Energy Conversion and Management 140 (2017) 71–90

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Wind energy potential in Chile: Assessment of a small scale wind farm for residential clients

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A R T I C L E   I N F O

Article history:
Received 6 December 2016
Received in revised form 4 February 2017
Accepted 22 February 2017

Keywords:
Wind power
Simulation tool
Residential consumption
Techno-financial assessment
Renewable energy investment
Energy policy tool

A B S T R A C T

This work presents a techno-financial evaluation of two Chilean locations with promising wind potential: Laguna Verde placed in the central region of the country, and Porvenir in the southern region. A small scale wind farm was studied, considering a nominal electrical production capacity of 90 kW. This facility is comprised of three wind turbine models, all available in the national market. Currently, the tariff method used in Chile is the net billing scheme, where the energy bought and sold to the grid has different prices. The study is based on 300 hypothetical residential households. The software tool used to perform the assessment was the Hybrid Optimization of Multiple Energy Resources (HOMER). For all the scenarios the results showed a Net Present Cost (NPC), instead of a financial profit from the proposed projects. A sensitivity analysis was also carried out. From the group of variables studied, the NPC exhibited itself as more sensitive to the price of buying energy from the grid and to the annual average wind speed. Finally, a few government policies and their applications are discussed.

1. Introduction

Studies show that energy consumption has a significant impact in the development of a country. For example, a positive bi-directional relation exists between electricity consumption and the Human Development Index (HDI) [1]. Niu et al. support this hypothesis, showing evidence of this relationship with a slight difference: the income level of each nation also affects HDI [2].

Considering the growth in the renewable energy market [3], there is an important opportunity This represents an important opportunity for countries to develop a clean energy matrix to impulse their economic growth [4], reduce environmental damage [5] and produce social benefits [6].

In this context, the European Union is concerned about the implementation of renewable energies in order to create a sustainable energy system. According to that, European countries agreed a 2030 Framework on climate and energy, aiming to not only guaranteed energy supply, but also to reduce greenhouse gas emissions. This will be accomplished by the imposition of at least a 27% in share of renewable energies consumption [7]. Meanwhile, most of the Latin American and Caribbean countries are adopting renewable energies targets in order to achieve certain levels of installed capacity share. Some of them even distinguish between conventional and non-conventional renewable energy sources [8].

Chile is not indifferent to this situation. The government has set ambitious goals regarding this subject through the establishment of the *Energy 2050 Policy*: at least 60% of the generated electricity has to come from renewable sources by 2035, and 70% by 2050 [9].

Nowadays, Chilean renewable energies represent approximately a 43% of the total installed capacity on the continental territory, which have a capacity of 9651 MW. From this, an important part is covered by conventional sources. In fact, the hydro-power represent a total of 69% of the renewable energy matrix [10] followed by solar energy with a 14% and, in third place, is wind energy with 13%. The remaining percentage corresponds to other types (such as biomass or biogas sources).

Among these other alternatives, the solar source shows the highest development and it is the most widely studied. The photovoltaic technology has been vastly examined in both small and large scale. For instance, the feasibility of electricity generation by means of photovoltaic (*PV*) panels at residential level has been studied [11]. Parrado et al. have investigated the convenience of producing electricity in off-grid configurations at large scale in northern Chile [12].

The wind potential in Chile could be situated in a middle stage of research. Several studies have focused on the potential in a large scale approach [13], including a complete analysis of the projects for the future years [14]. Also, options as the offshore plants as been investigated using wind turbines of 8 MW [15].

Focusing in small scale, there was an study conducted in Eastern Island using a hybrid configuration (*PV* and wind system)

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http://dx.doi.org/10.1016/j.enconman.2017.02.062
0196-8904/

Nomenclature

Abbreviations

AC	alternating current
SIC	central electric system of Chile
DC	direct current
EPBT	energy pay-back time
ESCO	energy service company
ESPC	energy service provider company
GWP	global warming potential
HDI	human development index
HOMER	hybrid optimization model for electric renewables
LCA	life cycle assessment
BT1	low voltage client, type 1
CASEN	national survey of socioeconomic characterization
NPC	net present cost
O&M	operation and maintenance
PV	photovoltaic
POB	price of buying energy from the grid
POS	price of selling energy to the grid
SEM	southern electric system of Chile
WRF	weather research and forecasting model

Greek Symbols

ρ	air mass density, kg/m^3
δ_d	daily perturbation of electricity demand
δ_h	hourly perturbation of electricity demand
η	overall efficiency of the turbine
α	total perturbation of electricity demand

Roman symbols

E	electrical energy, kWh
U^*	friction velocity, m/s
z	height above the ground, m
C_p	power coefficient of the wind turbine
P_{out}	power output of the wind turbine, kW
P	required power, kW
Re	Reynolds number
D_{rotor}	rotor diameter of the turbine, m
Δt	short period of time, s
z_0	surface roughness length, m
A	swept area of a horizontal-axis wind turbine, m^2
k	Von Carman constant
$f(U)$	Weibull probability density function
U	wind speed, m/s

[16] but there are no studies reported to date using non-hybrid systems. It is important to remark that this hybrid approach has proved to be successful in other countries. A study was done in South Africa using solar, biomass and wind system [17]. This same implementation was shown to be suitable for other locations, as India, where it was categorized as the most reliable configuration among other clean alternatives [18].

An interesting characteristic of small scale instances is that they could take advantage of the low wind speed presented in some locations, because generally they have they optimal performance around 11 m/s [19]. Furthermore, they could be more suitable to fulfill the energy demand of isolated small villages.

Returning to the local scenario, Chile currently has a total of 158 energy projects under development, adding 13,659 MW to its energy matrix. In particular, the wind projects correspond to 3,300 MW [20]. These facilities are expected to be fully operating by 2017–2021.

The purpose of this study is to determine the financial feasibility of installing small scale wind farms in Chile (continental territory), through the evaluation of real scenarios in locations with promising wind potential.

This work is organized as follows: Section 2 establishes the wind energy conversion system to be studied. Section 3 presents the different approaches for the characterization of the environmental conditions and the energy demand, through surveys and software. Section 4 describes the economic model, life cycle assessment and wind energy model. Section 5 explains the case studies, including the evaluation of their results, a sensitivity analysis and some government policy tools regarding the subject. Finally, comments, conclusions and suggestions for future work are presented in Section 6.

2. Wind energy conversion system

To asses the true potential of any wind project, it is important to determine the basic configuration of the energy conversion system [21]. When small wind turbines are installed, the power generated and transmitted is set in direct current (DC), by the action of a rectifier. In order to connect the system to the grid, it is necessary the installation of a power inverter before the electrical meter, which will change the type of current to alternating current (AC).

Then, the power requirements of the client (such as industrial plants, schools or community houses), can be supplied either by the wind farm or the grid. The implementation of this kind of configuration allows to sell the remaining power to the grid when the consumption is lower than the energy provided by the wind farm. Also, in order to quantify separately the energy bought and sold and bought energy to the grid, two meters have to be placed (for further details, see Section 4.1). A simplified scheme of the previous description is presented in Fig. 1. The figure illustrates no battery bank is needed.

3. Input data

3.1. Wind speed data

In this study, data on used wind speed is obtained from a numerical model named Weather Research and Forecasting (WRF). This model has been widely used in the past years, mainly in projects related to wind speed evaluation. In particular, Zhao et al. worked with this forecasting model for wind speed in China [22], and Giannaros et al. studied the performance of WRF for wind resources in Greece [23]. Carvalho et al. estimated the wind energy production using WRF, by modeling the wind speed in the Iberian Peninsula [24,25].

The methodology used by WRF consists in solving the governing equations that control the air circulation in the atmosphere. This approximation is based on the spacial discretization in all three dimensions, taking into account variables as the wind speed (U), temperature, pressure, humidity, among many others. The resolution of this set of equations formulated internally by the model is carried out using numerical integration, in both space and time [26].

As we mentioned in Section 1, Chile has not been excluded from wind power research. Currently, there is a project sponsored by the Ministry of Energy: the national wind explorer [27], which has