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Sustainable Expansion of the Brazilian Electricity Sector: An Approach using Sustainability Indicators

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Abstract: Perspectives for Brazilian Electricity Sector have continuously being changed in recent years. This is due to recent technological advances in wind turbines (with fallen costs), growing environmental constraints (specially related to hydropower potential), nuclear expansion uncertainties (after Fukushima event), among others. As a result of these facts, Brazilian auctions for electricity has surprisingly achieving good results for renewable, as wind power plants. The aim of this paper is analyze the attractiveness of power generation from a sustainability point of view, updating the study published in La Rovere et al (2010). The following generation sources are assessed: natural gas, large hydro, small hydro, nuclear, wind, municipal solid waste, municipal liquid waste, sugar cane bagasse, solar PV, agriculture solid residues, livestock solid residues and coal. Results show that Brazilian energy matrix is following the path of sustainability.

Keywords: Sustainability, Multi-criteria analysis, renewable sources of energy.

1. Introduction

Worldwide, Brazil has one of the largest shares on renewable energies in its energy supply mix: in 2010, was approximately 45% of the total (EPE, 2011). When considering total electricity generation, this renewable profile is even larger: near 80% comes from hydro power plants and alternative sources. When summed to ITAIPU imports (also from hydro power), Brazilian total electricity supply from renewables reaches about 85% from total.

For the next ten years, electricity generation capacity is estimated to add about 61 GW, where hydro is the largest source (52%) and wind (17%), according to ten year energy expansion plan (EPE, 2011a).

Keep this profile in medium and in the long term is a big challenge but there are evident benefits from this choice: it creates local jobs, contributes to reduce local and global pollution and, in some cases, improve local industry building capacity. From the energy planning perspective, it is also important assess the choices for energy supply expansion. Typically this is a multivariable problem as various interests are often conflicting, among economic, technological and socio-environmental objectives. Currently, main decision parameter is based on traditional economic feasibility analysis (the more economical competitive is a particular source of power generation, better is its insertion), although growing movement on national policies to incentive renewable sources can be observed, where we can cite PV expansion policy in Germany, for example.

So, the aim of this paper is analyze the attractiveness of power generation from a sustainability point of view, by using recent Brazilian power generation expansion results through a multicriteria method, in order to confirm the path of sustainability of Brazilian power sector.

2. Methods

The multivariable problem presented in earlier section will be assessed through the method called Data Envelopment Analysis (DEA), which is a multi-criteria methodology that allows alternatives to be assessed through their quantitative aspects. Input data for this method were fundamentally given by selected indicators considering issues in economic, technological and socio-environmental dimensions.

In this paper, overall methodology includes: (i) Initial formulation of indicators; (ii) Selection of a set of indicators; (iii) data collecting and processing; (iv) Application of DEA method; (v) analysis of results.

2.1- Initial formulation of indicators

Corresponds to the pre-selection of indicators related to the multiple dimensions involved in energy supply expansion problem. The main objective is to identify indicators that can explicit the driving forces of the supply expansion of energy for decision making.

This initial formulation of the indicators must to cover five dimensions of energy planning: technological, environmental, social and economic. The indicators established per dimension are, whenever possible, segmented by the phases of an electricity generation project, considering: (i) Extraction of primary source; (ii) construction phase of power plant; (iii) transportation of energy source; (iv) Operation of power plant.

2.2- Selection of a set of indicators

In this stage, pre-selected indicators are assessed according to a total of fifteen attributes, grouped under three major topics: conception, application and consistency. For each topic there is a set of five attributes (see figure 1).

Figure 1: Attributes adopted in the selection of indicators for the study.

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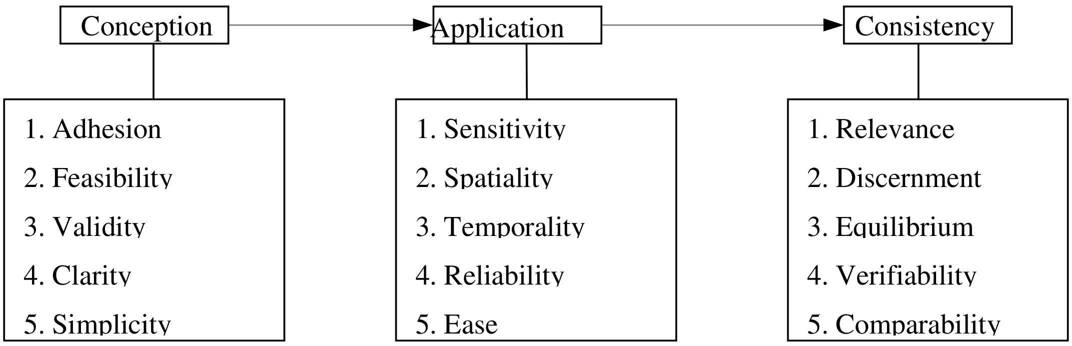

All pre-selected indicators are assessed according to a quali-quantitative criteria in which is assigned a integer value for attributes varying between 0 and 1, according the indicator matches or not each attribute. The top five proposed indicators are then selected in each topic presented in figure 1. By applying this methodology, the following indicators resulted from the selection (La Rovere et al, 2010):

- **Environmental:** Water consumption, specific CO_2 emissions, occupied area, non-CO_2 emissions (SO_X and NO_X) , percentage of effective land use;
- **Social:** Number of direct jobs created and average level of job income;
- **Economic:** Specific investment, cost-benefit index, percentage of imported inputs;
- **Technological:** Net generation efficiency, average annual availability, construction period and electricity generation potential.

After the selection is finished, indicators by dimension are aggregated in a synthetic index that integrates all these dimensions (social, environmental and technological). Through DEA method, final ranking is then determined.

2.3- Data collecting and processing

Information sources used to update the indicators include mainly recent specialized technical-scientific literature, like researching documents from scientific institutions available on their internet sites. When data were not available, some assumptions were made. These data are summarized in Table 1. Important to say that these data corresponds to average values and can vary considerably when considering specific projects.

Table 1: Indicators selected by electricity generation alternative: environmental and social.

Alternative	ENVIRONMENTAL					SOCIAL	
	Water consumption [m^3/MWh]	Specific CO_2 emissions [t CO_2/MWh]	Occupied area [m^2/kW]	Non-CO_2 emissions [kg/MWh]	Percentage of effective land use (%)	Number of direct jobs created [jobs/MWh]	Average job income level [R$/employee]
Large Hydro – 1	0	0	46,1	0	100%	0,0008	750
Large Hydro - 2	0	0	46,1	0	100%	0,0008	750
Natural Gas	3,8	0,484	22,2	0	100%	0,0011	750
Solar PV	0	0	9,9	0	100%	0,0040	750
Coal	7,2	1,043	22,2	0,002	100%	0,0024	750
Small Hydro	0	0	100	0	100%	0,0008	750
Sugar Cane Bagasse	50	12	8,43	0	100	0,0024	750
Agriculture Solid Waste	50	0,007	0	0	0	0,0024	750
Livestoch solid Waste	0	-0,484	0,003	0	0	0,0024	750
Nuclear	7,2	0	22,2	0	100%	0,0002	6.992
Wind	0	0	50	0	30%	0,0040	1.000
0Urban Liquid Waste	0	-0,484	0,003	0	100	0,0011	750
Urban Solid Waste	3	-2,33	2,0	0	100	0,0486	750

Table 2: Indicators selected by electricity generation alternative: economic and technological.

	ECONOMIC			TECHNOLOGICAL			
Alternative	Specific investment [US$/kW]	CBI [R$/MWh]	Percentage of imported inputs (%)	Net generation efficiency (%)	Average annual availability (%)	Construction period (years)	Electrical generation potential (GWh/year)
Large Hydro – 1	1.800	80	0%	95%	40%	5	214.795
Large Hydro - 2	2.500	120	0%	95%	40%	5	214.795
Natural Gas	800	140	50%	45%	70%	2	91.980
Solar PV	7.000	500	100%	16%	17%	1	>300.000
Coal	1.700	76	0%	35%	55%	2	89.615
Small Hydro	3.000	135	0%	95%	55%	2	71.619
Sugar Cane Bagasse	2.400	150	0%	30%	42%	1	4.770
Agriculture Solid Waste	500	143	0%	20%	80%	1	129.600
Livestoch solid Waste	1.500	128	0%	25%	92%	1	25.600
Nuclear	3.500	150	50%	35%	80%	5	43.000
Wind	2.100	100	40%	95%	35%	3	49.600
Urban Liquid Waste	1.500	128	0%	25%	92%	0,5	2.044
Urban Solid Waste	4.165	280	1,5%	25%	92%	1,5	75.240

3. Results and discussion

By considering the general values for Brazilian indicators presented in Table 1 and 2, results achieved by DEA method are shown in Table 3. According to these ones, hydro and biomass based sources achieve best results. In fact, top five expansion alternatives come from these sources. Effects as small scale, lower competitiveness and lower availability contributed to some sources are ranked worst than another.

Table 3: Results setting priorities for expansion alternatives for power generation

Energy alternative	RANKING
Large Hydro – 1	1
Agriculture Solid Waste	2
Sugar Cane Bagasse	3
Large Hydro - 2	4
Small Hydro	5
Nuclear	6
Urban Liquid Waste	7
Coal	8
Livestoch solid Waste	9
Urban Solid Waste	10
Natural Gas	11
Wind	12
Solar PV	13

Currently, Brazilian electricity matrix is dominated by hydropower (near 80% from total), and the sustainability analysis proposed show that this matrix achieves a great degree of sustainability. For the next ten years, main expansion of generation installed capacity will come from hydro – about 32 GW, according to EPE (2011). Another important sources includes: wind energy (10,7 GW) and sugar cane bagasse (4,7 GW). In this sense, this expansion profile shows that Brazil still continues to incentive renewable sources that are sustainable beyond the economic criteria. In fact, in recent years, competitiveness of wind energy, for example, was significantly increased, contributing to its sustainability competitiveness" also.

4. Conclusions

This paper intended to compare recent Brazilian electricity expansion under some proposed sustainability indicators, by considering dimensions that can be easily related to sustainable development. In this sense, it is important to consider technical-economical and socio-environmental aspects. Obviously, authors do not believe that this list covers all the aspects that should be considered in this complex problem, but we think this approach can contribute to this discussion.

According to achieved results, Brazil has a electricity matrix sustainable in a large degree, not only by environmental aspects, but also when economic and social ones are integrated. When analyzed the forecasts for this sector, this sustainability path is maintained in a large extent.

Nevertheless, the ranking of generating sources is largely influenced by the choice of the indicators as well as by the values for each proposed indicator. These parameters could change due to parameter dispersion and also to specific regional aspects. In spite of these limitations, it is worthwhile to cite that this methodology try to internalize socioeconomic aspects in the decision making process of implementing generation projects. Although significant improvement must be done in this methodology, preliminary results showed its potential to assess sustainability for electricity expansion assessment.

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Conflict of Interest

The authors declare there is no any conflict of interest of this paper.

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