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Forecast study of the supply curve of solar and wind technologies in Argentina, Brazil, Chile and Mexico

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ABSTRACT

This paper forecasts the supply curve of non-conventional renewable technologies such as wind and solar generating stations in Argentina, Brazil, Chile and Mexico using technological and economic parameters. It also estimates the additional investment costs in solar and wind generation for reaching the renewable energy target in each of these countries. To assess the power supply profile from 1 axis tracking PV and horizontal axis wind turbine (three blade) stations, two different scenarios are developed for 2014 and 2025. Scenario 1 estimates the PV and wind annual electricity yield by using polycrystalline silicon (cSi poly) as semiconductor material for PV cells and a Vestas 90–3.0 MW turbine for the wind for 2014.

Scenario 2 assumes a more efficient technology, such as CPV. In fact, the model employs 45% efficiency triple junction cells using ~3500 m2 for each 1 MW installed capacity in 2025. Moreover, this scenario also assumes a more powerful type of turbine, i.e. Vestas 112–3.075 MW. The biggest potential for wind power is found to be in Argentina, followed by Brazil, Mexico and Chile. In addition, a 550 MW installed capacity CPV power station, using triple junction cells could generate up to 4 TWh in Chile in 2025.

1. Introduction

Given the progressive increase in population growth, per capita resource consumption levels and the downward trend presented in the availability and quality of natural resources, governments should focus on sustainability issues when presented with their energy expansion plans. The energy scenario is a key subject within the political agenda of each Latin American country. The energy crisis experienced in Argentina in 2004 made clear the importance of risk mitigating strategies in the energy sector to avoid economic disruptions. Among many other strategies, technology discoveries render the use of capital stock more efficiently and therefore, more valuable as output rises using the same level of input resources. More sophisticated techniques are deployed in the production process delivering diverse and higher levels of output. Endogenous growth theory [1] identifies technological change as a key driver of economic growth. Given that ideas are considered public goods, non-conventional renewable resources prove to be the output of a public good and also extensive R&D or knowledge infrastructure.

New ideas subject to wind and solar generating stations need investments in R&D which eventually transform into prototypes and later into commercial applications. The adoption of these commercial available technologies increase cumulative capacity and reduce system's costs (need reference). Furthermore, investments in production and distribution of primary energy sources are crucial to develop a sound energy industry and boost economic growth. However, growth in the solar and wind industry is subject to two main driving forces. The first is associated with the past, i.e. the legacy of the capacity factor, efficiencies, economic structural factors and levels of national GDP. The second is the future or the speed of growth based on overhang technology improvements, potential infrastructure investments, energy demand estimations and potential national growth [2]. Because these two forces differ in each country to different degrees, the evolution of investments in solar and wind technologies are differentiated. This paper provides an estimation of the supply curve of wind and solar generating stations up to 2025 giving an updated overview on the solar and wind resources in Argentina, Brazil, Chile and Mexico. When assessing the solar energy generating potential, sites with high latitude tilt irradiation availability were chosen. The same

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Nomenclature

Al	Module Area m^2
$b_{(i)}$	Energy requirements per region TWh
CF	Capacity Factor %
η_{module}	Module Efficiency %
Δ	Installation cost average percentage difference %
hr	Hours per year 8760
GHI_{nom}	Nominal Global Horizontal Irradiation $kWh/m^2/yr$
DNI_{nom}	Direct Normal Irradiance $kWh/m^2/yr$
AT	Total Footprint Needed m2
$FC_{(x)}$	Forecasted Installation Costs per technology type USD
$TC_{(i)}$	Total Costs per Installed Capacity USD
IC	Installed Capacity MW
$GDP_{(i)}$	Percentage of Gross Domestic Product per region %
$I_{GDP(i)}$	Investment share of GDP per region %
$I_{(i)}$	Investment required per country targets USD
$Y_{el(i)}$	Annual Solar Electricity Yield GWh/yr
$C_{(t-1)}$	Installation Cost (last year of data) USD/MW
$\boldsymbol{x_{ren\_sol(i)}}$	Number of solar generating stations [-]
$\boldsymbol{x_{ren\_w(i)}}$	Number of wind generating stations [-]
$I_{GE(i)}$	Investment as share of government expenditure %
$GE_{(i)}$	Share of public expenditures %
ρ	Air Density kg/m^3
A	Swept Area m^2
V^3	Wind Velocity m/s
C_p	Coefficient of Performance %
V_0	Downstream Wind %
V	Upstream Wind %
$\boldsymbol{Yw_{el(i)}}$	Annual Wind Electricity Yield GWh/yr
D^2	Blade Diameter m
α	Roughness of the topography [-]
v_{120}	Wind Speed at 120 mts m/s
v_{80}	Wind Speed at 80 mts m/s
h_{120}	Turbine Height m
h80	Turbine Height m

methodology was applied to estimate the energy generated through wind generating stations in the four regions of study. High input resources reduce costs and increase competitiveness of solar and wind generating stations [3].

This paper estimates the potential electricity production generated by non-conventional energy sources based on two different scenarios. Scenarios 1 and 2 are linear and take the nameplate capacity of the largest worldwide PV and Wind power plant while assuming it will be placed in the already mentioned four regions of study. While Scenario 1 adopts current module efficiencies, Scenario 2 considers those efficiencies expected in 2025. The first two scenarios deliberately embrace the national GDP and public expenditures to evaluate the investment relative to those economic metrics. However, funds endorsement in infrastructure investment do not only represent a liability but also an asset. In fact, as cited by Refs. [4], cities are worth so much more than the embedded costs to build them.

One of the objectives of this paper is to give a plausible representation of the proportion of investments required to cover the expansion plans of non-conventional renewable generation in each of the four countries of study.

2. The model

2.1. Photovoltaic technology

The model aims to estimate the supply curve of non-conventional renewable generation in Argentina, Brazil, Chile and Mexico under two different scenarios. For the sake of simplicity, Scenarios 1 and 2 set a cap in the generating capacity. Therefore, we take the largest PV power plant in the world named “Topaz Solar Farm Obvispo County California” and simulate the same generating capacity in the areas of study. This specific plant has a nameplate capacity of ~550 MW. We assume the plant uses polycrystalline silicon (cSi poly) as semiconductor material in Scenario 1. Crystalline silicon had been extensively used in the solar sector, overriding other types of solar cells [5]. In Scenarios 1 and 2, the energy density is calculated by taking the amount of land (m^2) needed to generate 1 MW with an optimally oriented solar cell. We assume each solar panel is placed with an inclination that maximizes the electrical output of the PV plant. Therefore, the required field for such plant would be ~3.671.250 m^2. As referred in Table 1, the material needs ~6675 m^2 per 1 MW [6].

As illustrated in Table 1 the efficiency of polysilicon modules (Csi poly) is set at ~16% in 2014 [6]. However, even if we expect an increase in the efficiency of polysilicon modules by 2025, the maximum theoretical value these cells can achieve is 29.43% [7]. Scenario 2 adopts the CPV technology for triple junction cells because they can reach a theoretical efficiency of 59%, maximum performance compared to conventional silcon cells [8] and because it's low capital investment [9]. This model employs 45% efficiency triple junction cells using ~3500 m^2 for each 1 MW installed capacity [10].

As illustrated in Fig. 1 the maximum and nominal GHI values for each location were calculated to estimate the capacity factor. The latter highlights the degree to which the power plant can be utilized (refer to Eq. (1)).

The locations chosen in Latin America (see Table 2) ideal to set up a solar plant are: northern Chile, northern Mexico, Argentina and Brazil. The electricity generation per day is calculated using the nominal Global Horizontal Irradiance (GHI) in each of these locations. GHI values are the main input data outsourced from Meteonorm database using interpolating models among weather stations [11]. The GHI combines the diffuse and beam components of solar irradiance and it is particularly useful for PV stations. However, the DNI is also included since the model assumes CPV technology will be adopted in Scenario 2.

Tables 2 and 6 illustrate the relevant features of each location to install a 1 axis PV tracking generating station.

Equation (1) shows the dependency between the capacity factor of a PV power station and GHI/DNI values while keeping the module efficiency fixed at 16% in Scenario 1 and at 45% in Scenario 2. It depicts the relationship between the output generation of a 550 MW (IC) installed capacity, the total area (A_T), the number of hours per year (hr) and the module efficiency (η_{module}). Scenario 2 simply substitutes GHI for DNI values.

$$CF = \left[\frac{(GHI_{nom} * A_l)}{(IC * hr)}\right] * \eta_{module} \tag{1}$$

Equation (2) presents the calculation of the total area (A_T) of a 550 MW PV farm. Taking into account distances between modules to prevent shading effects we get a total area (A_T) that equals to a 38% increase of the land area (A_l) [12].

$$A_T = A_l + (A_l * 0.38) \tag{2}$$