.

LCOE approach

The LCOE measurement varies by the technology characteristics, project type, energy resource available at the site, as well as the capital and operating costs (IRENA, 2015). The approach used in the analysis of the offshore wind energy project in the archipelago consists on the estimation of the costs and energy produced every year during the life of the project, the discount of these flows to present value using the project's cost of capital (Weighted Average Cost of Capital, WACC), and the final calculation of the LCOE. This modelling approach offers a simple and easy way to assess the feasibility of the construction of an offshore wind plant near the archipelago without the need to make too many assumptions (IRENA, 2015).

The general formula for the LCOE is the following:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1 + WACC)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1 + WACC)^t}}$$

Where:

LCOE: Levelized cost of electricity generation

I_t: Investment expenditures in year t

M_t: Operation and Maintenance (O&M) expenditures in year t

F_t: Fuel expenditures in year t; in this case, this is zero

E_t: Electricity produced in year t

WACC: Weighted average cost of capital (i.e. discount rate)

n: life of the project; in this case, this is 25 (years)

The final LCOE formula for the offshore wind energy project in the archipelago is:

$$LCOE = \frac{\sum_{t=1}^{25} \frac{I_t + M_t}{(1 + WACC)^t}}{\sum_{t=1}^{25} \frac{E_t}{(1 + WACC)^t}}$$

As noted above, the LCOE model used takes into account the two main cost sources: project-specific installed costs (I_t) and the O&M costs (M_t) which in this case are the same as the "all-in" Operational Expenses (OPEX) of the project; this includes commonly excluded costs such as insurance and asset management costs (IRENA, 2020, Annex I). IRENA's O&M cost assumptions are based on real-project costs which range between \$0.017/kWh and \$0.030/kWh, being the most expensive value from those projects that have been built in less-developed offshore wind markets (IRENA, 2020, p. 83). For the purpose of this analysis, the average between these two values was used under the base case scenario, and the highest value was applied in the conservative approach. The total installed costs, on the other hand, cover the costs associated to the planning, development, construction and connection of the offshore wind energy project. The main costs are development costs, turbine costs, installation costs, foundation costs, electrical interconnection costs, and planning, project management and administrative costs (IRENA, 2020, p. 78-83).

WACC formula

The WACC formula used is the following:

$$WACC = \left(\frac{E}{V} \times R_e\right) + \left(\frac{D}{V} \times R_d \times (1 - T_c)\right)$$

Where:

WACC: Weighted average cost of capital

E: Total equity amount

D: Total debt amount

V = E + D: Total project cost

R_e: Cost of equity

R_d: Cost of debt

T_c: Corporate tax

Capital structure

The analysis in this report assumes a capital structure of 60% debt and 40% equity, a 10% interest rate on the debt side, and a 12% cost of equity. These values are assumptions based on experience valuing renewable energy projects in Latin-America and the Caribbean (LAC). A WACC of 9.3% was assumed in this analysis, taking a 32% income tax.

The LCOE gives the minimum revenue possible for the electricity generated, in this case by the offshore wind energy plant, that would not generate losses to the developer given the capital costs of the project (i.e. WACC). In fact, any price beyond this point would generate higher returns on capital. Data needed on costs related to investment and O&M expenditures are presented in real 2019 USD values. These values were retrieved from IRENA's Renewable Cost Database[2] which has data on offshore wind energy projects deployed throughout the world over the last twenty years; costs accounted are equipment cost and total installed cost, including fixed financing costs. Also, data on the capacity factor, distance from shore, water depth, and turbine rating was retrieved from IRENA's database to calculate the LCOE. Given the absence of information about potential projects in the Caribbean, and to better adjust this analysis to a real-world project, the weighted average of the costs and capacity factor of all projects built in 2019 (the latest data available) were used, as well as the average distance from shore, average water depth, and average rating from projects build during this year.

RESULTS

As mentioned in the previous section, the wind speed potential is within the optimal range for wind power generation and the water depth near the island of Providencia, which is in the maximum depth allowed for the installation of wind turbines are being produced. The area identified near Providencia for the installation of the wind farm is about 10 by 10 kilometers, has a water depth between 0 and 100 meters, and is about 6 kilometers from the northern shore of the island of Providencia.

Once the technical aspects of the area were confirmed, the LCOE was calculated. Given the lack of information about the site and on how the most recent technology would react in the Caribbean region, two scenarios were estimated for the LCOE for this site: a base case scenario and a conservative scenario. Data

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[2] IRENA's Renewable Cost Database uses prices as a proxy for costs. In fact, the data gathered on prices are a mix between actual prices and estimates obtained from surveys.

used to calculate the LCOE was taken from IRENA's report on Renewable Power Generation Costs in 2019. The two data set are the following:

Table 1 – Summary table of variables used and LCOE calculation

Item	Unit of measure	Base case scenario	Conservative scenario
Project main characteristics			
Turbine size	MW	6	6
Average depth	mt	35	35
Turbine spacing	km	1	1
Capacity factor	%	43.5%	30.2%
Total number of wind turbines to be installed	#	9	12
Installed capacity of project	MW	54	72
Project costs			
Total installed costs	$/kW	$3,800	$5,969
O&M costs	$/kWh	$0.024	$0.030
Total CAPEX cost	$ million	$205	$430
Total electricity output			
Annual electricity produced	GWh	205.8	190.4
LCOE	***$/kWh***	***$0.132***	***$0.271***

Source: IRENA, 2020. Author's own calculations.

The base case scenario uses the weighted average of all projects built during 2019, while the conservative approach uses the least efficient value for the capacity factor and the highest costs seen in offshore wind in 2019 (Table 1). Lower capacity factors are usually proper of projects located closer to shore and sites with lower wind speeds (IRENA, 2020, p. 81).

Wind turbine spacing is about 1 kilometer which suggests that the maximum number of wind turbines that can be installed in the area identified is 25 turbines. Considering that the archipelago's annual demand is 187.5 GWh (NREL, n.d.), the amount of 6-MW wind turbines required to cover the whole demand is 9 in the base case scenario and 12 in the conservative scenario for an expected annual electricity production of 205.8 GWh and 190.4 GWh, respectively.

The LCOE calculated, using a WACC of 9.3 percent as the discount factor, is $131.91 per megawatt-hour (or $0.132 per kilowatt-hour) under the base case scenario, and $270.64 per megawatt-hour (or $0.271 per kilowatt-hour) under the conservative scenario. The electricity tariff paid by the inhabitants of the archipelago is $0.26 per kilowatt-hour (NREL, n.d.) is higher than the LCOE estimated under the base case and almost equal to the conservative scenario. Under the base case scenario, savings achieved are around $0.13 per kilowatt-hour (or 49 percent). Under the conservative scenario, the LCOE value is $0.01 per kilowatt-hour above the current electricity tariff paid by the inhabitants of the archipelago.

DISCUSSION

Offshore wind development, like the rest of non-conventional renewable energy technologies, have not been considered for the diversification of the electricity matrix in Colombia. In fact, in 2018 non-conventional renewable energy technologies represented only 1 percent of the total installed capacity in Colombia (XM, n.d.). It was only until 2019 that solar PV and (in-land) wind technologies were included in the government's plan to reduce the impact of critical hydrological scenarios given the high participation of hydro (68 percent) in the electricity matrix. In this context, the government of Colombia committed to add 1,500 megawatts in the form of non-conventional renewable energy by 2022 (IDB, 2019). Recent auctions have produced a strong interest on developing these type of energy technologies in the countries even at prices lower than the current ones (IDB, 2019). Yet, offshore wind is an area that has not been explored because of the high costs compared to the electricity tariff that we see in the continental area of Colombia. However, in the island department where land space is an issue and the electricity tariff is nowhere near the continental tariff, offshore wind could be an alternative to consider to divest from fossil fuels, reduce the carbon footprint of these set of islands, and even reduce the electricity tariff.

Offshore wind

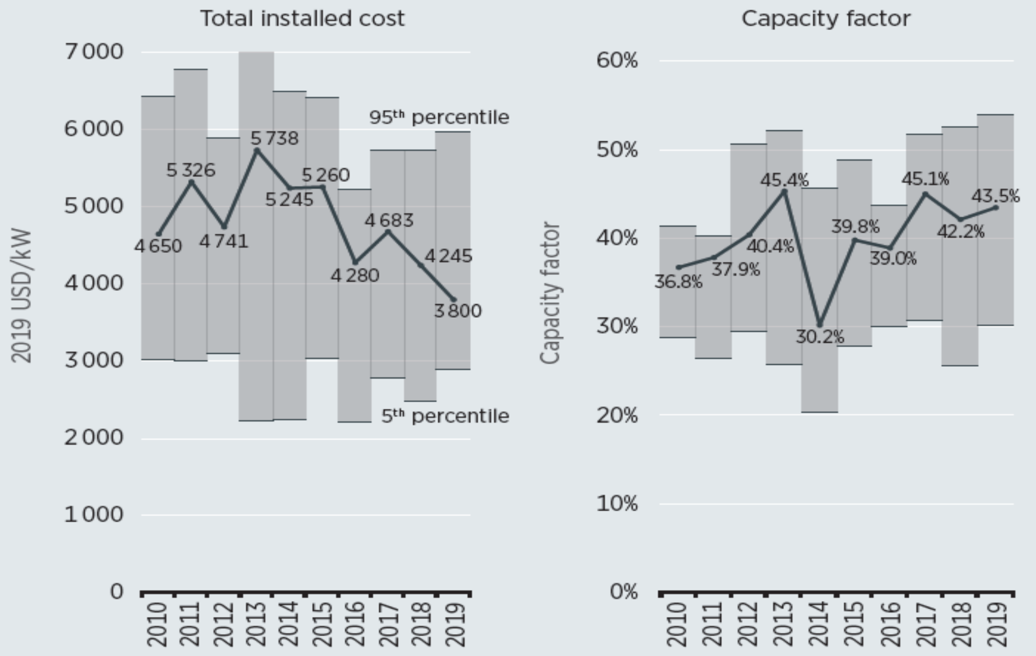
Offshore wind is a source of clean energy that could help mitigate climate change by decreasing the use of other sources that generate Greenhouse Gas emissions (NREL, 2010), as well as to increase energy security in a region that depends on imported fuels to supply the electricity demand. Wind assessment in the archipelago of San Andres, Providencia and Santa Catalina have only been done to assess wind speeds in-land. That study showed that the wind potential in the archipelago is suitable for wind power development (Realpe-Jimenez et. al, 2012). Moreover, it was determined that offshore wind technology could serve the country's energy demand (Rueda-Bayona et al, 2018).

An offshore wind turbine can operate perfectly with the wind speed estimated for the area identified for the development of an offshore wind energy project. Offshore wind turbines of 6 megawatt of installed capacity that are commercially available have been proven to work under similar wind speeds as the ones found in the archipelago of San Andres, Providencia and Santa Catalina of 6.75 meters per second. This wind class refers to annual average wind speeds of 6 meters per second. As an example, the SIEMENS SWT-6.0-154 offshore wind turbine works on I, S winds which means that it can work within a range of 6 to 10 meters per second wind speeds (SIEMENS, n.d.).

Offshore wind is an established technology, mainly in Europe and China; the United States is also starting to look at this technology as an option to diversify its electricity matrix (Browning, et al., 2020). It is a relatively new technology that has been increasing at a rapid pace. In fact, offshore wind installed capacity increased from 3 gigawatts to 28 gigawatts between 2010 and 2019 (IRENA, 2020, p. 75). Furthermore, plans to develop offshore wind energy projects have increased as costs decrease, and the technology becomes more efficient.

Evolution of costs for offshore wind energy

Figure 6 – Evolution of the global weighted average and range of total installed cost and capacity factor



Source: IRENA, 2020.

Compared to onshore wind, offshore wind technology has higher installation and O&M costs. Offshore wind operates in a more difficult environment, and its planning and construction and O&M processes are more complex. Yet, these costs have been decreasing since 2013 as more projects are being built (i.e. economies of scale) and the technology improves (Figure 6). The main drivers of cost reduction are the standardization of turbine and foundation designs, the industrialization of the manufacturing process for offshore wind components, the increased experience in the development of this type of projects at higher depths and farther from the shore, the introduction of specialized ships to conduct O&M activities, and the increased capacity of the wind turbines that are being installed with more efficient capacity factors and higher hub heights (IRENA, 2020, p. 75). Wind turbines installed nowadays are also taller, the blades are 1.5 times larger and the capacity doubles the capacity to the turbines installed in 2010 (IRENA, 2020, p. 76). In addition, less turbulent and higher average wind speeds give a more stable wind power production.

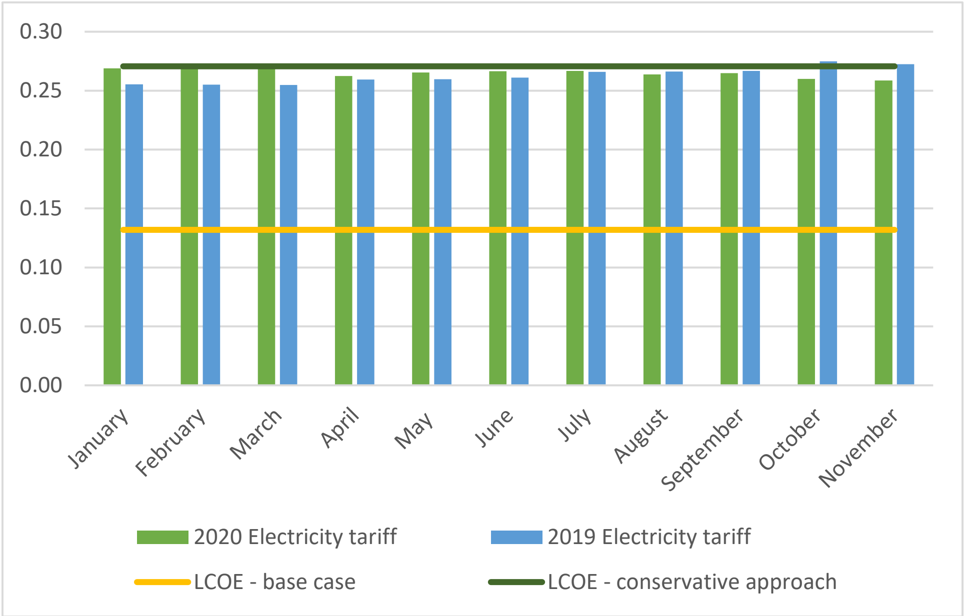
LCOE calculation

Using data on costs and wind turbine characteristics from real-life projects built during 2019 (IRENA, 2020, p. 75) and information on the capital structure for renewable energy projects in LAC, annual flows of costs and electricity production were estimated to then calculate the LCOE. This is a first approach made to have a sense on the feasibility of developing an offshore wind farm near the archipelago, given the current costs shown by similar projects in other parts of the world and using the technology that is currently available. In this sense, this work shows that it is highly likely that an offshore wind project can be developed to reduce the archipelago's reliance on fossil fuels due to the high electricity tariff compared to the LCOE estimated in both scenarios.

The LCOE calculated in the base case scenario is in the 95th percentile of LCOE values reported on IRENA's database from real-life offshore wind projects built during 2019, while the conservative scenario shows LCOE values higher than the upper bound values for LCOEs reported during this year (Figure 6). This is to be expected given the uncertainties related to the development of an offshore wind energy project in an area that has not been explored for this purposes and because the development of the first plant would pose higher costs as economies of scale in the area have not been reached. In fact, one of the main conclusions of the 2019 report from IRENA was that projects developed in new, unexplored areas for offshore wind development reported higher LCOEs (IRENA, 2020, p. 84).

When analyzed how would cost savings have looked between the months of January and November of years 2019 and 2020 if the project would have been built in early 2019, it was possible to determine that under the base case scenario savings were between $0.12 and $0.14 per kilowatt-hour, while under the conservative scenario there were some months in which losses were $0.01 per kilowatt-hour and others in which the balance was zero (Figure 7).

Figure 7 – Savings achieved throughout time



Source: Sopesa, 2020. Own calculations.

The cost of energy has a major impact on all economic activities, and it is therefore a major concern for the electricity industry (Bruck et al., 2018). Although the usual scenario is where non-conventional renewable energy is more expensive than traditional sources of energy due to the variability and uncertainty of the underlying energy source (e.g. wind, solar, etc.), some technologies are nowadays cheaper than certain non-renewable sources in some parts of the world. As a result of the increased experience in the development of offshore wind power projects, the specialization of the supply chain, the improved technology, suitable regulatory frameworks for wind energy development, and increased competition have opened the door for new and more project developments (IRENA, 2020, p. 75, 84). This has led to a decrease in the global weighted average LCOE of 29 percent between 2010 and 2019 for newly added offshore wind power projects throughout the world (IRENA, 2020, p. 84). As it was to expect, the more experienced countries in offshore wind development showed the lower LCOEs. Also, these values are low because farm-to-shore transmission asset development are not the responsible of the developer (IRENA, 2020, p. 84). Power purchase agreements (PPAs) of project to be commissioned in the following years keep showing a decrease in prices which suggest that prices will continue to fall in the near future (IRENA, 2020, p. 84).

The LCOE is a widely used measure for modelling the electricity price for renewable energy projects (Bruck et al, 2018). It is a very close approximation to the true cost of building an offshore wind plant, in this case. Yet, it is not an assessment of the electricity tariff as that would require other variables to be taken into account such as taxation, subsidies, potential CO2 pricing, and other incentives (IRENA, 2020, p.84).

Going forward: general financial analysis

Given the limitations on the calculation on the LCOE, a general financial analysis was done to calculate the electricity tariff at which the developer would be in a position to invest in an offshore wind energy project near the archipelago. To perform the analysis, the costs used to calculate the LCOE were used as well as the electricity generated. The debt payments were projected over a 20-year period, which is an acceptable tenor. The depreciation was calculated using the straight-line method, and the interest expense was calculated according to the current rate. Finally, a margin to the LCOE was introduced to calculate the electricity price required and the revenues needed to produce an Internal Rate of Return (IRR) equivalent to the cost of equity (12 percent), and a positive Net Present Value (NPV). In the base case scenario, the price needed to generate an IRR of 12 percent and a positive NPV (of $19.3 million, in this case) was $0.16 per kilowatt-hour. This means that the project can produce the IRR targeted and a positive NPV at a price that is 38 percent lower than the current electricity tariff; therefore, a project can be commercially viable and cost-efficient as long as the costs are around the weighted average for 2019 and the capital structure of the project gives a WACC of around 9.3 percent.

Subsidies, electricity tariff and potential savings

As mentioned in previous sections, the archipelago is a non-interconnected zone as it is not connected to the national grid and it uses fossil fuels to cover most of its electricity demand. As a result, the archipelago’s electricity tariff is heavily subsidized across the social strata one, two and three. The electricity tariff paid by the society is between 26 and 41 percent the real electricity tariff for the first 187 kilowatt-hour each month, and around 49 percent for consumptions between 187 and 800 kilowatt-hours (SOPESA, 2020).

This means that subsidies range between 51 and 74 percent, depending on the amount of electricity consumed.

This analysis made in this document uses the real electricity tariff, including the subsidy, to show the effect on the price and calculate savings for the government if it were to switch to offshore wind energy (and move away from fossil fuels). Estimations for the subsidies using November's regulated tariff published by SOPESA for the archipelago and the current demographic conditions showed that it is needed between $26 and $28.4 million every year to ensure the electricity generation of the islands. When the full electricity tariff is compared to the LCOE, fiscal savings of about $24 million could be achieved, while the savings using the price for electricity generated calculated in the financial model ($0.16 per kilowatt-hour) could be around $20.6 million every year. It is also worth mentioning that a small portion of the subsidy is still required to cover part of the electricity tariff charged to the archipelago's final users.

From the regulatory perspective, the debate on offshore wind energy in the country has not even began, despite the fact that other areas (like La Guajira) have been identified as areas with great offshore wind energy potential. Just to give an idea on how far behind Colombia is, in 2019 the first auction of non-conventional renewable energy sources such as onshore wind and solar was conducted, with several issues that needed to be addressed at the time.

In conclusion, the development of an offshore wind power plant near the archipelago of San Andres, Providencia and Santa Catalina is a cost-efficient source of energy even at costs similar to the higher bound reported by offshore wind energy projects built around the world in 2019. The current electricity cost in the archipelago, which is mostly generated using fossil fuels, is very expensive and allows for the highest costs reported in 2019 to still be cost-efficient. This is true when cost-efficiency is only based on the LCOE results obtained.

CONCLUSION

The archipelago of San Andres, Providencia and Santa Catalina is the only department (i.e. state) in Colombia that is composed of islands. It is composed by three islands, San Andres, Providencia and Santa Catalina, and more than 20 keys. It is located 775 kilometers northeast off the Atlantic (continental) coast of Colombia. Its 80 thousand inhabitants make the department the most densely populated from all the departments in Colombia with over 1.470 inhabitants per square kilometer. This department is considered is a non-interconnected zone as it is not connected to the national grid and relies on fossil fuels to meet its electricity needs. In fact, is the zone that receives the biggest portion of the subsidies granted by the Government of Colombia (40 percent of the total) for the purchase fossil fuels to generate electricity.

This reliance on fossil fuels inflates the electricity prices paid by the inhabitants of the archipelago. Utility rates in the archipelago are about $0.26 per kilowatt-hour, which is slightly below the Caribbean region average ($0.33 per kilowatt-hour). However, it almost doubles the price paid by Colombians that live in the continental part of the country (0.14 per kilowatt-hour). This panorama presents an important opportunity for the introduction of renewables in the archipelago, which could help lower the electricity tariff for the residents of the islands and keys, as well as reduce the archipelago's carbon footprint and align to the government's efforts to reduce its Greenhouse Gas emissions. Given the lack of space in land, however, the archipelago's maritime territory could play an important role in the cleaning of its electricity matrix by introducing offshore wind energy solutions.

This paper intended to open an overdue discussion on the feasibility of the integration of renewable energy sources in the electricity mix of the archipelago. In particular, this paper showed that, given the current status of the technology and using the latest data on the costs from offshore wind projects built around the world in 2019, the development of an offshore wind energy project could pose important monetary savings to the country via reduced subsidies for the generation of electricity, efficiencies, and GHG emission reductions given the fact that it will displace fossil fuels. When using the weighted average costs reported on IRENA's database, the cost per kilowatt-hour was reduced 49 percent, although the financial analysis showed that a higher price (but still 38 percent below the current price) for electricity was required to yield adequate returns for a potential investor; in both cases, moreover, a reduction of at least 75 percent of the subsidies was achieved. And when using the highest costs reported on IRENA's database, the cost per kilowatt-hour the offshore wind project was almost close to the current price paid for the electricity in the archipelago, which gives the maximum cost allowed for a project to be feasible. This was achieved by estimating the Levelized Cost of Electricity using the most recent offshore wind energy technology and costs associated to projects built during 2019 and reported on IRENA's Renewable Cost Database and taking into account the archipelago's offshore wind energy potential and bathymetry. This work intends to provide an initial approach to determine the feasibility of developing an offshore wind energy project in the area and additional information that would affect the cost of the wind farm is required to have a more detailed view on the cost-efficiency of developing such project in the archipelago.

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