Decarbonizing the Brazilian Power Sector

Main Issues

The following text was prepared by Instituto Nacional de Eficiência Energética [Energy Efficiency National Institute] for Instituto Clima e Sociedade [Climate and Society Institute]. It was developed between June and September 2017, under the coordination of Pietro Erber, with the support of Marcos José Marques and Jayme Buarque de Hollanda.

ACRONYMS

INEE	Instituto Nacional de Eficiência Energética
iCS	Instituto Clima e Sociedade
SIN / NIS	Sistema Interligado Nacional / National Interconnected System
EPE	Empresa de Pesquisa Energética
GCOI	Grupo Coordenador da Operação Interligada
BEN	Balanço Energético Nacional
WEC	World Energy Council
IEA	International Energy Agency
GHG	GreenHouse Gasses
BNDES	Banco Nacional de Desenvolvimento Econômico e Social
CCEE	Câmara de Comercialização de Energia Elétrica
PNE	Plano Nacional de Energia (long term)
PDE	Plano Decenal de Energia

INTRODUCTION

The following text was prepared by Instituto Nacional de Eficiência Energética [Energy Efficiency National Institute] for Instituto Clima e Sociedade [Climate and Society Institute] as a supporting document for a meeting with AGORA project to discuss alternatives to minimize in the long term GHG emissions in Brazil´s power sector.

In many countries, including Brazil, the electric power sector is undergoing significant transformations, albeit their nature and speed may vary considerably. New technologies, new energy sources, enhanced concern about the environment have been the hallmarks of these changes. Flexibility has been a major objective in order to cope with the high variability of renewables such as wind and solar energy.

Reducing fossil fuel based generation requires the utilization of new non-hydro energy sources as further development of hydroelectric generation faces significant social and environmental limitations. Therefore it will hardly follow the growth of electricity demand, as it did in the past. Since other renewable energy sources are becoming more competitive, a largely sustainable electricity supply expansion is feasible.

Present tendencies and Federal Government energy sector plans indicate an approximately constant share of fossil fuels based electricity generation through 2026 (Plano Decenal de Energia, EPE, 2017). Given feasible specific conditions in terms of regulation, efficiency, financing and realistic evaluation of each energy source utilization externalities, this share may be reduced so that by 2050 this sector’s full decarbonisation may be achieved.

Due to the priority of the environmental agenda, solar, wind and planted biomass tend to have much larger shares among the primary energy sources of electricity generation in Brazil, where natural conditions are particularly favorable to their development, even without the incentives that were pertinent to their early development stage.

Most renewable energy sources availability present marked seasonality. Wind and sunlight also present relevant intermittency. The major exception is planted forests biomass, which is available all the year round. Since demand in the National Interconnected System is less variable (monthly load factor is close to 80%, according to ONS recent reports) other generation sources must operate complementarily and/or the renewables variations and irregularities must be smoothed out by means of storage facilities, such as water reservoirs and batteries, as well as by exploiting regional diversities of supply availability and consumers flexibility.

Therefore, as wind and PV solar generation shares increase new energy supply and demand strategies have to be developed in order to reduce the cost of intermittent generation insertion into the interconnected system.

In another report to iCS[A], INEE presented a quantitative analysis of the potential development of electric power generation based on sugar cane and planted forests biomass, though 2050. In what follows, other renewable sources are also taken into account. Emphasis is given to their qualitative aspects identifying barriers to their development and possible ways to overcome them.

BRAZIL'S POWER SECTOR

Brazil is located in tropical and sub-tropical regions. It is endowed with several large river basins and favorable sites for hydroelectric generation. Brazilian electricity generation has one of the world's smallest dependencies on fossil fuels. Besides hydro, sugar cane residues and other biomass have been important traditional primary energy sources. Since the beginning of the century wind and more recently PV solar energy have presented significantly fast growth.

All these sources utilization is improved by a continental sized power grid (in Europe, its coverage would go from Lisbon to Moscow) that enables the country to profit from the seasonal diversity of the major river basins hydrological cycles. Its centrally coordinated operation main purpose is to minimize fossil fuel use and supply failure risk.

From its early days, in the beginning of the last century, Brazilian electricity supply has been mainly based on renewable sources, mostly hydro. In 2016 it supplied about two thirds of total national demand.

	Source	**TWh**	**%**
Renewable	Hydro	422*	*68*
	Biomass	49†	*8*
	Wind	33	*5*
	Solar	-	-
Non Renewable	Nuclear	16	*3*
	Natural gas	57	*9*
	Oil & Coal	29	*5*
	Other	14	*2*

Source: BEN 2017 (Relatório Síntese, ano base 2016)

INEE estimated that 4,4 TWh of diesel driven power generation were used for peak shaving in 2013 within consumers' premises. This generation's fuel consumption is not included in electricity generation statistics. Probably, this situation has not changed significantly.

* Includes 41 TWh imports generated by the Itaipu Binational hydro plant
† Sugar cane and paper and pulp residues cogeneration

GENERATION EMISSIONS IN BUSINESS-AS-USUAL SCENARIO

In 2016 the overall energy sector related GHG emissions totaled 429 MtCO2eq (BEN 2017). Power generation accounted for 59 MtCO2eq, about 14% of that total, a significant reduction with respect to 2015 when fuel consumption was particularly intense. Plans for the power sector expansion indicate that the fossil fuelled capacity should grow in absolute, if nor in relative terms. According to the Government official plan, elaborated and published by EPE in 2017 (PDE 2026), that capacity should increase from 20.9 GW to 23.3 GW from 2016 to 2026. Its main component is natural gas fuelled. Autoproducers are expected to contribute more heavily to total carbon emissions of the power sector than centralized generation connected to the Interconnected national system, as shown below:

Electricity Generation Emissions (MtCO_2 eq)

	2015	2020	2026
Power Sector Total	81	38	62
Interconnected System	64	24	37
Autoproducers	17	14	25

Source: PDE 2026

These PDE 2026 estimates for the coming years assume long term average hydrologic conditions. The evolution of the generating capacity available to the market (autoproducers excluded) as foreseen in the EPE 2026 Plan is the following:

Generating Capacity - GW

Source	2016	2026
Hydro	102.5‡	118.7
Wind	10.0	28.5
Biomass	12.9	16.9
Solar	-	9.7
Uranium	2.0	3.4
Fossil fuels	20.9	23.3
Imports	7.0	7.0
TOTAL	148.4	212.5

Source: PDE 2026

The long term energy sector government plan, PNE 2050, also elaborated by EPE, about one year before PDE 2026, estimates future demand but does not

‡ Includes 5.8 GW of small hydro (less than 30 MW each) and 7 GW of Itaipu

indicate specific primary energies supply figures for power generation. However, its assumptions and figures for total primary energy demand indicate that its outlook is basically “business as usual”, although mitigated by important elements that reflect the government concern about environmental issues.

RENEWABLE ENERGY SOURCES IN BRAZIL

Worldwide, decarbonisation of the power sector is viewed as much more feasible than that of other sectors, such as transportation, since electricity may be generated from all primary energy sources and there is much scope for efficiency increase. However, the major available sources have different characteristics.

World utilization of renewable energy sources, as shown below, indicates that their contributions to electricity supply will necessarily have to be differentiated.

World Utilization of Renewables for Power Generation 2014

Source	Capacity GW	Generation TWh	Capacity Factor %
Hydro	1055	3898	42
Wind	370	728	22
Biomass	93	423	52
PV Solar	181	211	13
Geothermal	13	94	83

Source: WEC, World Energy Perspectives, Variable Renewables Integration in Electricity Systems: How to Get it Right, presentaton by A. Clerici, WEC 23rd Congress, Istambul, 2016.

The capacity factor of a plant is the % of the time in which it is capable of operating at full load. It should be noted that in Brazil climate conditions provide higher wind and PV solar average annual capacity factors, mainly in the Northeast.

Hydro

Further development of the hydroelectric generation faces significant social and environmental limitations, so that it will hardly follow the growth of electricity demand, as it did in the past.

Hydroelectric plants built in Brazil during the last century generally benefitted from significant river flow regularization by many medium sized and a few very large reservoirs. Furthermore, the natural flow of the rivers of South-Central and Northeastern Brazil on which they were built did not present so large variations as those of the rivers that began to be exploited in the present century, mostly in the Amazon area. Besides reservoirs, large drainage area upstream from a given plant also enhances regularization of the river, since it benefits from rainfall occurrence diversity. This is not the case of small hydro, usually relying on small catchment areas that tend to present higher discharge variability. Their generation is usually higher when most plants in the same region are also benefiting from the wet season.

Construction of new reservoir capacity has been restricted by topographic features (mainly in the Amazon) as well as by requirements for environmental and social impacts compensation and mitigation, both regulatory and socially imposed on new plant designers and builders. On the other hand, the majority of the load is located in areas that have favorable conditions for building pumped storage plants, although none is available or foreseen in the near future yet.

By the end of the previous century, national energy storage capacity was equivalent to about six months of the National Interconnected System demand. Presently it is barely equivalent to four months demand, because the load has increased and practically no significant reservoirs have been built in the last two decades. Moreover, in the latter years these reservoirs have been half full, at best. By late June, 2017, available storage amounted to about 45% of the total 220 TWh capacity. Filling these reservoirs has been hampered by unfavorable hydrological conditions and by the need to compensate the variations of run-of-river generation of large plants of the Amazon basin and of wind power supply reductions.

A relevant issue concerning generation planning is the difficulty to evaluate externalities related to different energy sources. Hydro, as well as other renewables based generation, is usually compared to fossil fuels based generation according to their levelised costs, in spite of the frequent official manifestations favoring renewables. No carbon emissions penalties are effectively included in the comparisons. On the other hand, one of the government topmost priorities has been to keep tariffs low so that investment costs had to be restricted. This may have reduced the scope for environmental and social impacts mitigation and compensation and prevented some hydro plants to be built or jeopardized their design.

Sugar cane

Power from sugar cane, Brazil’s second largest primary energy source, accounted for 5% of Brazil’s electric power generation in 2016. With available technologies, it could supply up to 15% of Brazil’s power needs. Sugar cane processing plants are located close to major electricity markets. They operate continually during about seven months, the harvest period. In the South-Center region, where the majority of these plants are located, their operation coincides with the dry season. Hence, their generation delays or reduces reservoirs depletion and contributes to the reduction of fossil fuel based complementary generation.

Sugar cane production main products are sugar and ethanol, although electricity relevance tends to increase significantly, mainly if fiber rich varieties of cane will be more widely adopted. Sugar and ethanol markets differ considerably and ethanol is more likely to lead this staple production.

Wood

Most wood based power is presently generated by cogeneration facilities of pulp and paper industries, mostly for their own use. The expansion of this industry depends mostly on the international market. Forestry production for the pulp and paper industries has achieved record productivities, up to five times greater than observed in temperate climate countries. Another utilization of planted forests biomass is for charcoal production, which is presently in low demand, due to the reduction of steel production.

The high productivity of planted forests is now beginning to be exploited for power generation for the grid. Biomass from planted forests is the only renewable and potentially important energy source which availability is neither seasonal nor intermittent. As the initial investment in these generating facilities is an important component of their generation cost they should be operated with high capacity factors, as a base load supplier. Since their turbines are steam driven, they usually do not have the flexibility that is necessary to compensate for the sharp variations of supply from other sources, such as wind and PV solar.

There are 6.5 million hectares of planted eucalyptus and other species, mostly available for electricity generation. Present installed capacity is 1200 MW and 670 MW will be commissioned in the next three years. According to the 2015 Paris Agreement Brazil should plant 12 million hectares of forests and recover 15 million hectares of degraded pasture with forests through 2030., their sustainable exploitation, partly for electricity generation, may supply the country with at least 200 TWh annually by 2050[B]..

Forest biomass potential is probably underrated, although in 2016 it accounted for 8% of the country's total primary energy sources, according to BEN 2017. New utilizations, such as wood chips for co-firing in coal driven power plants and for pellets production are expanding significantly.

Wind

Until the beginning of the present century, wind power generation in Brazil was negligible. In 2002 the government set up PROINFA, a subsidized investment program for wind, small hydro and biomass projects, that gave a start to wind power development, benefitting from earlier wind surveys promoted by ELETROBRAS. Technical improvements, scale economies, high selling prices and fiscal incentives, motivated by environmental concerns and industrial development, enabled the country to count on 10.4 GW of wind installed capacity by June 2017.

Wind power generation is growing due to the existence of good sites and stimulated by tax incentives. Their growth, however, presents a new set of problems due to their intermittence.

Wind conditions are very good in the Northeast, where about 75% of the total wind power capacity has been installed. The remainder 25% is mostly in the South region, where wind is also favorable, but more erratic than in the Northeast. Technical improvements, higher poles, larger propellers and generators, regional transmission interconnections reinforcements are contributing to enhance wind power competitiveness and reliability. However, even in the Northeast wind speed variations are eventually sharp and may substantially reduce power generation for many hours or even days.

As the present wind powered capacity in Northeastern Brazil is about half of the region’s total installed capacity, when wind is weak the region must rely on generation from other regions, over long distance transmission lines. In order to maintain the interconnected system stability when wind generation presents sharp variations, more than usual spinning reserve, transmission capacity and system protection must be provided, increasing the cost of energy supply. If the spinning reserve is provided by gas turbines, considerable amounts of fuel may be wasted. If it is based on hydraulic machines, either water or energy from the system may be consumed. Improvements in weather forecasting should reduce, but not eliminate the need of keeping large reserve capacity in order to cope with wind and, in the near future, solar variations.

Solar PV

Solar PV generation has developed very fast in the last ten years due to very important investment cost reductions. As well as wind power, it presents sharp intermittency due to clouds movement, besides daily and seasonal variations of insolation. Moreover, while wind plant full capacity may be available during more than half of the time, solar PV capacity factor may reach 24 % in low latitudes and favorable climate conditions. Therefore, both in the case of solar PV and wind, continuity of supply requires a complementary source or storage of part of the generated electricity.

Solar PV may be developed in large numbers of panels adding up to several tens of MW, delivering their generation to the grid. This approach benefits from economies of scale, although it incurs in transmission losses. On the other hand, solar PV may be an important component of distributed generation if it is connected to the local distribution network. In this way, it supplies the local consumer and may sell the eventual surplus to the local utility. In Brazil, this operation (Net Metering) has been regulated similarly to several countries practice.

Thermal solar generation, in which solar energy heats a fluid that drives generating equipment, may store part of the heat provided by insolation. These plants are not presently foreseen in Brazil, due to their high initial cost.

Other Biomass Sources

Industrial and urban residues and agricultural short crops biomass become relevant primary renewable energy sources, including for power generation. Brazilian climate and soil conditions favor the production of short crops, such as elephant grass, that may be harvested more than once a year and have productivities similar to that of planted forests.

HINDRANCES TO BRAZIL´S POWER SECTOR DECARBONIZATION

Power Sector Main Agents And Purpose

The roles of the main entities that integrate the Brazilian power sector have been described in INEE's previous report to iCS. The main purpose of the power sector planning and operation is to minimize supply costs, particularly those related to investment, fuel consumption and environmental impacts, as well as to keep failure of supply risk at an acceptable level.

Until recently consumers were regarded as passive energy users. Remote control systems, electric vehicles batteries charged from the grid and able to supply it, autoproducers able to sell their surplus generation to the grid (prosumers) are becoming commonplace and are increasing the power sector complexity. The growing share of renewable energy sources that present high variability already make a difference with respect to the recent past, when regulated hydro supplied more than 80% of the market.

Another relevant feature is the importance of social and environmental licensing requirements to be fulfilled in order to build new facilities. More recently they have been enhanced by the 2015 Paris Agreement's NDCs endorsed by the Brazilian Government.

It should be noted that presently a new legal power sector framework is being discussed. Many changes are envisaged, such as reduction of restrictions and subsidies, commercial criteria, costs allocation, sustainability enhancement, so that the present legislation and regulations will have to be modified or replaced. The new legislation should begin to be discussed in the Chamber of Representatives by the end of the present year.

High Interest Rates

For a long time Brazil's high interest rates have reduced capital intensive ventures attractiveness, although in many cases a significant share of the investment (related to local expenditures) were financed by BNDES, at very low (below market) rates. Presently these rates (TJLP) for long term operations are being modified and another and higher rate (TLP) definition for BNDES long term loans is being discussed.

Relatively high discount annual rates, about 10%, have been adopted for planning purposes. High rates, when applied to long term costs and benefits in order to evaluate their present value, tend to reduce their expression to negligible terms. This has improved fuel based generation competitiveness with respect to renewables such as hydro, wind and solar.

Intermittence and Seasonality

At the interconnected system level, synergies with other energy sources may compensate for intermittence, providing complementary generation and additional investment in different facilities enable the system operators to cope with sharp variations of their supply, that jeopardize system stability. Individual users of distributed generation may have storage facilities in their own premises or procure backup from the local utility.

Presently intermittency has been complemented by energy from hydroelectric plants' reservoirs (including from distant regions) and thermal generation (mainly natural gas driven). In the Northeast, where the wind powered capacity is close to half of the total installed capacity the situation is particularly critical because of the protracted scarcity of rainfall and low storage in the local reservoirs. Besides operation costs due to additional thermal generation, sharp supply variations require additional spinning reserve, long distance transmission capacity, system protection investment in order to reduce the probability of system supply failure.

Intermittent Energy Insertion

Wind and solar generated electricity (both PV and thermal) have practically zero marginal operating cost. Since wind and solar energy cannot be saved in kind, they must be utilized or wasted. Hence their utilization has a higher priority with respect to all other sources (except to hydro, when the reservoir is spilling) and, as a consequence, these other sources capacity factors tends to be reduced. Depending on their remuneration criteria, such as marginal cost, their revenue may be reduced and new investment in such plants, mostly the conventional ones, will become less attractive, although the system needs them, including to provide back up to the intermittent ones.

In some countries, like Germany and Denmark, where intermittent installed capacity is close to or larger than maximum peak demand, the marginal operation cost eventually becomes negligible or negative, meaning that generators must pay consumers to take up their energy, since closing down most plants, often at short notice, would be too costly. In countries like Denmark and Scotland, there are periods of many hours when their total electricity consumption is supplied solely by wind power. The following data and figure illustrate this situation. (WEC, World energy Perspectives….)

The before mentioned WEC presentation by A. Clerici, on Variable Renewables Integration shows that intermittent energy sources contribution to electricity generation had already reached very high shares in 2015, as follows:

Intermittent sources contribution to total generation:

Denmark: 52 %

Portugal: 24%

Ireland and Spain: 23 %

Germany: 20%

Intermittent sources installed capacity and system peak demand ratio:

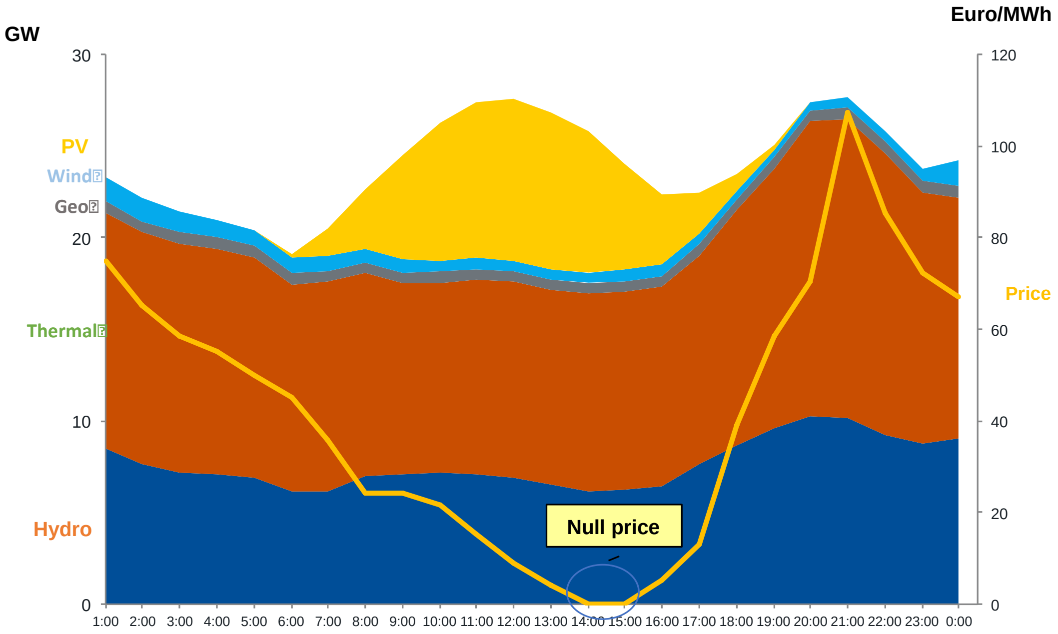
Germany: 102 %

Denmark: 96 %

Spain: 72%

Portugal: 54%

Source: WEC, World Energy Perspectives.



Source: Terna, GME

According to the same WEC presentation, some countries intermittent sources share is already large enough to affect the operation of their interconnected systems. In 2015 wind power reached 145 GW in China and 73 GW in the USA. Solar power in China was 43 GW and 40 GW in Germany. In Brazil, wind power installed capacity was 10.1 GW and solar 0.04 GW by December 2016.

Another relevant feature of wind and solar is the extent and sharpness of the variations of their availability, and therefore, of the generation they provide. Hence, in order to secure power system stability, spinning reserve must be increased. This reserve entails some kind of energy consumption. Besides enlarged spinning reserve, areas in which intermittent energy generation is relevant, such as the Northeast of Brazil, may depend on the back up provided by other regions, if available, across long distance transmission lines.

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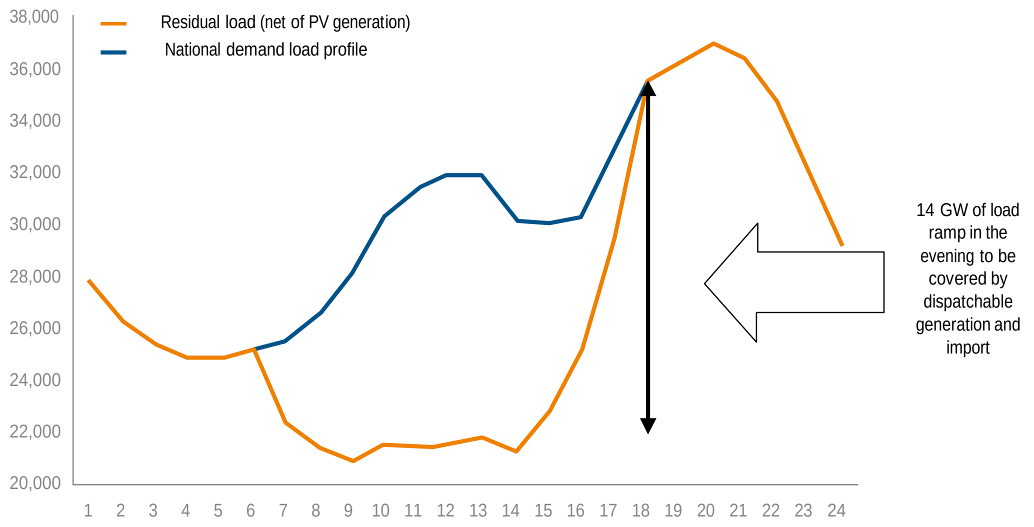
DEMAND AND VRES EFFECT

WORLD ENERGY COUNCIL



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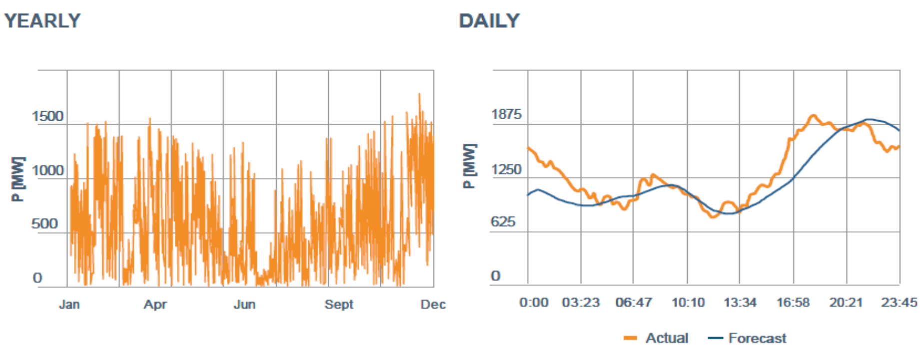
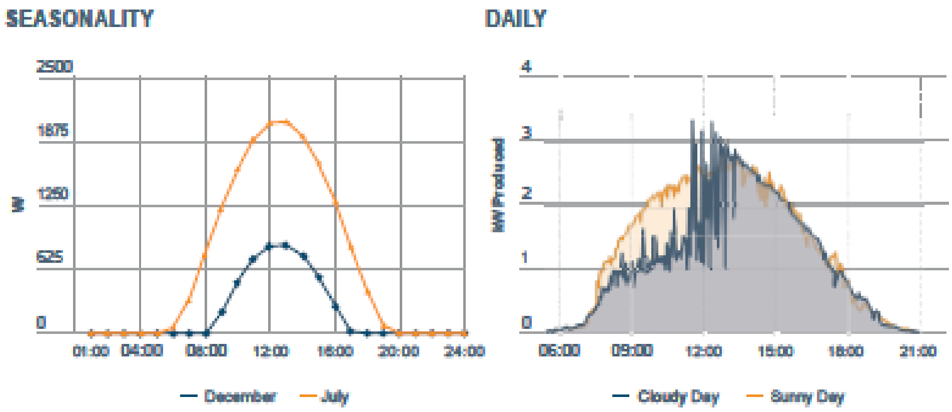
YEARLY AND DAILY VARIABILITY IN IRELAND OF GLOBAL WIND FLEET POWER PRODUCTION



SEASONAL AND DAILY VARIATION OF THE POWER GENERATION FOR A SMALL PV PLANT IN CENTRAL ITALY



Pricing of renewable power generation

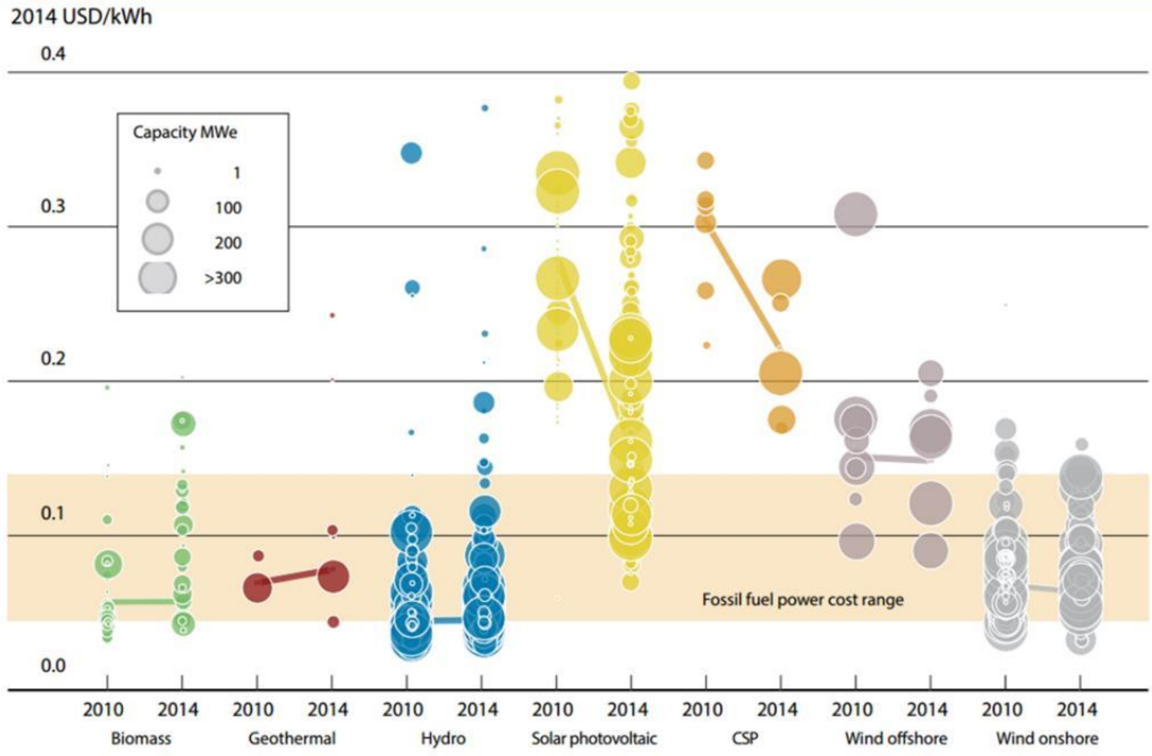
Recent investment costs of PV solar and wind powered generators have been markedly lower than a few years ago. In 2014 solar PV plants cost was reduced to about 50 % of their 2010 average. Worldwide, from 2004 to 2014 wind power capacity increased at a 23% annual rate and solar PV annual increase has been 51%. Their generation costs, including upfront investment, operation and maintenance (usually quite low) and their average expected annual capacity factor are summarized into the Levelised Cost of Energy (LCOE), expressed in monetary units per MWh of expected average annual generation.

These costs vary significantly according to local insolation or wind patterns. In Northeastern Brazil, the average capacity factor was 43% in 2015 while in the South, where winds are more erratic, albeit adequate for electric power generation; this factor was lower.

The Northeast has the most favorable insolation. However, even in much lower latitudes, insolation is higher than in the most favorable parts of Germany, where this technology is widely utilized. The average capacity factor of solar PV in Brazil is about 22%.

The following figure compares the typical levelised costs of electricity generation from different renewable energy sources:

Levelised Costs of Energy – 2010 to 2014



**Size of the circle represents the size of the project. The centre of each circle is the value for the cost of each project on the Y-axis*

Source :WEC

Intermittent sources energy marketing

In November 2015 the Brazilian government carried out the second auction for “reserve energy” (wind and solar power generation). Wind energy contracts averaged US$ 53/MWh (R$ 203/MWh) and PV solar was sold at US$ 77/MWh (R$ 298/MWh). More recently, in other countries, these energy prices reached more attractive levels. In 2016 new supply contracts for wind power generation in Morocco, where the capacity factor is as high as 55%, prices were US $28/MWh. In the same year, a PV solar contract price in the United Arab Emirates (UAE) was US$ 30/MWh. In 2017, in Mexico and in the UAE, PV solar was contracted at US$ 24/MWh.

These very low prices may reflect lower capital costs, efficiency increases, lower investment per unit capacity and new market conditions, due to reduction of subsidies and of investments in developed countries, mainly in Europe. By 2007, European wind generation prices reached as high as US$ 448/MWh. In 2012 they had been reduced to US$ 182/MWh. The following table indicates the reduction of European share in wind and solar world installed capacity:

Wind and Solar Generation Capacity

		2011	2015
Solar	World GW	69	222
	Europe %	75	43
Wind	World GW	239	432
	Europe %	40	33

Source: WEC, idem

Since 2012 the reduction of investments in intermittent renewable sources by developed countries has been compensated by the investments of developing economies in these energy sources. In 2016 total world investment in renewables almost equaled the investment in other sources (The Economist, July 2017).

The prices indicated above for wind and solar PV are highly competitive with those for electricity generated from more traditional sources, by "dispachable" plants. Evidently, these costs do not include the costs related to the insertion of intermittent generation into the Interconnected system or the back up required by *prosumers*. Insertion costs involve compensation for supply sharp variations that may affect the system stability and the quality of supply to increasingly demanding consumers. Hence, more investments to increase spinning reserve, long distance transmission capacity and power system protection are needed. Non-scheduled thermal or hydro generation is often the immediate consequence of unexpected wind or solar generation reduction.

The majority of these costs are unavoidable, given the variable pattern of these sources generation. But some may be due to the effort to preserve the nominal installed capacity contribution of these plants. This may be a mistake, for their capacity contribution, since it is not reliable; it is only partially significant if and when large numbers of generators in different locations are operating. What must be valued is their energy contribution, which is considerably reliable, at least on average monthly basis. This has been more evident in thermal generation based systems, like in Europe, where whenever a wind plant generates, it saves fuel. In hydro based systems it may also be advantageous, but the benefit evaluation is more complex. These issues will be discussed further on.

With regard to distributed generation by solar PV panels, net metering, when applied to low voltage *prosumers* entails the reduction of distribution network investment and maintenance costs remuneration, since their monomial tariff involves network and energy supply costs. Hence, the adoption of binomial tariffs for such consumers is being considered, so that only the value of their energy consumption reduction or their energy supply to the grid will be considered.

Fiscal issues

Decarbonisation results, however praised, have not been monetized yet. On the other hand, renewables such as small hydro, wind and solar plants equipment has benefitted from fiscal exemptions. Their consumers have also been benefitted by at least 50% reductions of their transmission and distribution tariffs.

Electricity taxes in Brazil amount to about 35% of the average tariffs, varying according to the state. Therefore, they reduce electricity competitiveness with respect to other energy sources, as shown by the widespread peak shaving diesel based generation by medium voltage connected consumers.

Pre-sal

The important reserves of oil and natural gas discovered in 2007 are under accelerated development. Most natural gas reserves are located close to the South East region coast, close to the main industrial areas and may be considerably expanded. According to BEN 2016, in 2015 oil proven reserves were 2.1 billion cubic meters and natural gas ones were 430 billion cubic meters. Considering also inferred and estimated reserves, these figures would almost double. Brazil also imports about 40 million cubic meters per day from Bolivia under a long term contract. Two regasification facilities enable frequent imports of LNG, mainly for power generation.

Pre-sal natural gas production is associated to oil extraction. Hence, large quantities of natural gas will be available for power generation in the near future and will compete with renewable sources, particularly planted forests biomass, that in spite of its large potential, is still very little exploited and organized for power generation, unless carbon emissions are effectively penalized.

Free consumers

Consumers, which load is equal to or larger than 3 MW or, if they are supplied from incentivized sources, such as small hydro or wind, equal to or larger than 500 kW, may buy their energy supply directly from generators or from commercializers. At present, it is not clear whether they will be able to buy directly from intermittent sources generators, since their production is sold to the National Interconnected System, through CCEE, and charged to all System consumers. This direct purchase should be more feasible if these generators were associated to storage facilities or back up providers that would compensate for their intermittence.

OVERCOMING DIFFICULTIES

Integrating intermittent energy sources

Integrating large-scale deployment of intermittent energy sources into the power system is considerably enabled by improvements in power system planning and operations. Challenges associated with power system operation can be addressed through technological options and changes in existing operational practices.

These options and practices include technical and economic measures. Their adoption depends on system characteristics and the penetration of intermittent energy sources. Integrated planning, including supply and demand sectors, inter-regional planning across different balancing areas can be relevant to accommodate higher shares of intermittent energy sources.

Given the unique technical and economic attributes of intermittent energy sources the technical, economic and institutional implications of their integration into the power systems become more evident and demanding as their shares increase. At low shares, their integration into most systems does not pose any major challenges. High shares, however, have broad implications for the power system at all timescales, ranging from several years to days, hours, minutes and seconds.

The main characteristics of intermittent energy sources deployment are described as follows, by IEA report (Status of Power System Transformation 2017, System Integration and Local Grids):

> **Phase 1** – the system operator and other power system actors do not need to be concerned with the intermittent energy sources outputs and their variability. Total and net load do not differ significantly.
>
> **Phase 2** – the existing generation fleet will see changes in their generating pattern because of intermittent sources and local grid conditions may be affected, including congestion due to changes of power flow. However, the system can accommodate the new situation largely with existing system resources and by upgrading certain operational practices.
>
> **Phase 3** – system flexibility becomes key for integrating intermittent sources (flexibility relates to how quickly the power system can respond to changes in the demand and supply balance in a timescale of minutes to several hours); plants that used to run continually now reduce their output at different times.
>
> **Phase 4** – system stability becomes the main challenge, requiring technological investment options and improved operational practices; few plants run around the clock since all plants adapt their output to accommodate highly variable renewable sources generation; the system ability to recover from disturbances is reduced.

It should be noted that the transition between these phases does not occur abruptly. They are just a conceptualization intended to identify the main issues that more or less gradually become relevant, according to the nature of the power system and of the sources involved.

Intermittency compensation and reduction

By complementary generation

Discontinuities of energy supply may be covered by other energy sources, such as hydro or natural gas fired plants generation. The choice may depend on the characteristics of the supply interruptions, such as normal duration, sharpness of variation. However, coverage of discontinuities of supply does not eliminate the need to protect the system from transients, the sharp and unforeseen variations of supply.

In the case of wind power in the Northeast and other sources which capacity factors are relatively high, complementation from another source makes more sense than for those which capacity factor is low, such as solar PV. Whether this complementation comes from hydro plants or fuel driven ones, non-negligible costs are involved, in terms of reservoir depletion or fuel consumption effects.

Gas turbines may not be able to pick up load with the required speed if wind or solar supply is sharply reduced. For this purpose, they would have to be already spinning when necessary. This means considerable amounts of wasted fuel. On the other hand, they do not have enough inertia to provide transients back up and, since their capacity factor may be low, gas supply price may be increased.

Using interconnected system hydro plants to provide complementation has been common practice in Brazil. The marginal cost of hydro electric generation may vary considerably, according to the reservoir storage condition, besides the present and the expected inflow. Transmission distances also count, because of investment and energy losses. If reservoirs are spilling, marginal generation cost is zero. Otherwise, it will tend to the cost of fuel, plus the cost of the risk of market supply curtailment, as the reservoir depletion increases. The latter, of course, is more significant when reservoirs are mostly depleted. Besides, depletion causes loss of head and therefore of productivity, in terms of kWh per cubic meter of water either stored or used.

In view of the large storage capacity of the Brazilian interconnected system – SIN, about 220 TWh or four months of total generation requirements, its full and exclusive utilization for intermittency compensation has been considered. In this case, all hydro plants would be operated as run of river. However, actual storage varies considerably so that by mid 2017 it was only 95 TWh. When wind capacity will be 15 GW, it would require 46 TWh of complementary annual generation. As the intermittent generating capacity is increasing but the reservoir capacity is not, the contribution of the present storage will be gradually diminishing. However, it would be very important to evaluate how much the present storage capacity may contribute to complement intermittent sources. This requires complex simulation models, so it is beyond the scope of this study.

Actually, reservoir operation is subject to rules, some of which belong to their licensing requirements, such as minimum downstream discharge, flood control and, last but not least, plants must comply with generation contract quantities and schedules. Although it may be considered that theoretically some restrictions might be removed, the feasibility and the validity of this hypothesis must be given more detailed and detained study.

Complementation may also be made from biomass generation, mainly of planted forests. This renewable source has the advantage of being continually available, while sugarcane biomass is available during about seven months, the harvest period. Forest biomass supply is more flexible than from sugarcane plants since these must operate continually (in heat & power combined cycle), since operating it at low capacity factors would increase their generation cost and eventually shorten their equipment useful life.

On the other hand, some consumers may accept to use intermittently supplied energy and sign contracts with such generators. They may sign back up contracts with the local utility or provide it within their premises, by installing batteries.

Finally, it should be noted that complementation is basically a means to transfer intermittency of one energy source to another, involving considerable redundancy of equipment and investment. As the intermittent generation share increases, this procedure tends to become more inadequate.

By storage

Since it is difficult to foresee intermittent sources supply interruptions (although weather forecasting and location diversity tend to allow for limited capacity availability) their capacity supply reliability is quite low, if not negligible. However, their monthly or, at least annual energy supply contribution is considerably reliable, comparable to hydro generation. So, the integration of intermittent energy generation into the grid may be effectively implemented by ensuring the utilization of their reliable contribution, the energy they generate, whenever it is generated. This requires storage, provided by batteries, hydro plants reservoirs (to a limited extent), pumped storage hydro or other systems, to be adopted according to each case.

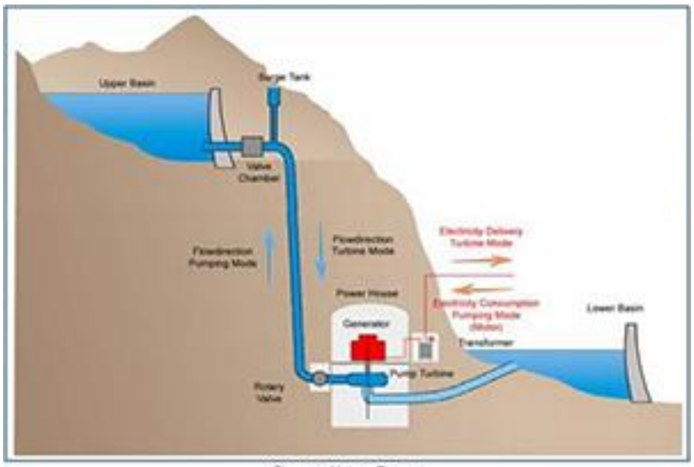
Thermal solar generating plants use heat storage to increase their capacity factor. Refrigeration and buildings space cooling or heating also commonly use storage systems, in order to profit from cheaper energy hours and use it when it would be more expensive. Other systems are being used, according to the size of the load, such as compressed air and hydrogen.

There are two basic types of energy storage, power and energy. Power intensive storage present a MWh/MW ratio in the 0.1 to 0.5 range, so the plant may operate at full capacity during up to half an hour. Energy intensive ones' ratio ranges from 4 to 8, since the may operate at full capacity during many hours. Pumped storage plants may have much larger capacity, enabling them to provide much longer periods of full capacity generation.

Some wind power plants use locally installed batteries. Distribution utilities may also use batteries to smooth out the supply curve of distributed generation. They will be also able to rely on the aggregated battery capacity of electric vehicles when large numbers will be connected to the local network. Large pumped storage, for which Brazil presents very favorable development conditions, is another way to store large quantities of energy. The energy used for pumping is the less costly one available, not necessarily from intermittent plants, depending on location and consequent transmission losses.

All storage systems present losses, which depend on the technology adopted and local conditions. Overall efficiency may be around 80% but they do not entail fuel consumption and, in the case of pumped storage, large generators provide significant transient back up to system stability, due to their large inertia. This of course is not the case of batteries, which chemical inertia runs against the absorption of transients. For this purpose they may be associated to large capacitors.

China, presently the major investor in wind and solar energy has 41 GW of pumped storage plants under construction. In 2015 the world hydro installed capacity was 1212.3 GW of which 144.5 GW were pumped storage plants. China already has 58 GW, Europe 51 GW and United States, 23 GW of pumped storage plants. There are experiences of using the sea as the lower reservoir, in order to reduce environmental impacts and investment. The following figure illustrates the basic scheme of a pumped storage plant.



Source: Alstom Power

Other means and considerations

Improvements in weather forecasting will enable system operators to timely take the necessary measures to cope with unfavorable conditions. Present hydro plants reservoirs and those that will eventually be built may provide some storage backup to wind and solar generation. However, the relative size of this storage capacity, as compared to the overall generating capacity of the interconnected system, is diminishing and both the latter capacity is growing fast. Besides, this storage is needed to compensate for the seasonality of the present and new hydro plants, most of them in the Amazon and with no storage of their own and on very variable river flows.

Hence, in order to reduce the cost of utilizing intermittent energy sources, power sector planners must evaluate the costs of the means that are required to compensate for that characteristic of their supply. Different energy sources, plant sizes, weather conditions, consumers features and technological advancement allow for different solutions, whether complementary generation from other sources, pumped hydro storage or batteries, stronger interconnection with different regions, special supply contracts or other means.

Distributed generation

Due to their increasing competitiveness, consumers are adopting small scale PV solar and cogeneration to supply at least part of their needs. This “beyond the meter generation” or distributed generation is a game changer, both for the distribution utilities that provide the network services and the back up when these sources availability is interrupted and to consumers that have such equipment and may sell their surplus to the local network. This bidirectional flow of energy between the utility and the *prosumer* may entail additional utility costs, both in operation and investment, mainly in network and protection reinforcements. Distribution losses usually diminish, although in the presence of large amounts of distributed generation they may increase, due large reverse energy flows.

The utilization of electrically driven vehicles will entail large quantities of batteries connected to the distribution network while they are being charged. Since they may be allowed to have bidirectional flows, they will be able to supply ancillary services to the network. This will require the network load management to have access to these batteries, by sending command signals beyond the customers' meters. It may also be considered that such storage capacity provided by vehicles batteries may contribute to improve the supply from distributed generators, such as solar PV panels.

Vehicle To Grd - V2G

Vehicle-to-grid (V2G) is a system in which plug-in electric vehicles, such as electric cars (BEV) and plug-in hybrids (PHEV), communicate with the power grid to sell demand response services by either returning electricity to the grid. This is another means to mitigate unbalances of supply and demand. These vehicles batteries can provide short term and sharp response. Their batteries could be used to let electricity flow from the car to the electric distribution network and back.

The importance of this mitigation potential can be evaluated considering and that at any given time over 90 percent of cars are parked. Therefore, if only 10% of the present Brazilian car fleet were plugin hybrids with an average 50 kW generating capacity, their aggregate power would amount to more than Brazil's power sector installed capacity.

INEE has been studying this subject since 2009[C] but this subject has not been as much developed as one might expect considering its evolution in other countries.

CONCLUSIONS & RECOMENDATIONS

- Decarbonizing Brazilian power generation through 2050 is feasible and significant emissions reductions may be attained by 2030, considering the large potential for renewable sources development and energy efficiency improvement.
- In order to reduce GHG emissions and to fulfill its 2015 Paris Agreement targets, the Brazilian power sector will have to prioritize the sustainable utilization of renewable energy sources.
- The Brazilian power sector institutional framework will soon undergo important modifications, presently under public discussion. They will affect this sector's rules and priorities, in order to enhance its sustainability.
- BNDES long term loans interest rates will be increased. This may also affect supply alternatives relative competitiveness.
- Since the relative importance of hydro storage capacity has been reduced, a business as usual power supply scenario will increasingly rely on fossil fuels, mainly natural gas.
- The importance of wind and solar for the preservation of the environment and their diminishing costs tend to increase their share in the country's electric power generation. Their intermittency, sharp supply variations and zero marginal operation cost are particularly relevant to the procedures and costs of their insertion into the National Interconnected System.
- The large-scale uptake of intermittent energy sources challenges traditional policy, market and regulatory frameworks, regardless of market structure.
- In most power systems, intermittent generation deployment will require additional investment in flexible resources besides improved operation procedures. Securing such investment becomes an important aspect of the overall policy, regulatory and market frameworks. Sufficient flexibility can be delivered though an appropriate mix of the four power system resources: flexible generation, grid infrastructure, demand response and storage (IEA, 2014).
- Since they have low environmental impact and null marginal operation cost, their utilization has top priority and tends to reduce the utilization of other energy sources. This may reduce their attractiveness to potential investors.
- Sharp supply variations of distributed intermittent sources affect the cost of back up provided by the local utility.
- Large shares of renewable intermittent energy sources require compatible and reliable storage capacity, independent from external factors such as energy demand or hydrological conditions.
- Compensation of intermittency by means of complementary generation from other sources is a solution that tends to have growing costs as these sources share increases, since it leads to redundancy and low utilization of

investments. It is an effort to artificially preserve the installed capacity of these plants, which is scarcely reliable, while their valuable contribution is energy supply, which avoids the consumption of fossil fuels.

- These sources require specific measures in order to maximize their benefit to all users and to avoid operating, economic and financial damage to other system components.
- Consumers may also bring an important contribution to the utilization of renewables, including intermittent ones. Some consumers, like electric vehicles batteries, have considerable flexibility and could temporarily reduce their load or send energy into the grid.
- Externalities related to different energy sources must be evaluated and included in the selection of alternative power sector expansion options. Otherwise, and as presently, the advantage of renewables with respect to fossil fuels consumption will remain rhetorical.
- It is necessary to evaluate the full costs and benefits of these sources utilization, not only the levelised cost of energy – LCOE, since it does not consider their insertion costs and particular features. To compare conventional (dispachable) plants with intermittent ones according to the respective LCOE is misleading and may lead to inadequate investment decisions.
- According to world experience, the best way to associate intermittent energy sources based plants into the interconnected system is to store part of the energy they generate in order to make it available when their primary sources are not. The nature and the technology to be adopted depend on the primary sources, the local conditions and the pattern and size of their own operation.
- Instead of basing future auctions of energy from intermittent sources on their LCOE, and considering it as reserve energy (energia de reserva), these plants should compete in normal auctions, open to all parties, in which their bid prices would reflect also the costs of the means to compensate for their intermittency. These costs might be evaluated by EPE if the investor did not have the possibility of providing the necessary compensation, either by storage or other means. Then, part of the investor revenue would be directed to the system costs clearing house, the CCEE and consumers would pay the real cost of the energy they use.
- Finally, in order to decarbonize the Brazilian power sector other measures than the expansion and adequate insertion of wind, solar and hydro based generation should be considered. Efficiency increases of electricity supply and demand as well as the utilization of renewable biomass should be intensified. This is the case for planted forests biomass and urban disposal. In the former case, where less investment is required and more abundant

supply than the present should be available due to the Paris Agreement targets, the generation capability estimates are very significant.

[A] REDUCTION OF THE CARBONIZATION OF THE ELECTRIC POWER INDUSTRY BY THE USE OF THE COMBUSTIBLE RESIDUES OF THE SUGAR-ALCOHOL -INDUSTRY // EXECUTIVE SUMMARY
http://www.inee.org.br/down_loads/eficiencia/English_Estudo_ICS10_Maio.pdf

[B] See Annex V of the above repport (in Portuguese) …

[C] See http://inee.org.br/ver2009/index.html