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Economic Analysis of Renewable Energy Generation Technologies in the Northeast of Brazil

Pieter de Jong and Ednildo Andrade Torres

Universidade Federal da Bahia, Escola Politécnica/PEI, Rua Aristides Novis, nº2, Federação, CEP 40.210-630, Salvador, BA, Brazil

Abstract. This study compares the economic viability of five renewable energy technologies – wind, solar photovoltaic, concentrated solar thermal, biomass and wave power – to various other technologies including hydroelectricity, nuclear power, coal power and gas power sources. The Levelised cost of Electricity (LCOE) is calculated for 12 different Brazilian case study projects, 9 of which are located in the Northeast region. Initial results found that using a discount rate of 5%, the hydroelectric plants had the lowest LCOE, but were only slightly cheaper than the wind power case studies. Solar photovoltaic (PV) was found to be the most expensive technology followed by wave power and concentrated solar thermal power (CSP).

Keywords: Renewable Energy, Solar, Wind Power, Hydroelectricity.

1. Introduction

In recent years, due to increasing fossil fuel prices, the local manufacture of wind turbines and the introduction of carbon credits through the Clean Development Mechanism (CDM), large scale wind farm projects are now viable and have been undertaken by private enterprise in Brazil [4], [7] and [8]. The Northeast (NE) of Brazil has areas with excellent solar and wind energy potential, yet despite the huge potential, there is still an apparent lack in the development of large scale wind and solar technologies [4]. Therefore the objective of this study is to analyse the economic viability of these developing renewable energy technologies in the NE of Brazil and compare them to more traditional generation technologies. Specifically the Levelised Cost of Electricity (LCOE), which is used to benchmark the economic viability of different electricity generation technologies, is calculated for 12 different case study plants following the NEA-IEA-OECD [18] methodology. Given the particular energy generation challenges faced by the NE (see section 1.1) and the region's enormous wind and solar energy potential (see section 1.2), the majority of the case studies chosen are within the NE.

1.1. The electricity matrix in the Northeast region of Brazil

While Brazil overall has the world's largest water resources, the Northeast (NE) region is mostly semi-arid receiving only a small percentage of the annual total national rainfall. The region suffers from frequent droughts (the most recent in 2012), which can also affect the power supply, as the majority of the electricity matrix is supplied by hydroelectricity. However large hydroelectric potential in the NE region is entirely saturated and hence it is no longer possible to build new hydroelectric power stations [7]. In 2011 the NE imported almost 20% of electricity from the North and Southeast regions and this figure grew to 25% in 2013 [20]. Therefore the NE region will be faced with particular challenges in order to maintain electricity generation with the growing demand in consumption expected during the coming decades. Rather than constructing fossil fuel power plants which is currently the trend [16], a more sustainable and cleaner alternative would be to invest more in renewable energy generation given that the NE region is privileged with excellent solar and wind resources. While the Northeast states of Bahia, Ceará and Rio Grande do Norte have recently experienced a rapid growth in wind farm deployment (due to their favourable conditions in terms of wind speed, frequency, distribution and turbulence), the huge potential for solar power in Brazil remains largely unexploited [7].

1.2. Brazilian Wind and Solar energy potential

The onshore wind power potential in Brazil (at 50m above ground level) is approximately 145,000MW and more than half of this potential is in the NE region according to the Brazilian Atlas of Wind Power Potential [2]. The annual average daily solar radiation (on an inclined plane) for the Northeast region of Brazil is 5.9kWh/m^2 [15] the highest solar resource potential in the country. Yet until 2012 there were no suitable government regulations for connecting photovoltaic (PV) systems (or other small generator systems) to the electricity grid and reselling excess energy back to the electricity providers. However in April 2012, ANEEL approved a resolution that allows consumer micro and mini installations of renewable sources (including PV) to be connected to the grid and exchange electricity for credits with the local distributor [3]. Nevertheless renewable energy sources such as wind and solar power still suffer from unfair barriers that discriminate against renewable energy. In addition to high import duties, solar power is still at a disadvantage due to a lack of government support policies, such as subsidies, tax incentives and defined pricing [15]. Rather than focussing on the LCOE (which includes the lifetime costs of fuel, operations and maintenance and decommissioning costs) energy infrastructure planners and decision makers often focus on the high up-front capital costs of renewable energy compared to that of conventional energy sources.

2. Literature on the Economic Viability of Renewable Energy

Various international studies comparing the Levelised Cost of Electricity (LCOE) have been completed which do include renewable technologies such as wind, solar PV, concentrated solar thermal power (CSP) and wave power [18], [13], [19] and [1]. The NEA IEA OECD report [18] has LCOE data comparing traditional generation technologies in Brazil. Unfortunately the NEA IEA OECD report [18] does not have LCOE data for solar PV, CSP or wind power in Brazil. Besides the NEA IEA OECD [18] analysis comparing the LCOE of Brazil’s principle generation technologies Cardemil and Colle [5] examined the economic viability of a concentrated solar thermal power system in Brazil. But there are almost no studies which specifically examine the LCOE of different electricity generation technologies including grid connect renewable technologies in Brazil, let alone focussing on the NE region. Therefore this study aims to present a more complete analysis of LCOE for Brazilian electricity power plants including renewable technologies and focuses predominantly on the NE of Brazil.

3. Materials and Methods

In this study, the costs to produce electricity (MWh) of different generation technologies is compared using the levelised Cost of Electricity (LCOE) calculation following the methodology of the Nuclear Energy Agency (NEA), the International Energy Agency (IEA), and the OECD. The formula for the LCOE is derived by choosing a constant price of electricity that will result in the Net Present Value of all the revenues equating to the Net Present Cost of the entire project over the lifetime of the project. Then, resolving for this constant price of electricity gives the LCOE as shown below [18]:

$$LCOE = P_{Electricity} = \Sigma_t((Investment_t + O\&M_t + Fuel_t + Carbon_t + Decommissioning_t)*(1+r)^{-t}) / (\Sigma_t(Electricity_t*(1+r)^{-t})) \quad (1)$$

Where:

- $Electricity_t$: The amount of electricity produced in year “t”;
- $P_{Electricity}$: The constant price of electricity (assumed to be stable and unchanging during the lifetime of the project);
- $(1+r)^{-t}$: The discount factor for year “t” (the interest rate “r” is assumed to be stable during the lifetime of the project);
- $Investment_t$: Investment costs in year “t”;
- $O\&M_t$: Operations and maintenance costs in year “t”;
- $Fuel_t$: Fuel costs in year “t”;
- $Carbon_t$: Carbon costs in year “t”;
- $Decommissioning_t$: Decommissioning cost in year “t”.

The LCOE is calculated with a discount rate of 5% (which is approximately the real interest rate in Brazil). Using the real interest rate, allows for the effects of inflation and it is assumed that fuel costs, and operations and maintenance (O & M) costs increase in accordance to the inflation rate.

4. Financial and Technical Information on the Case Studies

For all the Brazilian case studies listed below, plant data including total investment, operations and maintenance, and fuel costs together with installed nominal power and capacity factor specifications, annual energy generation data, CO2 equivalent emissions, construction lead times and assumed lifetime is summarised in table 1.

The renewable energy case studies in the NE region of Brazil include: ***Brotas de Macaúbas Wind Farm*** [24]; ***Caetité, Guanambi and Igaporã Wind Farms*** (also known as Alto do Sertão I) [21]; ***Tauá solar PV*** [17]; ***Pituaçu Solar PV*** [6]; and ***Bioenergia (BEN) biomass power plant*** [23]; ***Bom Jesus da Lapa CSP (simulation)*** [5];

The hydroelectric case studies (under construction) in the Brazilian Amazon include: ***Belo Monte hydroelectric power station*** [10], [11]; and ***Santo Antonio hydroelectric plant*** [22].

The ***Angra-3 nuclear pressurised water reactor (PWR)*** [9] under construction in the state of Rio de Janeiro was chosen as the nuclear power case study.

The fossil fuel case studies (recently commissioned) in the NE region of Brazil include: ***Itaqui "Clean" Coal power station*** assumed to have carbon capture and sequestration (CCS) [17]; ***Energia Pecém - Coal power station*** [17]; and ***Parnaíba - Gas power station*** [17].

Currently there are no examples of commercial scale wave power plants or concentrated solar thermal power (CSP) installations operating in Brazil. Therefore additional LCOE data from international studies [1] and [18] for wave power and CSP technologies was considered in the overall LCOE results.

Table 1: Case study financial and technical data

Project input data	Units	Brotas de Macaúbas Wind	Caetité, Guanambi & Igaporã Wind	Belo Monte Hydro	Santo Antônio Hydro	BEN Biomass	Angra 3 Nuclear	Itaqui CLEAN Coal	Energia Pecém Coal	Parnaíba Gas	Tauá Solar	Pituaçu Solar	Bom Jesus da Lapa CSP
Installed Capacity	MW	90	294	11,233	3,150	53	1,405	360	720	3,722	1	0.408	30
Capacity Factor	**%**	**40%**	**46%**	**40%**	**70%**	***85%***	**81%**	***85%***	**85%**	***80%***	**18%**	**18%**	***20%***
Average Power Generated	MW	35.7	134.0	4,462	2,218	45.1	1	306	615	2,978	0.178	0.072	6
Hours per year	hrs/year	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Energy Generated per year	**millionkWh/yr**	**313**	**1,174**	**39,087**	**19,430**	**395**	**10,000**	**2,681**	**5,387**	**26,084**	**1.56**	**0.63**	**53**
Wholesale price of energy	$/MWh	68.81	72.25	39.09	38.61	no data	73.59	no data	no data	61.88	no data	*creditted*	no data
Investiment Cost	**$ millions**	**193**	**579**	**14,851**	**7,475**	**92**	**5,149**	**891**	**1,386**	**1,485**	**5.0**	**2.3**	**131**
Costs per kW of installed capacity	$/kW(inst)	2,141	1,973	1,322	2,373	1,728	3,664	2,475	1,925	399	4,950	5,581	4,370
Cost per $kW_{average}$ generated	$/kW(ave)	5,398	4,322	3,328	3,370	2,033	4,510	2,912	2,254	499	27,799	31,664	21,850
Operation & Maintenance (NEA, 2010)	**$/MWh**	1% of investment	1% of investment	**2.20**	**2.20**	**28.53**	**14.08**	**34.3 / 39.8**	**34.3 / 39.8**	**4.89**	0.25% of investment	0.25% of investment	**42.95**
Decommissioning (NEA, 2010)	$/MWh	**≈ 0**	**≈ 0**	**≈ 0**	**≈ 0**	**≈ 0**	**0.76**	**≈ 0**	**≈ 0**	**≈ 0**	**≈ 0**	**≈ 0**	**≈ 0**
Price of Fuel (NEA, 2010)	**$/MWh**	N/A	N/A	N/A	N/A	**17.33**	**10.55**	**13.94**	**13.94**	**52.35**	N/A	N/A	
Emissions factor (Carbon Credits/MWh)	$tCO2_{eq}$/MWh	**0.2055**	0.2055			**0.2055**					**0.2055**	0.2055	**0.2055**
$CO2_{eq}$ emissions intensity (IPCC, 2012)	$kgCO2_{eq}$/MWh	12	12	**287**	29	18	16	**100**	**1,001**	**469**	46	46	22
$CO2_{eq}$ emissions(+) / credits(-) per year	tCO_{eq}/yr	-64,266	-241,224	11,200,000	563,461	-81,098	160,000	268,324	5,392,787	12,233,291	-321	-129	-10,801
Lead construction times (NEA, 2010)	years	**1**	**1**	**4 through 8**	**4 though 7**	**2**	**6**	**4**	**4**	**2**	**1**	**1**	**1**
Assumed Lifetime of technology	**years**	**35**	**35**	**60**	**60**	**40**	**50**	**40**	**40**	**30**	**30**	**30**	**30**

- An exchange rate of US$1 = R$2.02 (from May 2013) was used to convert Reais to US dollars.
- Taxes were not included in the LCOE calculations.

5. LCOE Results

From all the data collected the LCOE was calculated using a real interest rate of 5% for all the Brazilian case studies considered and also for the international examples of CSP and wave power technologies. Figure 1, shows the LCOE separated by component costs for all the Brazilian case studies (with the exception of the solar power projects). Figure 2, shows the LCOE separated by component costs for the Brazilian PV and CSP case studies, and for the international CSP and wave power projects.

The LCOE analysis shows that the cheapest technology of all the case studies analysed was hydroelectricity. Both plants have a LCOE of approximately $27.50/MWh. Wind power is the second cheapest generation technology in Brazil. The Caetité, Guanambi and Igaporã wind farm complex, has a LCOE of $35/MWh and Brotas de Macaúbas Wind Farm has a net LCOE of $41.67/MWh. The biomass, fossil fuel and nuclear technologies all have a LCOE ranging from $61/MWh for the Parnaíba gas plant and the nuclear reactor, to $70.70/MWh for the Itaqui – "Clean" Coal power station. The "clean" coal power station was more expensive than the Pecém plant due to the 30% increase in capital costs for environmental controls such as carbon capture and sequestration (CCS) equipment.

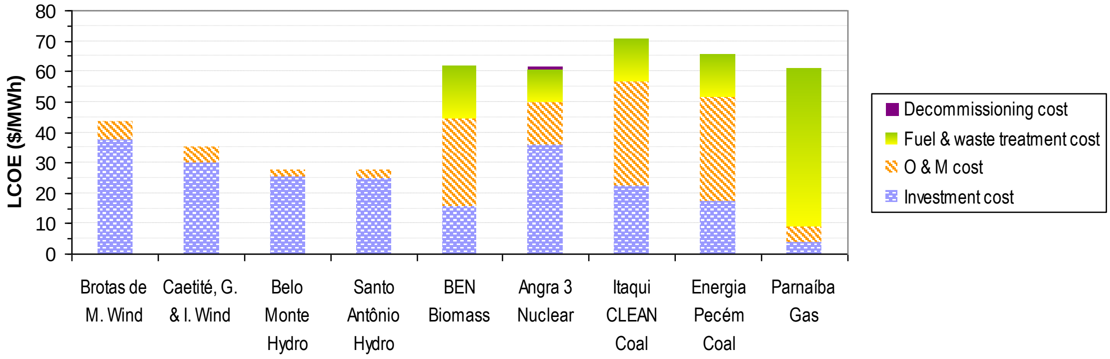

Fig. 1: LCOE using a 5% discount rate.

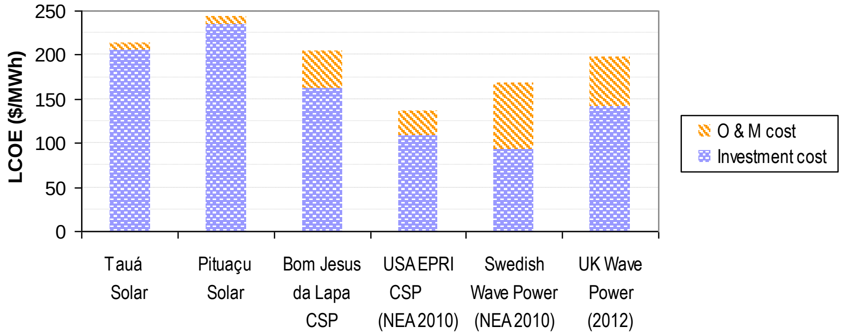

Fig. 2: LCOE using a 5% discount rate.

Considering PV, CSP and wave power technologies analysed, the USA EPRI CSP plant with a LCOE of $136/MWh was the cheapest and not surprisingly was significantly cheaper than the Brazilian solar thermal case study. The second cheapest of these developing renewable technologies (CSP and wave power) was the Swedish wave power plant with a LCOE of $169/MWh and a capacity factor of 35%. According to the NEA-IEA-OECD report [18] an Australian wave power plant has a capacity factor of 56%. Wave and tidal generators have an advantage of greater output regularity and higher capacity factors compared to wind and solar power. The Brazilian solar power case studies all have a LCOE above $205/MWh making them uncompetitive compared to the other technologies. The Solar PV systems with LCOE results of $214/MWh and $244/MWh for the Tauá and Pituaçu solar systems respectively were the most expensive technologies.

6. Conclusion

Results considering the current situation in Brazil (using a 5% discount rate) showed that the hydroelectric plants had the lowest LCOE due to their large economies of scales, but were only slightly cheaper than the wind power case studies. However, when using a 10% discount rate, the Caetité, Guanambi and Igaporã wind power case study had the lowest LCOE of all the case studies. Solar photovoltaic (PV) was found to be the most expensive technology followed by wave power and CSP.

Brazil has a very low overall emissions factor due to its relatively clean electricity generation matrix. However the majority of easily accessible hydroelectric resources in Brazil are already saturated and this is particularly the case in the NE region of Brazil. Therefore unless proper incentives are provided for solar, wind, geothermal and wave energy development, the percentage of electricity produced from non-renewable sources is likely to increase with the construction of new fossil fuel plants. Very recently there has been substantial growth in planned wind farms in the NE, however there is potential for a great deal more development and support for solar power lags far behind. To exploit and develop the full potential of wind and solar power in Brazil requires the implementation of effective government policy, more subsidies, tax exemptions and financial incentives to encourage large scale research, deployment and close the economic gap that exists between these unexploited renewable technologies and traditional generation technologies. It is anticipated that a follow up publication to this work will demonstrate the impact of environmental externality and transmission system costs on the LCOE from different generation technologies.

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