ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/318318482

Impacts of COP21 to the Brazilian power sector

Article · July 2017

CITATIONS
0

READS
254

4 authors:

Rafael Kelman
PSR Energy Consulting
36 PUBLICATIONS **755** CITATIONS
SEE PROFILE

Rebeca Doctors
École Polytechnique
8 PUBLICATIONS **35** CITATIONS
SEE PROFILE

Ana Deveza
Federal University of Rio de Janeiro
6 PUBLICATIONS **6** CITATIONS
SEE PROFILE

Mario V. F. Pereira
PSR Energy Consulting
185 PUBLICATIONS **9,049** CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project DSGE Models for the Brazilian Economy View project

Project game theory View project

All content following this page was uploaded by Ana Deveza on 10 July 2017.

The user has requested enhancement of the downloaded file.

Impacts of COP21 to the Brazilian power sector

Rafael Kelman, Rebeca Doctors*, Ana Carolina Deveza*, Mario V. F. Pereira**
**PSR, Rio de Janeiro, Brazil, email: {rafael,rebeca,ana,mario}@psr-inc.com*

Abstract
The paper evaluates the impact of Brazilian Nationally Determined Contribution (NDC) to the power sector in the context of the Paris Agreement during the twenty-first session of the Conference of the Parties (COP) of December 2015. It investigates the adequateness of specific targets of the NDC by comparing additional power supply costs with mitigated greenhouse emissions. The study evaluates power system expansion and operation for the 2030 horizon considering a "business as usual" scenario (no targets to the power sector) and a "COP21 Scenario" with targets for energy efficiency and the share of non-hydro renewable electricity production.

Keywords: Renewable energy, Paris Agreement, power grid, policy impact.

Section I – Introduction

In December 2015, a group of 195 nations signed the Paris Agreement in which efforts must be made to curb Greenhouse Gases (GHG) emissions to limit the end-of-century global warming to *well below* 2°C. On a national scale, the agreement is put in force though the Nationally Determined Contribution (NDC) - an official document that establishes emissions targets staring in year 2020. The Brazilian NDC – ratified in September 2016 - set an absolute emission target of 1.3 $GtCO_2eq$ by 2025 (37% below 2005 level) and of 1.2 $GtCO_2eq$ by 2030 (43% reduction) (Brazil, 2015).

Although the Brazilian NDC mentions *flexible pathways* to meet these targets, specific actions focusing on the main sources of GHG emissions are listed for Land Use Change (42% of total GHG emissions), Energy (26%) and Agriculture – including food cropping and livestock - with 23% (SEEG, 2016).

The Brazilian NDC targets a 45% share of renewable sources in the 2030 energy matrix (Brazil, 2015). To meet this goal the country will increase: (i) the share of ethanol and other biofuels in the transport sector, (ii) the share of non-hydro renewable sources in the power sector from 9% to 23% and (iii) the role of energy efficiency to achieve savings equivalent to 10% of the consumption.

Despite the global emission targets and sector-specific measures, the Brazilian NDC did not include a study with a comprehensive assessment of technologies and alternatives to reach the objectives in an economically effective manner. Specific targets are also detrimental because they leave less maneuver space for governments in face of the expectations of stakeholders and the public opinion. Adjustments may be especially necessary if – as usual - reality diverts from the plan. As an example, the severe economic crisis was largely unaccounted for by the Brazilian government when the NDC was drafted a few years ago. This rationale explains why several nations were rather vague when defining their NDC (Rogelj *et al.*, 2016).

The Brazilian NDC was surprising in at least one account: it differentiated hydroelectricity from other renewables sources in the 23% electricity production target. This contradicts a historical position of the country to support hydro power and to confront groups that characterized it as a non-renewable source of energy due to potential reservoir methane emission.

From a supply perspective, 23% of non-hydro renewable participation in the power matrix and 10% energy efficiency, both relative to year 2030, leave nearly no room for new hydropower developments, which have historically been the main source of electricity in the country. The economic crisis aggravates this, as there is small demand requirements with respect to the forecast made in 2014-2015, when the NDC was prepared.

This paper aims to contribute to an economic assessment of the proposed measures for the energy sector in the Brazilian NDC. Similar economically-driven studies were made for measures in other sectors, such as Land Use (Escolhas Institute, 2016). To evaluate the feasibility of the power sector measures set in the Brazilian NDC, two long-term scenarios are evaluated in this paper: (i) Baseline scenario, modeled after current market conditions with long-term expansion unaffected by *post* COP 21 policies; (ii) COP 21 scenario with a long-term plan designed to meet energy sector-wise targets of NDC measures, as formulated.

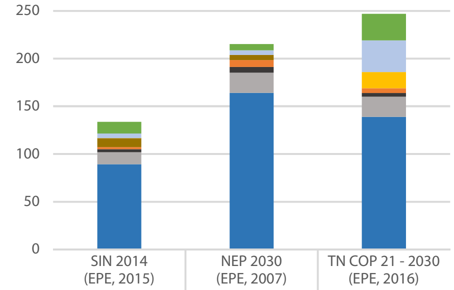
The remainder of the paper is organized as follows: section II provides an overview of the Brazilian power matrix, section III presents the modeling approach used in this study, and required adaptation measures for a high inception of Variable Renewable Energy sources (VRE), such as wind and solar power. Section IV presents results and comparisons between the two scenarios while the last section presents the conclusions of the study.

Section II – Brazilian power matrix

The current share of renewable sources in Brazilian electricity matrix is 75% (EPE, 2015), of which 80% is hydropower, 9% bioelectricity mainly from sugar cane bagasse, 4% wind power and 7% of other sources. Brazil has a good potential for solar power (Pereira *et al.*, 2012), but competitiveness has been low, which explains why centralized solar photovoltaic still has a negligible share of the matrix (EPE, 2015).

The following figure shows the installed capacity per source of the SIN (*Sistema Interligado Nacional*, in Portuguese), the Brazilian national grid, for year 2014 (EPE, 2015) and two different projections for year 2030, the first from National Energy Plan (EPE, 2007) prepared in 2007 and labeled as NEP 2030, while the second and recent projection comes from Technical Note *"Brazilian commitments in confronting climate change: energy production and use"* (EPE, 2016), (TN COP 21). Both projections were made by the Brazilian Energy Research Company (EPE – *Empresa de Pesquisa Energética*, in Portuguese), a branch of the national Ministry of Mines and Energy (MME – *Ministério de Minas e Energia,* in Portuguese).

It is interesting to observe how biomass projection made in 2007 for 2030 (7 GW) underestimated reality (already 12 GW in 2014). For wind power, the forecast for 2030 (5 GW) was achieved in 2014 and currently (2017) there is more than 10 GW of installed wind power.



	SIN 2014 (EPE, 2015)	NEP 2030 (EPE, 2007)	TN COP 21 - 2030 (EPE, 2016)
🟩 Biomass	12	7	28
🟦 Wind	5	5	33
🟨 Solar	0	0	17
🟫 Others	10	6	0
🟧 Nuclear	2	7	5
⬛ Coal	3	6	4
⬜ Natural Gas	13	21	21
🟦 Hydro	89	164	139

Figure 1. SIN capacity in 2014 and 2030 (GW).

A long-term supply and demand scenario was devised for the COP 21 and the baseline scenarios. This scenario differs from official forecast presented in the EPE Technical Note of 2016 in three important aspects: (i) the demand growth rate is much smaller, a more realistic assumption in view of the current economic crisis; (ii) SDDP - an electric system operation model - was used to simulate the behavior of the SIN in detail and assess externalities associated to requirement of additional reserves; (iii) forecast of expanding sugar cane bagasse cogeneration was reduced because the driver for this expansion - the ethanol industry - unfortunately faces harsh times and prospects for new cars sales or ethanol exports are discouraging;

Figure 2 presents the technology share of each scenario of the study for the end of the planning horizon (2030).

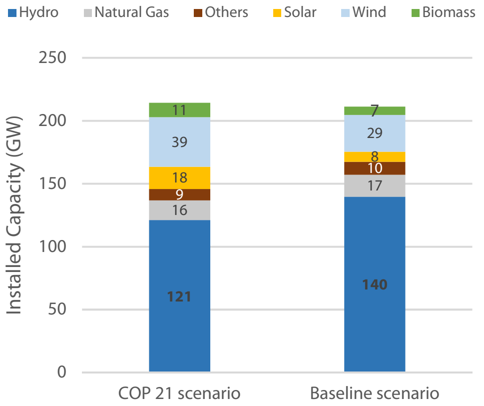


Figure 2. Installed capacity comparison for 2030.

As established by the Brazilian NDC, the share of non-hydro renewable sources reaches 23% in the COP 21 scenario and there is an effort to increase energy efficiency to 10% of the market by 2030. This is 7% higher than the baseline that includes some "inertial" or "technology-related" efficiency gain of 3% during the same period. The increased share of VER in the COP 21 with respect to the baseline scenario (2.1 pp for solar photovoltaic, 4.8 pp for wind power and 2.4 pp for biomass) is achieved at the expense of 6.3 percentage points of hydropower firm capacity.

The figure below shows *firm capacity* (roughly the installed capacity times a mean production factor for technologies and firm energy production for hydropower – associated to low hydrology period). In fact, 15 hydropower projects of Baseline, totaling 20 GW, such as the 8 GW mega-project São Luiz do Tapajós were discarded in COP21.

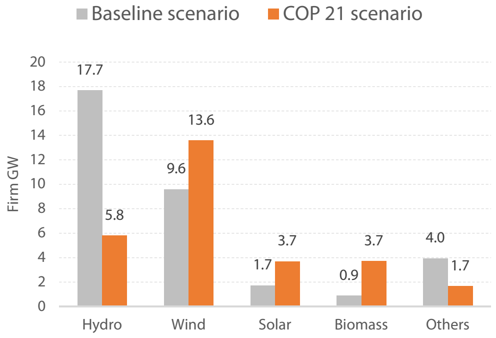


Figure 3. Firm capacity additions (GW average).

Section III – SDDP model and adaptations

The comparison between Baseline and COP 21 scenarios was made by simulating the operation of the SIN with a Stochastic Dual Dynamic Programing (SDDP) based model (Pereira & Pinto, 1991). SDDP calculates the least-cost stochastic operating policy of SIN, while considering operational details of hydropower (detailed reservoir operation with plants in cascade), thermal plants (efficiency curves, unit commitment and others), VRE sources (scenarios of wind and solar power, seasonal production for sugar cane bagasse). Hydrological uncertainties and transmission network constraints and losses are also considered. (PSR, 2017).

VRE short term (hourly) production uncertainty was sampled from a stochastic multivariate (nonparametric) model based on Bayesian networks and kernel probability distributions (Borges & Dias, 2016). Different scales of time: monthly mean inflows to hydroelectric plants; hourly periods for wind velocities and solar radiation (both transformed into power outputs with an engineering module). Scenarios produced with the model were imported to the SDDP model for the different cases evaluated in the study.

The following diagram illustrates the high-level process with data sources identified in green, models in blue, the modeled expansion plan in orange and demand data preparation in yellow.

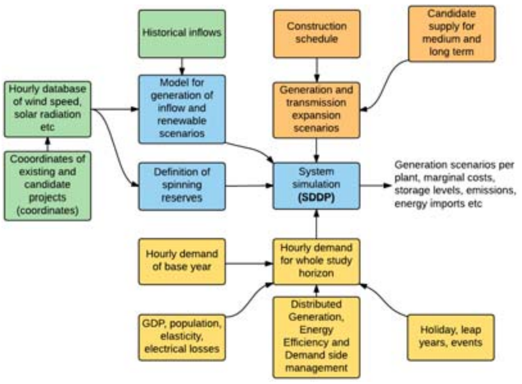


Figure 4. Dataflow and models used.

It is expected that wind power will have the highest non-conventional renewable installed capacity in the medium, long-term (IEMA, 2016) (EPE, 2016). To account for the increase of VRE, we tabulated hourly variation of wind power output with data provided by the National System Operator (ONS – *Operador Nacional do Sistema,* in Portuguese). A dataset of hourly production of 72 wind farms in four Brazilian states were used, with data from January 2015 to July 2016. Hourly production changes of nearly 20% of the installed capacity were observed, as shown in the histogram.

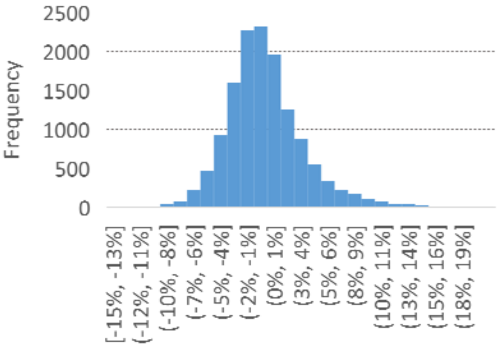


Figure 5. Wind power 1h-variation (% of capacity).

Historically, spinning reserves were not an issue for the operation of SIN, given the large hydropower share with regulating reservoirs and low short-term intermittency (mostly related to equipment outage or extreme events, such as World Cup finals). The rapid growth of wind power and the joint effect of NDC goals and economic recession (less room for new hydropower developments) all lead to additional reserves.

Baseline and COP 21 expansion plans consider respectively 30 GW and 40 GW of wind power installed capacity by 2030, departing from 10 GW of 2017. If the current relative variability of wind power is assumed to be the same in 2030, then a total reserve between 6 GW and 8 GW will be needed to mitigate the intermittency of the non-hydro renewables.

Part of the reserve can be met with existing resources allocated to hydro plants of the Northeast subsystem, because of the high concentration of wind and solar power plants in this region. This group consists of the plants connected to the Automatic Generation Control(AGC)[1] and Xingo HPP (3 GW), currently not in the AGC, but with good potential due to its large water head and location in the same region.

We assume that 30% of the installed capacity of these hydropower plants are withheld for reserves. Hydropower plants *outside* the Northeast system are also considered in a strategy which require idle capacity (assumed as 30%) for the power lines connecting this system to the remaining SIN. After local and external limit, additional reserves must be procured. Corresponding investment and externalities (increased operating costs) are quantified in each scenario. For the investment part, we consider an open cycle natural gas thermal plant of 1 GW for the Baseline scenario and 3 GW for the COP 21 scenario (amounts determined by previous methodology). In both scenarios, this additional supply enters operation from 2027 and reaches full

---

[1] The Automatic Control Generation seeks a balance between supply & demand, to maintain the nominal frequency of the system.

capacity by 2030. It is worth noting that this situation is analogous to the current reality of markets such as the German, where VRE variability is offset by controllable plants and more network integration (Grave *et al.*, 2012).

Section IV – Comparison between scenarios

Costs comparison

COP 21 has lower costs with respect to the baseline scenario. The present value of total costs, which include investment and operation is R$ 13 billion smaller than the baseline scenario (R$ 288 billion to R$ 301 billion).

This result is counter intuitive because COP 21 considers the expansion of significantly more expensive sources of energy, especially in the case of solar photovoltaic. To understand the result, we disaggregated the total cost for the different measures established in the NDC.

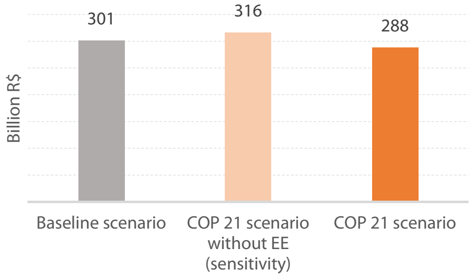


Figure 6. Present value of total costs comparison.

As seen from the figure above, COP 21 costs R$ 15 billion more than the Baseline scenario if the 23% share of non-hydro VRE sources is considered by 2030. The savings presented before are explained by the second component: increased energy efficiency measures are economically beneficial. The reason for this is the low opportunity cost of energy efficiency, set at R$ 99 per MWh - much lower than the levelized cost of all sources of electricity (CEBDS, 2016).

To increase energy efficiency in the country becomes a straightforward conclusion from this exercise. Thus, the NDC has merit of including the 10% target as a measure, although how this efficiency will be achieved was neither part of the NDC nor of EPE's technical note (EPE, 2016).

Pursuing energy efficiency is by no means a trivial task, as there are many barriers that hinder its development. For example, required investments are to be made by the private sector, who tend to be reluctant in face of perceived risks (will measures be effective?), priorities (pressing issues for managers tend to leave it behind), or lack of financial resources (including difficulties in financing measures, such as equipment update). It is clear that a large effort needs to be made to improve the dialogue between the productive sector, the government and final users (CEBDS, 2016).

Emissions comparison

As mentioned in the Introduction of this paper, the targets set by Brazil are to reduce GHGs absolute emissions to 1.3 GtCO$_2$eq by 2025 and 1.2 GtCo$_2$eq by 2030 (Brazil, 2015) . Even though the energy sector accounts for two thirds of global emissions (IEA, 2015), the Brazilian power sector is mainly composed by renewables, thus contributing little for total emissions (only 4% of total emissions of the energy sector in 1990). The drought of 2013-2014, raised the emissions of the power sector to 15% of emissions of the energy sector (Observatório do Clima, 2015).

The cumulative emissions for the studied period (2016-2030) of both scenarios is shown next. The difference between cumulative emissions of the two scenarios is 45 MtCO$_2$eq. It is equivalent to 2% of Brazil's total emissions in 2014 (1,800 MtCO$_2$ eq) or 9% relative to the energy sector for the same year (480 MtCO$_2$ eq).

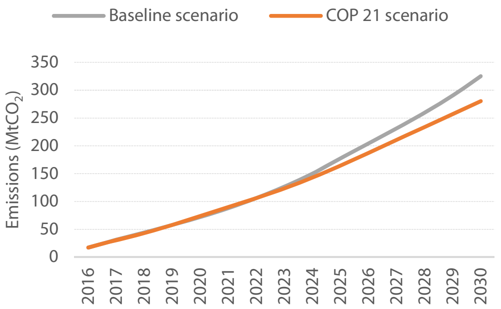


Figure 7. Cumulative emissions for 2016-2030 period.

The previous result allows us to estimate the shadow prices of reducing power sector related GHG emissions. As discussed, COP 21 plan without considering energy efficiency measures costs R$ 15 billion more than the Baseline scenario in terms of present value. Assuming an annualization factor of 10% (resulting from a discount rate of 10% and a period of 20 years), the reduction of 45 MtCO$_2$ eq would cost R$ 1.5 billion per year. Assuming an exchange rate of 3.3 R$/US$, we calculate the shadow price as 10 US$/tCO$_2$ eq.

It is worth mentioning that this exact value (10 US$/tCO$_2$ eq) was considered an *inflection point* for different carbon taxes evaluated in a recent study elaborated by the Miles Consortium Project (Spencer *et al.*, 2015). Thus, several other GHG reducing measures should be pursued prior to measures of the Brazilian NDC for the energy sector (with exception of energy efficiency). An interesting complementation of the present study would be to compare the shadow prices emission reduction among different sectors to maximize social welfare.

Section V – Conclusions

The paper investigated the economic adequateness of power sector related targets of the Brazilian NDC. It was motivated by the fact that – to the authors' knowledge, no studies were presented by Brazilian authorities to economically justify these targets *vis a vis* alternatives measures with perhaps smaller mitigation opportunity costs.

Considering the current economic crises of Brazil and the 10% energy efficiency target, there would be no room for new hydropower projects in the country. Thus, supply would be met by non-hydro renewables sources, mostly wind power, solar power and sugar cane bagasse cogeneration. As a result, short-term variability becomes a critical issue related to operating reserves. Backup power generation must be procured from 2027.

The study compared costs of two scenarios (with and without Paris Agreement related targets) and concluded that there is an increase of R$ 15 billion in the present value of investment and operating cost with NDC-biding measures for an overall GHG emission reduction of 45 $MtCO_2$ eq. As a reference, the opportunity cost of $10 per tCO_2eq exceeds a sample of alternatives presented in a recent study, suggesting mitigation can be procured cheaply outside the power sector. One measure of the NDC – the 10% energy efficiency target by 2030 - is effective and economically justifiable, thus should be implemented.

Acknowledgement

This study was funded by a project developed for the National Confederation of Industries (CNI) of Brazil. The authors would like to thank CNI for this engagement and for its contribution to this work.

References

Borges, C. & Dias, J., 2016. A Model to Represent Correlated Time Series in Reliability Evaluation by Non-Sequential Monte Carlo Simulation. *IEEE Transactions on Power Systems*, : 1–1, ISSN: 0885-8950, DOI: 10.1109/TPWRS.2016.2585619, Available: <http://ieeexplore.ieee.org/document/7501555/>, [Consulted: March 7, 2017].

Brazil, . 2015. *Intended Nationally Determined Contribution towards achieving the objective of the UNFCCC*. Brasília, Presidência da República, Available: <http://www.mma.gov.br/images/arquivos/clima/convencao/NDC/BRASIL_NDC_portugues.pdf>, [Consulted: March 6, 2017].

CEBDS, . 2016. *Consumo eficiente de energia elétrica: uma agenda para o Brasil*. Rio de Janeiro.

EPE, . 2007. *Plano Nacional de Energia 2030*. Rio de Janeiro, ISBN: 9788578110796.

EPE, . 2015. *Balanço energético nacional 2015*. Rio de Janeiro.

EPE, 2016. *O Compromisso do Brasil no Combate às Mudanças Climáticas : Produção e Uso de Energia*. Rio de Janeiro.

Escolhas Institute, . 2016. *Quanto o Brasil precisa investir para recuperar 12 milhões de hectares de florestas?* São Paulo, p. 124.

Grave, K.; Paulus, M. & Lindenberger, D., 2012. A method for estimating security of electricity supply from intermittent sources: Scenarios for Germany until 2030. *Energy Policy*, 46: 193–202, DOI: 10.1016/j.enpol.2012.03.050, Available: <http://linkinghub.elsevier.com/retrieve/pii/S0301421512002558>, [Consulted: March 7, 2017].

IEA, . 2015. *World Energy Outlook Special Briefing for COP21*. International Energy Agency.

IEMA, . 2016. *Prioridades para a integração das fontes renováveis variáveis no sistema elétrico*. São Paulo, Instituto de Energia e Meio Ambiente, Available: <http://www.energiaeambiente.org.br/wp-content/uploads/2016/12/NT_integracao_final.pdf>, [Consulted: March 7, 2017].

Observatório do Clima, . 2015. *Análise das emissões de GEE no Brasil (1970-2013) e suas implicações para políticas públicas.* Available: <http://mediadrawer.gvces.com.br/oc/original/sintese_2015.pdf>, [Consulted: August 12, 2016].

Pereira, M. G.; Camacho, C. F.; Freitas, M. A. V. & Silva, N. F. Da, 2012. The renewable energy market in Brazil: Current status and potential. *Renewable and Sustainable Energy Reviews*, 16(6): 3786–3802, ISSN: 13640321, DOI: 10.1016/j.rser.2012.03.024, Available: <http://dx.doi.org/10.1016/j.rser.2012.03.024>.

Pereira, M. V. F. & Pinto, L. M. V. G., 1991. Multi-stage stochastic optimization applied to energy planning. *Mathematical Programming*, 52(1–3): 359–375, ISSN: 00255610, DOI: 10.1007/BF01582895.

PSR, . 2017. *Software | PSR*. Available: <http://www.psr-inc.com/softwares-en/>, [Consulted: March 7, 2017].

Rogelj, J.; Elzen, M. Den; Fransen, T.; Fekete, H.; Winkler, H.; Schaeffer, R.; Sha, F.; Riahi, K. & Meinshausen, M., 2016. Perspective : Paris Agreement climate proposals need boost to keep warming well below 2 ° C. *Nature Climate Change*, 534(7609): 631–639, ISSN: 0028-0836, DOI: 10.1038/nature18307, Available: <http://dx.doi.org/10.1038/nature18307>.

SEEG, . 2016. *Emissões no Brasil de 1970 a 2014*. Available: <http://seeg.eco.br/>, [Consulted: August 1, 2016].

Spencer, T.; Pierfederici, R.; Waisman, H.; Colombier, M.; Bertram, C. & Kriegler, E., 2015. *Beyond the Numbers : Understanding the Transformation Induced by NDCs A Report of the MILES Project Consortium*. Paris, France, 80 p.

View publication stats