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Towards a Future Scenario for Offshore Wind Energy in Chile: Breaking the Paradigm

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Abstract: Offshore wind energy continues to be a potential candidate for meeting the electricity consumption needs of the Chilean population for decades to come. However, the Chilean energy market is skeptical about exploiting offshore marine energy. At present, there are no offshore marine energy farms. This is probably attributable to the current legal framework, payback period, initial costs of inversions, and future wind speed trends. This work aims to break this paradigm by advancing knowledge regarding the main issues concerning offshore marine energy in Chile. To this end, we estimated the Levelized Cost of Energy (LCOE) from 2000 to 2054 using the CMIP RCP 4.5 and 8.5 climate projections. These projections were based on the estimations for a 608 MW offshore wind project located along the Chilean coast. A comprehensive analysis of the legal framework for implementing offshore marine energy is also presented. The results show that the LCOE ranges between 24 USD/MWh and 2000 USD/MWh. Up to 80% of the study area presents favorable results. Future climate scenarios did not affect the project's economic viability and notably indicated two major zones with low interannual variability. In terms of legal frameworks, there is a gap in a Chilean trans-ministerial law that ends up causing several processes to be duplicated. Further research is needed to reduce the uncertainties associated with offshore wind energy generation on the Chilean coast. This study aims to further knowledge related to both the opportunities and challenges associated with offshore wind.

Keywords: offshore wind energy; Chile; future scenarios; climate change



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1. Introduction

Because of current trends in global energy consumption, the scenarios for future energy demand have garnered a great deal of attention. On a global scale, offshore wind energy has grown rapidly, with over 29 GW of installed capacity existing in Europe (75%) and China (23%), who are the market leaders [1]. In fact, Europe has a long history of investment and support of offshore wind energy development and expects that by 2030, the offshore wind energy potential will exceed its current goal of about 76 GW [2]. These facts have led to special attention being given to offshore wind energy assessments in other continents in recent years, demonstrating great potential in North and South America, Asia, and Africa, among others [3–10].

The offshore wind industry still has a low installed worldwide capacity compared to onshore wind and solar photovoltaics, which have 621 and 509.3 GW, respectively [1,11]. One reason for this difference is that offshore wind energy is a capital-intensive technology, which gets reflected in higher prices [12]. For instance, up to 75% of its lifetime cost can be an upfront investment [13].

Nevertheless, the current state of the offshore wind market relies on government subsidies to maintain the competitiveness of wind projects. This is the case of feed-in tariffs (FIT) subsidies, which can range from 0.12 USD/kWh in the case of China, to up to 0.3 USD/kWh in Japan [14].

Several mechanisms for promoting the spread of this technology by governments have been observed, such as investments and policies like the FIT, progressive tax, Renewable Portfolio Standards (RPS), and low-interest loans [15]. In addition to market maturity [16], these mechanisms have encouraged a consistent and incremental growth in the offshore wind market over the last few decades, reaching 6 GW of installed capacity in 2019 alone [1]. In 2020, cost reduction continues to be a necessary and expected part of developing a competitive offshore wind energy industry [17,18]. Indeed, the Levelized Cost of Energy (LCOE) for offshore wind energy has decreased steadily in the last decade [19]. This decline in LCOE values is attributable to several factors: an increase in project size, a continued optimization of technology, the installation processes used, and an improved market regulatory framework [20–22]. Consequently, offshore wind energy has become an attractive energy source for other countries which have adopted the experiences of world leaders in the form of new installations and assessments of their own offshore wind energy potential. For instance, the United States is starting to increase its investment in offshore wind energy to become a world leader, as it has more than 2000 GW of offshore wind capacity and a development goal of 25 GW of installed capacity by 2030 [1,23]. Furthermore, in South America, offshore wind energy has gained more attention during the last decade in Colombia [24,25], Brazil [26–28] and Chile, which has almost 4,000 km of coastline [9,29].

In Chile, the possibility of future impacts arising from climate change has led to several legal and political changes with regards to renewable energy generation [30]. The main legal modifications were aimed at creating a goal of 20% electric energy generation by 2025 [31]; the renewable energy requirements on the electric generation industry (e.g., RPS) and the long-term milestone for Chilean energy sets a goal of 70% generation by renewable sources by 2050 [32]. Moreover, recent research is starting to increase knowledge about Chile's offshore wind and wave energy potential. For instance, Mattar and Villar-Poblete [29] conducted an initial work about offshore wind energy potential using satellite and reanalysis data. Mattar and Guzmán-Ibarra [9] gained the first insights into perspectives on technical and economical offshore wind energy, examining aspects such as a nationwide LCOE, Net Present Value (NPV), Internal Rate of Return (IRR), and Pay-Back (PB). However, several modeling assessments have been performed on the great potential of marine energy in Chile, such as the nearshore wind-wave energy resource in central Chile using numerical models [33–35]. The initial wind potential maps provided by the Ministry of Energy in Chile deserve special attention, as they bridge the gaps in onshore wind energy, despite retaining information in terms of offshore wind potential [36].

The Chilean National Energy Commission (CNE) makes a database available of national installed capacity in terms of renewable energy, energy generation, and future energy demands. By 2019, Chile had a national installed capacity of nearly 25.3 GW, of which 5 GW corresponded to either wind or solar energy generation [37]. Additionally, a steady increase is expected in Chile's energy demand over the following 20 years, rising from 71.6 GWh in 2019 to 108.9 GWh in 2039, equivalent to an annual rate of about 1.95 GWh per year [38]. Currently, land-based wind energy represents 18% of the national installed capacity of renewable energy (Figure 1).

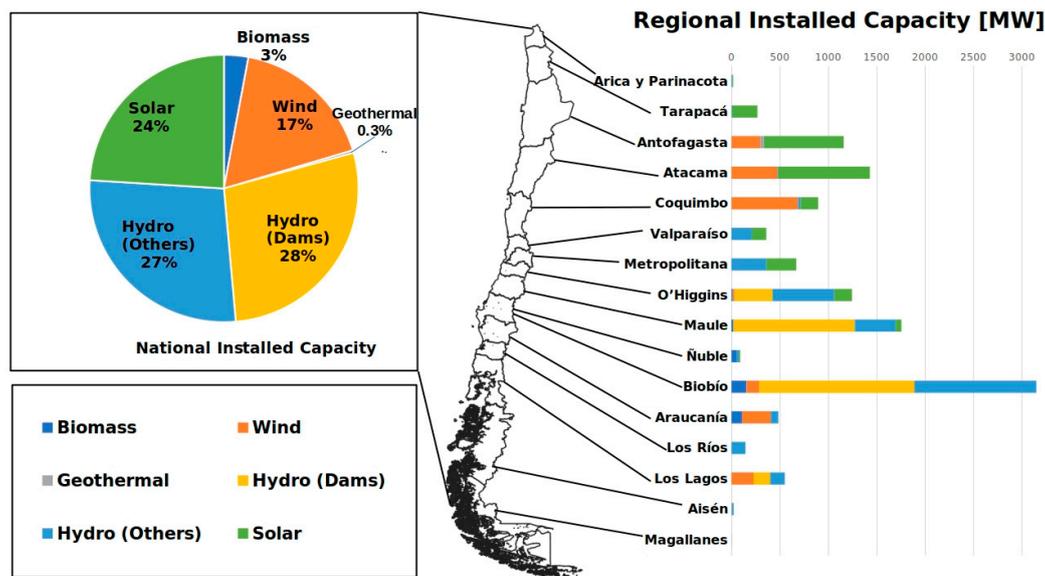


Figure 1. Percentage of national installed capacity of renewable energy (left) and regional installed capacity of renewables in MW [37].

Despite the advances in offshore wind energy potential and the improvements in the legal framework of renewable energy generation, there are still no offshore wind projects in Chile. New sources of information about offshore wind perspectives based on potential, resource assessments, and LCOE generate potential scenarios to develop this technology. In this sense, this manuscript assesses the high cost of installing an offshore wind farm, coupled with insufficient knowledge about LCOE. These factors are the main paradigm that raises economic skepticism regarding this technology in the country. As such, there are some strategies that could change the government incentives for mitigating the investment risk on marine renewable energies and strengthen the current trends in Chilean offshore wind energy. Knowing what must change could make a difference in terms of the investment incentives for offshore wind. To this end, this work aims to identify how future prices are associated with climate scenarios with regard to offshore wind energy exploitation. This work also contributes to further decisions regarding offshore wind projects in Chile. The manuscript is structured as follows: Section 2 presents the study area, Section 3 describes the data and methodology used, Section 4 shows the results and analysis of the information, Section 5 presents the discussion, and Section 6 provides the relevant conclusions.

2. Study Area

The study area encompasses the Chilean coast between 18° – 56° S from the coastline, up to the limit of the Exclusive Economic Zone (EEZ) (200 nautical miles) (Figure 2). This area was selected for the wind energy potential demonstrated by Mattar and Guzman-Ibarra [9] and Mattar and Villar-Poblete [29]. These works assessed the techno-economic viability of an offshore wind installation and the offshore wind potential in the study area. In this area, the institutional jurisdiction for offshore wind projects falls to the ministries of Energy, Defense, and Economy and the environmental legal frameworks. Namely, the Ministry of Energy regulates the bidding process and the technical norms pertaining to Chile's energy system through the National Commission of Energy (CNE) [39]. The Ministry of Defense controls the use of the territorial sea, seabed, and beaches [40]. Through the undersecretary of fisheries and aquaculture, the Ministry of Economy manages the offshore project and its spatial relation to other economic activities already approved near the offshore project zone [41]. Finally, through the Environmental Assessment Service

(SEA), the Ministry of Environment verifies the fulfilment of the environmental standards and the life-cycle of the project [42].

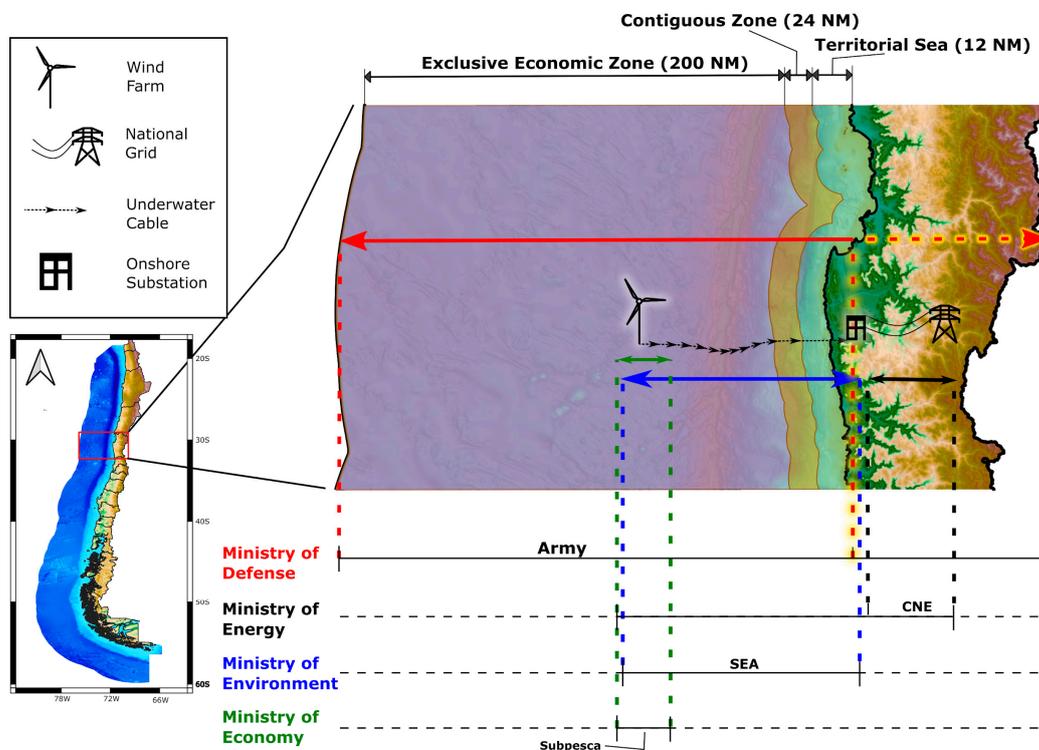


Figure 2. The study area presented with the different marine zones and legal framework ministries. At the top are the three different categories of sea jurisdiction measured in nautical miles (NM). At the bottom, the extent and legal overlap of the four ministries regulating the offshore projects.

3. Data

3.1. Data from ERA5 and CMIP5

The wind speed data provided by the ERA5 reanalysis was used. Starting in the year 2000 and continuing through to 2020, the “10 m wind speed” component was used, corresponding to the monthly average horizontal speed of the wind at the height of 10 m [43]. The future projections of wind data were extracted from the Climate Model Intercomparison Project-Phase 5 (CMIP5) multimodel archive of climate simulations. The CMIP5 RCP future climate projections on near-surface wind data considered in this work are from the HadGEM2-CC model of the UK Meteorological Office, and its horizontal resolution is around 1.25° in midlatitudes [44]. Future wind data was taken from future climate projections of two RCPs: RCP 8.5 is a “business as usual” emission scenario, characterized by rising GHG emissions and high concentration levels of these gases in the atmosphere. RCP 8.5 can be seen as the projection of future GHG concentration and radiative forcing if no emissions mitigation strategies are employed until the end of the 21st century. RCP 4.5 is a midrange stabilization scenario, where GHG emissions are mitigated by policy actions, strategies, and technologies employed to achieve emission targets before 2100 [45–47]. For both RCPs, the time window is between 2020 and 2050.

3.2. Technical and Economic Data

The technical and economic data available in the study conducted by Beiter et al. [48] were used as the primary source of costs for an offshore wind project. This study is a spatial-economic cost-reduction analysis for the offshore wind industry on the U.S. territorial sea, developed by the National Renewable Energy Laboratory (NREL). Such work was used due to its extensive documentation regarding each stage of an offshore wind project. It

contains information on both technical and economic data regarding the different stages of a project and how some environmental variables can impact the final pricing of the energy produced.

The main expenditures related to offshore wind energy are broadly classified into capital expenditure (CapEx) and operational and maintenance expenditure (OpEx) [13]. This includes the amount of cash invested upfront for the initial expenditures of the project and the ongoing costs of both operating and maintaining the project to keep it operational. All relevant stages for the development, installation, operation, and decommissioning of an offshore wind project, as well as their approximate costs, are presented in Table 1. Bathymetry and distance to shore will impact the final capital expenditure and operational expenditure values. For this reason, two maps were used as variables to evaluate the spatial variability of the study area. The cartography generated by the Global Ocean & Land Terrain Model [49], presented in 15 arc-second intervals, was used to determine the water depth values for every pixel. Similarly, a map of geodesic distances to the mainland was generated on GIS software to determine the distance of each pixel to the cable landfall. For any given location, there will be taken into consideration both the water depth and distance to shore. This information is critical to account for the cost variability regarding the installation and acquisition of the project and its substructures, and the length of the electrical system.

Table 1. The costs of a 600 MW offshore wind project by category and types [48].

Cost Category	Category	Cost (USD/kW)	Note
Turbine	CapEx	1583	-
Development	CapEx	196	-
Ports and Staging	CapEx	25	-
Operations	OpEx	31	-
Substructure	CapEx	Variable	Dependent on water depth
Assembly and installation	CapEx	Variable	Dependent on the distance to land and water depth
Electric System	CapEx	Variable	Dependent on the distance to land
Maintenance	OpEx	Variable	Dependent on on-site specific features
Engineering and Management	CapEx	Multiplier	3.5% multiplier applied to the total value of CapEx
Insurance during Construction	CapEx	Multiplier	1% multiplier applied to the total value of CapEx
Commissioning	CapEx	Multiplier	1% multiplier applied to the total value of CapEx
Installation Contingency	CapEx	Multiplier	30% applied to installation CapEx and 5% to non-installation CapEx
Procurement Contingency	CapEx	Multiplier	5% of non-installation CapEx
Decommission	CapEx	Multiplier	65% of installation CapEx

4. Methodology

4.1. Wind Energy Estimators from CMIP5 Data

Wind power was estimated through the method proposed by Weibull [50,51]. The area under the probability density function $f(V)$ curve is called the cumulative distribution function. Therefore, the Weibull cumulative distribution function can be found by

taking an integral of $f(V)$, denoted by $F(V)$. Both functions are given in Equations (1) and (2), respectively:

$$f(V) = \left(\frac{k}{c}\right) \left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^k\right] \quad (1)$$

$$F(V) = 1 - \exp\left[-\left(\frac{V}{c}\right)^k\right] \quad (2)$$

where:

V = Wind speed (m s^{-1})

k = Shape Weibull parameter (-)

c = Scale Weibull parameter (m s^{-1})

The wind power density and wind power were obtained by Equations (3) and (4), assuming a value of air density (ρ) of 1.225 Kg m^{-3} .

$$WPD = \frac{P}{A_T} = \frac{1}{2} \rho V^3 \Gamma\left(1 + \frac{1}{k}\right) \quad (3)$$

$$WP = \frac{1}{2} \rho A_T V^3 \Gamma\left(1 + \frac{1}{k}\right) \quad (4)$$

WPD = Wind Power density (W m^{-2})

WP = Wind Power (W)

ρ = Air density (Kg m^{-3})

A_T = Rotor area of the wind turbine (m^{-2})

V = Wind speed (m s^{-1})

k = Shape Weibull parameter (-)

Γ = Gamma function

For the purpose of estimating rotor area, the wind turbine model Vestas V-164 9.5 MW was considered. This is one of the most powerful wind turbines on the market and has a hub height and diameter of 110 and 164 m, respectively [52]. To estimate Wind Energy Generation (WEG), the average annual power (P^*) of the Vestas V-164 9.5 MW was considered, in addition to the period during which this wind turbine is working. The WEG formula is denoted by Equation (5).

$$WEG = P^* T \quad (5)$$

where:

WEG = Wind Energy Generation (MWh)

P^* = Average annual power of the Vestas V-164 9.5 MW wind turbine (W)

T = Period of generation time (hours)

4.2. Spatial Trends of WEG

In this work, a well-known method for trend detection, the Mann–Kendall test, was implemented [53,54]. This is a non-parametric method frequently used to detect trends in climate data [55–58].

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad (6)$$

The significance (p , quantified at the 0.05 level) of the trends in the WEG anomalies time series was evaluated with the Mann-Kendall (MK) test [53].

4.3. Inter-Annual Variability of WEG

The temporal variability of WEG was analyzed by different descriptive statistics, including minimum (Min), maximum (Max), range (R), and standard deviation (S). Furthermore, the inter-annual variability (IAV) represented by Equation (7), was quantified following the approach proposed by [59].

$$IAV = \frac{\sigma}{WEG_m} \quad (7)$$

where:

IAV = Inter Annual Variability (-)

σ = Standard Deviation of WEG (MWh)

WEG_m = Mean of WEG (MWh)

4.4. Economic Analysis

The LCOE was the central metric used to determine the economic potential of offshore wind in the study area. To compute the LCOE values, the methodology presented by Short et al. [60] was used (Equation (8)). These values are dependent on distance to shore, water depth, and wind speed.

$$LCOE = \frac{I \times FCR}{Q} \times \frac{O\&M}{Q} \quad (8)$$

where:

LCOE: Levelized cost of energy (USD/MWh)

I : Initial investment (USD)

FCR: Fixed-charge rate

Q : Annual output (MWh)

O&M: Annual operation and maintenance costs (USD)

The annual output of energy (Q) corresponds to the total energy production in a given year. It depends heavily on both the on-site wind speed behavior and the wind turbine model used as a reference. Beiter et al. [48] used a 600 MW project with 6 MW turbines as a reference, using the "Openwind" package from AWS Truepower to calculate energy output. Due to the differences in methodology and the fact that Beiter et al. [48] has cost references for 10 MW turbines, the decision was made to keep the size of the project within a similar range but using available information. The V164-9.5 MW Vestas turbine model [52] was used to compute the values of Q , keeping the size of the hypothetical offshore wind project at 608 MW.

Most of the information presented by Beiter et al. [48] is absent on local sources, most likely due to a lack of experience regarding offshore wind power generation in the Chilean context. To offset the lack of local information it is assumed that the economic behavior presented by Beiter et al. [48] will be similar to the study area. Therefore, the same equations are used to calculate cost. The main emphasis is made on the environmental differences between the Chilean and U.S. coast; mainly water depth, wind speed, and distance to shore.

Both the initial investment (I or CaPex) and the operation and maintenance costs (O&M) vary greatly according to changes in water depth and distance to shore. The location of the assembly site and staging port will influence the cost of the offshore project. Additionally, the distance to the coast will determine the composition of the electrical system, as well as the use of an offshore substation. It is assumed that the assembly site, the staging port, and the underwater cable landfall are located at the nearest site on land. A 33-kV system is used when the project is up to 9 km away from shore; when the project is between 9 and 115 km, a 220-kV system is used; above 115 km, a HVDC system is used. Bathymetry values will define the kind of substructure used in the project. For up to 80 m of water depth, a fixed-bottom substructure was used. For deeper waters, a floating substructure is needed. Since the floating substructure cost data were not disclosed by

Beiter et al. [48] due to confidentiality, the acquisition costs presented by Bjerkseter and Ågotnes [61] were used. Because most of the pixels in the study area represent a water depth greater than 80 m [49], the floating substructure model was mainly used. However, some nearshore sites have shallower waters, allowing for the use of fixed substructures.

Some of Chile's economic metrics were used to better model the behavior in the study area. The tax rate used was 25%, corresponding to a "First category taxing rate" [62]. The discount rate used corresponds to an 8.74% discount for "wind energy technology actives", issued by the Chilean Ministry of Energy [63].

4.5. Economic Variability

It is expected that the LCOE will decrease over time; the study of Valpy et al. [64] was used as a reference to reflect this decreasing trend. In it, the impact of 57 technology innovations on the LCOE of offshore projects is evaluated, anticipating up to a 36% decrease in the LCOE by 2030. Based on the NREL's annual technology baseline, a cost decrease in line with a logarithmic fit lasting through to 2050 is assumed [65].

Similarly, the study of IRENA [12] on renewable generation costs was used as a reference to simulate the potential variability in costs between the year 2000 to 2020. It was assumed that the behavior of the LCOE of the project would be similar to the changes seen in the average cost of electricity in the offshore wind market. The Consumer Price Index (CPI) was used to estimate the current value of LCOE between the years 2000 and 2020 (using 2020 as a base year). For future estimations, a steady 2 percent inflation rate was used, this being the mean inflation rate of the previous two decades. Figure 3 presents the general flowchart of this work.

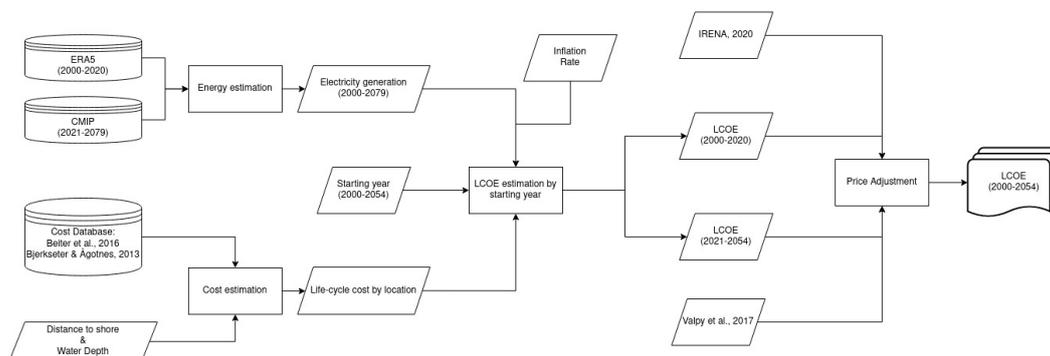


Figure 3. General flowchart for LCOE estimation.

5. Results and Analysis

5.1. Inter-Annual Variability (IAV) of WEG

The results of the WEG interannual variability for the RCP 4.5 and 8.5 future scenarios show similar values in the south of Chile between 42°–54° S (Figure 4). There, the IAV is relatively low, with changes ranging from 30% to 50%, which means that the WEG will not change very much even if the most severe scenario is reached. Regarding central Chile between 30 and 42° S, it is possible to observe the highest IAV in the RCP 4.5 scenario with changes above 90% in both far and near offshore locations. On the other hand, in the most severe scenario, the IAV values are lower, ranging between 60% and 80%. This means that in principle, a more severe climate change scenario does not imply a more significant interannual change in the WEG for the coasts of central Chile. Finally, for northern Chile between 18 and 30° S, the lower interannual changes are observed near the coast in the RCP 8.5 scenario, with IAV values ranging between 20% and 30%. In both cases, the highest values are near the coast and around 70%.

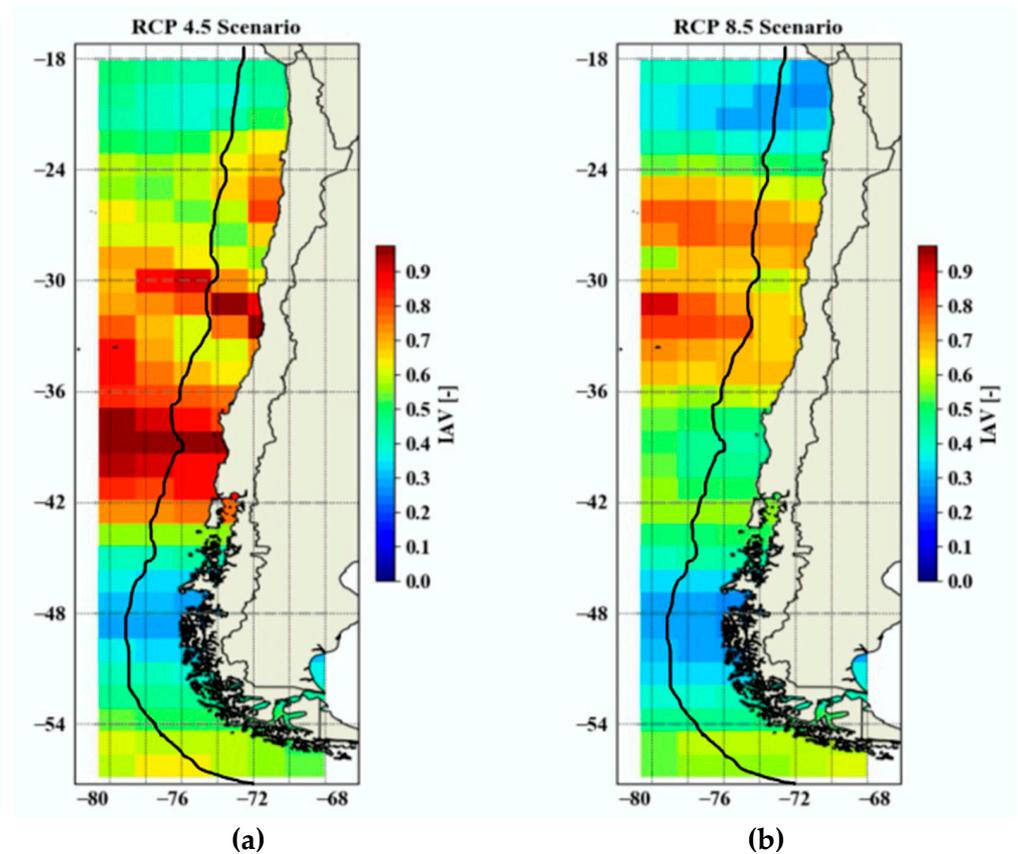


Figure 4. Interannual variability of WEG for 4.5 (a) and 8.5 (b) RCP future scenarios between 2020 and 2054.

5.2. Spatial Trends of WEG

Regarding the spatial trends of the WEG, the only significant trends near the coast are observed in the 4.5 scenario in central Chile (Figure 5). Therefore, for the most severe scenario, two significant trend areas are observed both in southern and northern Chile. Those trends are, however, in the far offshore range. In northern and central Chile, significant trends indicate an increasing WEG, whereas for the significant trend in the area of southern Chile, a decrease of WEG is observed.

5.3. LCOE and the Energy Legal Framework

The Levelized Cost of Energy (LCOE) results show significant variability in the price of energy in the study area (Figure 6). The values obtained ranged from 24 USD/MWh to almost 2000 USD/MWh in some sectors. Most of the sites with the least viable economic potential were concentrated in the central zone between 33° and 41° S. Figure 3 presents the evolution of the LCOE according to its starting year of production and the representative concentration pathway (RCP) projected.

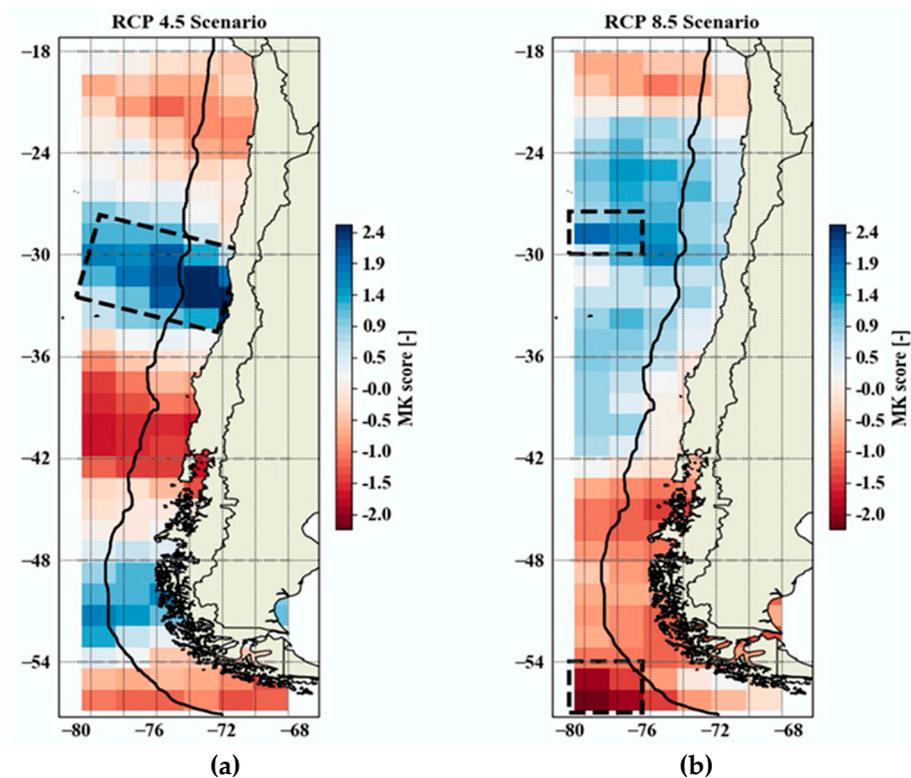


Figure 5. Mann–Kendall trends for wind energy generation between 2021 and 2051 for the RCP 4.5 scenario (a) and RCP 8.5 scenario (b).

There was a general decrease in LCOE values in RCP 8.5 and RCP 4.5 trajectories over the projected years (2021–2054). While the decrease in LCOE was more significant in the RCP 8.5 scenario, both followed a similar trend in cost reduction. This reduction was significantly driven by the decrease in CapEx and OpEx presented by Valpy et al. [64] and Hundelberry et al. [66]. The results obtained have some similarities to the data presented by Mattar and Guzman-Ibarra [9]. In said research, the southern part of Chile showed the most promising results regarding economic viability due to high wind speed. However, the northern part of the country had no competitive LCOE values, unlike what is shown in the current results. The differences can be attributed to the different sources of information used regarding the wind turbine model, wind speed, and cost dataset.

Zones with high wind speed and low LCOE could be profitable for installing an offshore wind farm and even supported by the legal framework of the Chilean state. However, several constraints have been taken into consideration related to the Chilean legal framework for energy projects (Figure 7). The offshore project can partake in the bidding process regulated by the CNE [39] as an “unconventional renewable energy project”, directly competing with other energy projects. To be able to do so, it must be approved by the ministries of Energy, Defense, and Environment. For example, the Ministry of Defense manages the coastal and sea activities through the emission of “maritime concession” [40]. To be able to function within the legal boundaries, an offshore wind farm would have to be granted a “major maritime concession” due to having a time span longer than ten years. This procedure can have a duration, by law, of up to 180 business days.

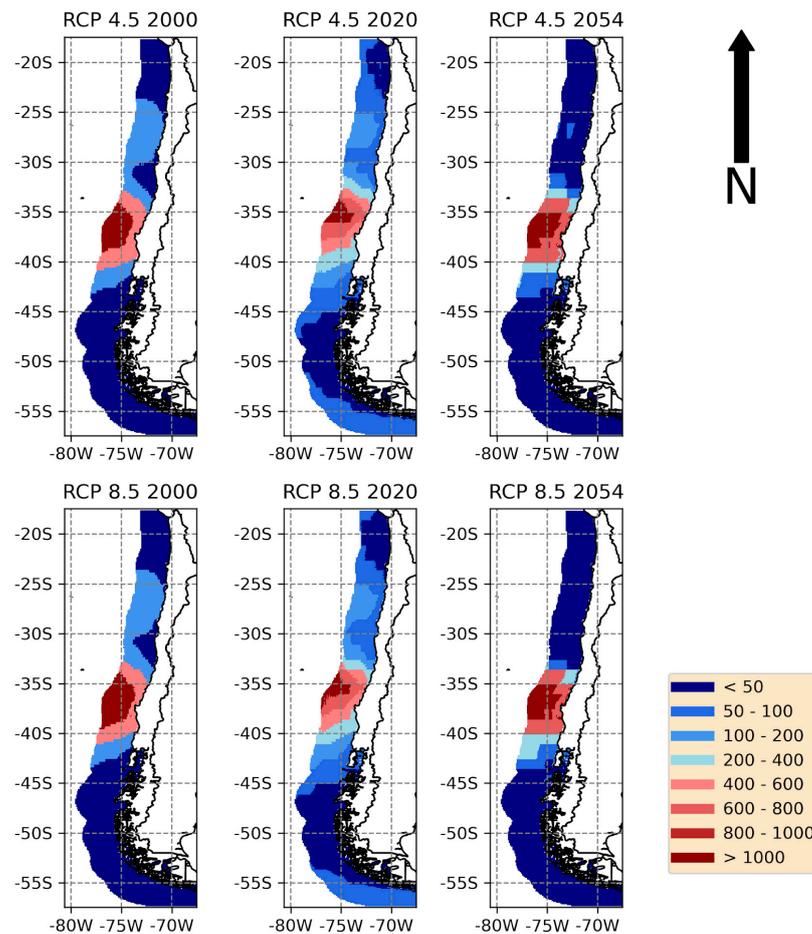


Figure 6. LCOE (USD\$/MWh) spatial variability according to starting year (2000, 2020, 2054) of production and RCP (4.5, 8.5).

Additionally, the SEA has to grant a favorable environmental qualification resolution (RCA), showing that an environmental impact assessment was performed, and the impacts are within the legal limits [42]. The granting of the RCA is a multi-part procedure involving many other public institutions and can have a timespan of well over 300 business days. It's important to emphasize that both the issuance of the favorable RCA and the major maritime concession are entirely independent processes, and the granting of one does not legally guarantee the granting of the other. Consequently, an offshore wind project becomes a high-risk investment due to the lack of both incentives and coordination of the public institutions that deal with offshore energy projects.

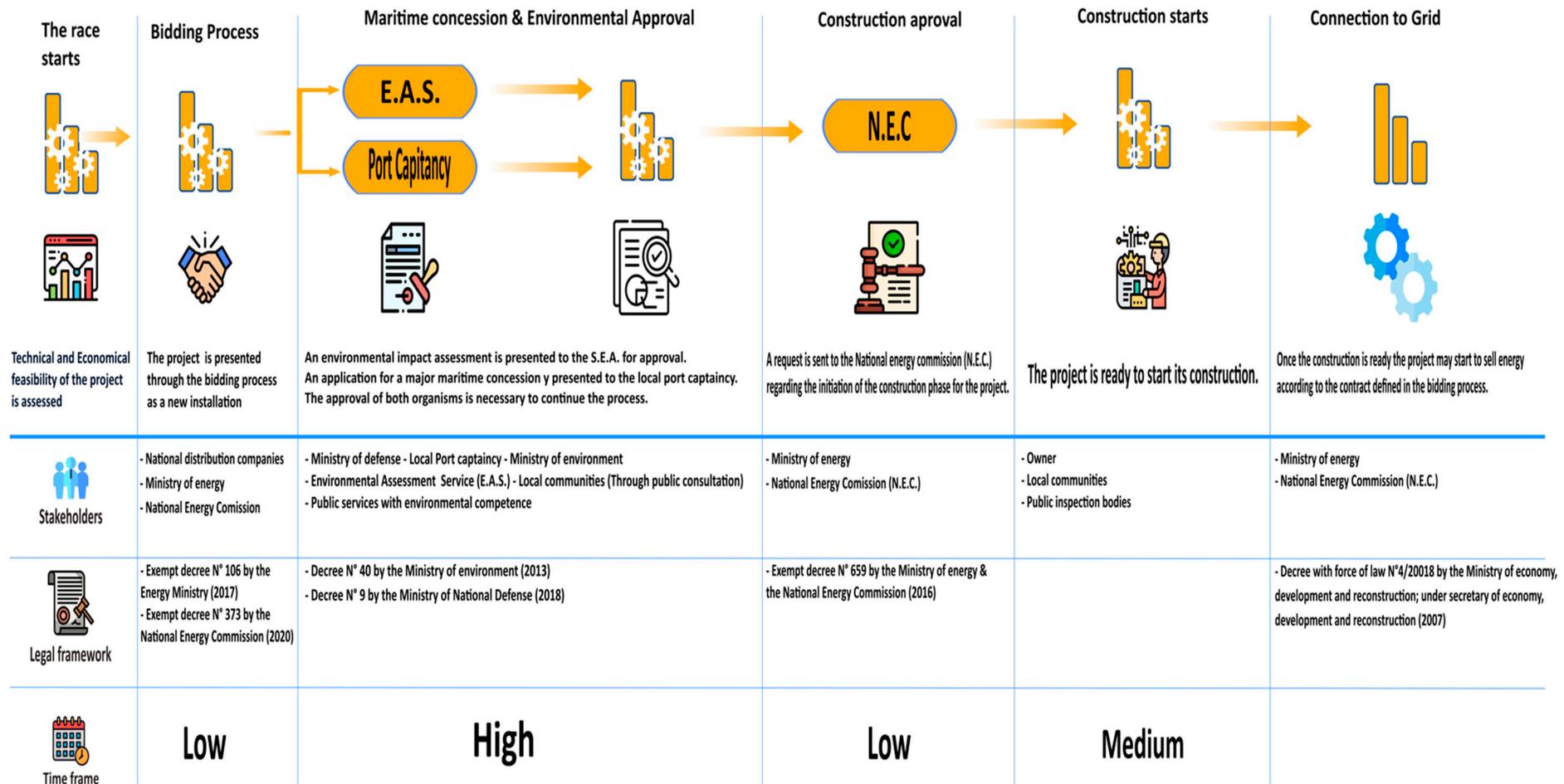


Figure 7. Legal race for any marine renewable project in Chile.

6. Discussion

This work provides new economic insights and fills gaps in environmental data, such as bathymetry along the coast of Chile. However, there still remains a lack of clarity in terms of the investment costs for an offshore wind project in Chile based on the current political framework for legal energy. The offshore wind energy that sits untapped as a source of energy in the current Chilean coast energy paradigm exceeds the current demands of the national market and is fairly competitive compared to the mean market price [67]. Exporting energy from the region could be a potential market to develop offshore wind energy in Chile. Indeed, the region of Central and South America has a projected energy demand increase of 26.9 TWh per year [19]. This could be a future opportunity for expanding the current energy production of Chile to other countries using offshore wind energy as a source.

Most of the economic information used in this study relies on prior experiences deployed in foreign markets; thus, the results obtained are inherently related to the assumptions and data used to make a viable estimation of the economic behavior of an offshore wind project. These assumptions are necessary to carry out more assessments due to the lack of local information. However, the reality is that there are several uncertainties regarding many of the sites associated with an overall low LCOE, which might compromise their viability. For example, many zones in the study area have water depths that exceed those of the projects on which the economic data is based. Additionally, the survivability of the turbines and the viability of their installations and decommissioning due to extreme environmental conditions can also be limiting factors [68]. Future studies that provide more information regarding the impact of local conditions on an offshore wind project could help to further reduce those uncertainties.

One of the main assumptions made in this study is the complete and widespread availability of connections to the grid along the coast. However, there are no mechanisms in place that provide incentives for new technologies or help to ensure that a project might be connected to the national energy grid. It is essential to account for the absence of incentives hindering the industry in future studies and the reluctance to make any changes in the legal framework to start a new energy project in the sea, or even near the shore. In stark contrast to the experience of other markets that have more incentives, such as feed-in tariffs [22], this might be a new step toward the expansion of the energy market in Chile.

Offshore wind energy provides new opportunities for reducing the impact of climate change on land wind speed, as demonstrated by several models [69]. In addition, future scenarios of offshore wind energy help reduce uncertainty and create an opportunity for exploring new markets associated with renewable energies. In the southern part of Chile, such as in Patagonia, a wind-hydrogen installation based on electrolysis is currently being implemented [70]. The results of this study may help expand this industry to other parts of the country, positioning the northern part of Chile as a hydrogen producer that uses offshore wind energy. This approach takes advantage of the energy-demanding mining activities currently located in the north. As a consequence, it is possible to change the current energy consumption in the country by leveraging renewable energy generation as well as the hydrogen system to produce clean energy.

7. Conclusions

The availability of offshore wind energy and the economic viability of an offshore wind farm were estimated along the Chilean territorial sea from 2000 to 2054. The estimations of LCOE ranged from 24 USD/MWh to almost 2000 USD/MWh, with favorable sites located in approximately 80% of the study area. However, the Chilean regulatory framework lacks any type of incentives or laws concerning offshore wind energy. The lack of a trans-ministerial legal framework results in several duplications in administrative processes. Consequently, any potential offshore wind project has to deal with several uncertainties regarding its approval and connection to the grid. Increasing the coordination of the public institutions regulating the offshore energy projects would be a necessary step towards

increasing their viability. Thus, to harness the offshore wind energy potential already present in Chile, the current paradigm governing it must be broken.

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