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Chapter 17

How much is possible? An integrative study of intermittent and renewables sources deployment. A case study in Brazil

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17.1 Introduction — understanding of the question

This article discusses the existence of limits to the expansion of intermittent renewable resources (IRRs) to meet electricity demand and the risks that societies are willing to face when considering this expansion.

As we know, energy risks comprise four dimensions: supply capacity (adequacy), energy quality (power quality), risks associated with high costs (which society may not be able to cope with), and environmental risks. This article does not directly analyse the dimension of energy quality, mainly
associated with the availability of transmission and distribution networks, although this dimension is also implicitly addressed in the text.

Power generation and the risks associated with the scale of availability are absolutely linked to the existence of natural resources (renewable or otherwise) such as water availability, oil and gas reserves or wind and sunlight.

It happens that, within an economic logic, the closest resources are always prioritized and therefore the most economical. As resources become scarce, either because they are depleted or more distant from the main centres of consumption, environmental impacts tend to be more intense and costs higher. The example of Hydroelectric Power Plants (HPP) in Brazil, a country that has guided its electric power industry from water resources and still has ample potential to be explored,\textsuperscript{1} is emblematic. Due to growing opposition from environmental activists, Brazilian hydroelectric plants have increasingly been designed to format run-of-river plants, avoiding large reservoirs. The ‘stock’ of energy that can be stored in these hydroelectric plants has been reducing in the timeline \[1\]. Fig. 17.1 shows the reduction of the electricity production capacity of the Brazilian hydroelectric plants (installed capacity) at the same time that it signals a rather robust expansion of intermittent sources in this decade.

The first dimension of risk deals with the capacity to serve (adequacy) from an infrastructure of plants and systems capable of using energy

\textsuperscript{1} Despite the fact that these are located at great distances from the load centres (usually more than 3000 km away) and with a greater complexity due to the fact that they are mostly found in the area of the plain that surrounds the great Brazilian rainforest – the Amazon.
resources. It happens that with the exhaustion of the most favourable resources, the search for new projects, less favourable from the economic point of view or more distant or even more sensitive to environmental impacts is the solution. Despite these restrictions, as the Brazilian economy has faced a severe economic recession in recent years, the supply dimension cannot be considered problematic, with a consistent structural surplus in the coming years. The mechanisms of compulsory contracting by distribution companies, defined by the Brazilian regulator, also contribute to assure the security. Fig. 17.2 shows this stable structural surplus over the next 5 years.2,3

The environmental security dimension, however, is permanently in conflict because of the existence of natural resources for the construction of new HPPs in the northern region of the Amazon’s outskirts. This fact has intensified the debate on the possibilities about future generation could be based only on intermittent renewable ones, a thesis that is ardently defended by environmentalists.

At the end of 2005, Brazil had 69.6 GW of installed capacity in hydroelectric plants and planned to install a further 31.1 GW until 2015 from hydraulic sources. However, elapsed 5 years (2010) the installed capacity of hydroelectric plants had grown by only 4.7 GW and the official planner of the Brazilian electrical system estimated that by 2020 new 40.8 GW of hydroelectric projects would be implemented. The reality showed that in the last decade (2010–19) 23.3 GW were implemented, that is, little more than the planned half. Again, in a new planning cycle, which is now beginning, there is an expectation of growth in hydroelectric works, but now with much

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2. It should always be noted that it does not make sense to assess supply risks for horizons longer than 5 years, because in the event of an imbalance between supply and demand, there would always be time to implement new projects.
3. The figures are analysed before the COVID-19 crises.
less emphasis, since only 1.7 GW of large hydro resources are being planned for implementation by 2030, which shows a potential withdrawal of Brazil to make use of the still possible uses. All of this information are available in the planning reports from EPE [1,3,4], Table 17.1 presents a summary of this context.

These figures exemplify the importance of environmental risk with the ‘victory’ of the HPP opponents, either by the inability to meet the planned expansion or by the very rapid expansion of intermittent sources already implemented or planned. Table 17.2 presents the evolution of these renewable sources and the associated planning scenarios.

As it is easy to see, as in different ways to the hydroelectric power plants, intermittent renewable sources have been surpassing the expectations of the Energy Research Company — EPE, the Brazilian entity responsible for energy planning in Brazil.

In the dimension of the tariffs, considering that Brazil is a country with a long tradition of inflation and indexed prices, there is a culture of monitoring prices in terms of present value. Fig. 17.3 presents the evolution of residential tariffs of a large electricity utility on a 100 basis, corrected for inflation for 2016 present values. Although this figure refers to a specific concessionaire, the profile of this evolution is homothetic with the other 64 companies that operate in this segment around the country.

Again, it is easy to understand that real prices have been reduced in the timeline, which would reflect the conclusion that also in the drive of prices the risk is not relevant.5

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4. EPE is the acronym in Portuguese language.
5. We are not analysing whether a possible worsening of the economy contributes to the increase of the economic risk of energy prices based on the per capita income of the population.
Therefore, keeping the other conditions constant, \(^6\) the article deals with the risk conditioning factors that arise from the significant expansion of intermittent renewable sources in order to characterize an eventual limit to this expansion.

### 17.2 Irresistible expansion

The publication A New World – The Geopolitics of the Energy Transformation of the International Renewable Energy Agency \(^6\) acknowledges the great energy transformation the world is experiencing with the unprecedented growth rate of renewable energy sources, in particular solar

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\(^6\) Ceteris paribus.
and wind, as well as the International Energy Agency’s World Energy Outlook [7] evidence where every year expectations are exceeded by reality. The mentioned reports attribute this explosion in growth, which they prefer to call energy revolution, to some forces of change, including the declining costs, pollution and climate change, the emergence of new business models, and policies to encourage renewables stand out.

17.2.1 Wind

The expansion of installed capacity of wind farms in the world has grown at an average rate of 20.7% per year since 2001, reaching about 591 GW at the end of 2018 according to the information contained in the Global Wind Statistics report published by the Global Wind Energy Council [8]. In Brazil, the growth profile of wind power plants is no different. In the period between 2005 and 2018, the average annual growth was 62.3% per year according to the Brazilian Wind Energy Association [9]. The same entity informs that in the forecast up 2023 this growth will still remain extremely high with an average annual performance of 44.2% per year [9].

17.2.2 Solar

The expansion of solar sources shows the same very strong trend. In 2018, for the first time 100 GW were installed in a single year. In the year 2000, the world installed capacity of photovoltaic plants was only 1.2 GW, when Germany started its feed-in tariff incentives. In 2007, there were 9.2 GW of solar photovoltaic plants and by 2018 this capacity had already reached 505 GW, that is, a growth of more than 42,000% since the beginning of the century. Fig. 17.4, elaborated from the Renewables 2019 Global Status Report, shows the annual growth of installed and accumulated capacity over the last 10 years [10]. For the future, the Solar Power Europe organization signals a continuity of this exacerbated growth, predicting in its most conservative scenario that in 2023 there will be 610 GW of installed capacity and in the most daring scenario 1044 GW, resulting in a growth of 15.4% per year (pessimistic scenario) or 25.9% in the most optimistic scenario [11]. In Brazil, this movement is still in its beginning, but the trend will be similar to the international picture as evidences from Table 17.2.

17.3 Undesirable effects of the intermittent renewable resources expansion

The previous section presents data from an extraordinary expansion of the IRRs; however, there may be effects not as desirable as it might seem at first analysis.
17.3.1 Complexity

The first dimension of these effects is the increasing technical complexity in the operation of interconnected electrical systems.

As is well known, the interconnected operation of large electrical energy systems has never been trivial. Even in the early years of the industry, adjustments to maintain the stability of the pioneering interconnections was a very difficult task and required frequent adjustments between the operators of different plants. Until the mid of the 1930s, adjustments were manual and required frequent telephone contacts between operators, with low quality and insecurity of supply being the marks of this process [12].

The economic crisis that pervaded the 1930s, still in the last century, was curiously a drive to motivate advances in the search for greater reliability. President Roosevelt, involved with the serious economic and social problems in the United States, tried in every way to rescue the economy and minimize unemployment. The creation of the Federal Power Commission (FPC), the Tennessee Valley Authority and the implementation of a comprehensive rural electrification plan increased the demand for greater controls [13]. In 1935, the FPC declared that the reliability of electrical systems was not just an engineering problem, but an economic and social issue and as such required all possible efforts in its equation [13].

The Second World War increased the need for reliable systems as a result of the high demand for energy for the industrial purposes required in the war effort. In the 1950s, the technological race was to automate load and generation controls in the search for savings for utilities. Only in the late 1950s did the North American Power System Interconnection Committee consider the possibility of interconnections being extended from coast to coast [13].
In 1967, the American interconnected systems (involving some regions of Canada) accounted for 94% of all connections. Part of this interconnection effort was greatly encouraged by the 11/9, 1965 blackout, which involved some 30 million people in an area of 200,000 km² for 13 hours [14]. It was the first electrical accident of this magnitude and became a benchmark for damages to the economy and the safety of people and institutions. It is worth noting that accidents of this magnitude had not yet been mapped as a possibility. According to Cohn, the specialists in electrical systems until then had not anticipated that electrical grids could be subject to such a relevant cascading effect. Many other countries and even North American interconnections later experienced other episodes of major shutdowns. A relevant example of the impacts that these accidents can have on people’s lives and the economy is the Great Blackout of India in 2012, which lasted over 48 hours and involved 700 million people [13]. Brazil also had experiences with massive blackouts, in 1999 with 97 million people affected, in 2009 with 67 million affected, and in 2014 involving 12 million people [14,15].

The need for coordinated operation of electrical systems, as already evidenced, arises as a result of nontrivial technical demands, which require the operation and planning functions of interconnected networks to enable the most economical and safe (reliable) drives of plants and the grid. They also need to provide nondiscriminatory access to the interconnected system, facilitating the highest possible level of competitiveness.

The second dimension is that of ensuring the competitiveness promoted by competitive access to networks. Free access to the Transmission and Distribution networks not only requires coordination in the short term, but also medium- and long-term arrangements. This is a dimension of the problem that had not arisen when, in the mid-1960s, the interconnection of systems was becoming a necessity. At the time, the concessionaires were building the lines for their own use and were not dedicated to evaluating a pricing system for their availability. With this reality, fundamental questions arise. Who will focus on planning and building lines for the competition? What are the fair prices? What are the rights of who builds and who can become an accessor? If networks are in absolute control of a few agents, how would this affect competitiveness and how can discrimination be avoided? Alternatively, if the networks are owned by multiple agents, who will exercise coordination in a neutral way? All these questions can be found in Sally Hunt’s classic book and serve as an economic justification for the existence of independent operators of the electric grid [16]. These reasons transcend electrical and energy reasons. Hunt’s questions were present in the experience in California in 2001, when Enron scandalously manipulated prices by exercising market power for which the regulator was not properly prepared to avoid [17,18].

Interestingly, the competitiveness bottlenecks initially pointed out by Hunt [16] may be changing. Asset ownership, which has always represented
market power, is changing thanks to online accounting and measurement apps capabilities. The situation is reversed and the ‘Small Distributed Generation Aggregator,’ with no fixed asset investment costs, now has advantages. The market power now resides in free access to networks, operating costs and tariffs that apply to the services provided by these assets. In this scenario, regulatory agencies are increasingly dependent on the expertise of independent operators for the balance between competitiveness and security associated with the challenges of expansion of the Small Distributed Generation units and its aggregators.

Another dimension to consider is the planning of the ‘electric grid,’ which still has to live with the obsolescence of the infrastructure. This finding is made explicit by Bakke [13], exemplifying that in the United States transmission lines are on average more than 25 years old and generation plants, also in average terms, more than 35 years old. This challenge ends up being the responsibility of the Independent System Operators (ISOs) and Regional Transmission Operators (RTOs) if not for institutional determinations, for practical reasons for safety.

In the same reference [13], Bakke concludes that these demands are not only of technology and investments, but of rules and laws that determine the incentives to promote the upgrading of infrastructure to the required level.

The priority of IRRs as public policy, when it happens, needs to be accompanied by infrastructure to meet the new operational demands that will result from these choices.

These policies can facilitate or create entry barriers for investors in renewable projects and even traditional enterprises such as thermal power plants. The latter are fundamental for supplying reserves, acting on the basis of the system or in a complementary way. The intense growth of these IRRs, it is not too much to repeat, has led to the emergence of nondispatchable plants. In spite of these intermittent characteristics, the IRRs can be used to meet energy needs, but they can also help in strategies to modulate the load and to supply ancillary services, but obviously they depend on competence not yet fully installed in the ISOs/RTOs.

Among other demands, it is possible that these independent entities are called upon to manage the so-called ancillary services, which briefly represent the electrical needs of the system (electric and not energetic). They may also require the existence of systems dedicated to supervision and communication, allowing the achievement of operational stability and security in sub-regions affected by specific contingencies from the regional point of view, but recurring in the timeline. The border measurements between subsystems, the exchange of energy and power between adjacent systems, and short-

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7. Plants whose natural resources happen without any link with the needs of demand, and generation may occur at times where there are no requirements for its production.
medium- or long-term planning, as already mentioned, also enter the list of attributions of these operative entities.

The same can be applied in relation to decisions related to safety, as we can exemplify the Brazilian case with the existence of the Electric Sector Monitoring Committee, which can, in a discretionary manner, establish operating orders outside economic merit order in a manner superior to the decisions of the Brazilian National Operator. Thus there may be ancillary services of an electrical level and of a security. Its establishment and funding are at the core of independent operators’ activities that affect the tariffs.

The complexity of the problems faced by these entities still tends to take shape due to the growing importance that electric energy has gained in all facets of modern life, where any interruption produces physical and economic risks that are no longer acceptable to contemporary societies.

This is also due to the increasing and accelerated insertion of IRRs, which bring with their intermittence a great volatility of production. The same happens with the uncertainties about energy production that have always existed in technological, climatic and demand behaviour aspects. The atomization of production, with thousands (in some time there will be millions) of units of Small Distributed Generation (SDG) with consumers who alternate the role of producers, consumers and storage, makes this picture even more complex. It is also worth mentioning that the RTOs/ISOs have barely begun to confront this SDG expansion and the future influence of electric mobility, which is still in its initial phase. The literature on these consequences is in its childhood.

To cope with these uncertainties, there is a need for increasingly rapid responses from operational decisions, and without such independent entities, this ability to respond would be unfeasible. Apart from the advantages to be found in this proliferation of IRRs, there is no doubt that systems are becoming increasingly complex. The main challenges are to standardize technical criteria and give consistency between adjacent ISOs/RTOs and even between all operators in the same country, a fact that is far from being achieved.

The conceptual problem of RTOs/ISOs has not only become increasingly complex (it is not too much we repeat again), but it is no longer, simply a problem of attending to imbalance energy and power, but it is also an issue that affects the governance of the electricity industry and the very shaping of public policies.

To better illustrate this dimension of public policies, one can exemplify with decisions regarding the pursuit of competition (free access, transparency of rules, isonomy of treatment), quality, safety and the existence of structured subsidies specifically for intermittent sources.

In Brazil, this situation resulting from the volatility of production capacity (and prices) does not really represent a picture of novelty, since the hydraulic generation with HPPs with no reservoirs has already been a reality for the last 20 years. The increase of this complexity is due to the
impossibility of new hydroelectric plants with storage capacity in multiyear storage reservoirs, especially for environmental licensing reasons.

17.3.2 The operation problem with the increasing insertion of intermittent renewable resources

It seems to be clear that system operators have always faced difficulties in adjusting production to demand; however, this has always occurred more intensely (except in electric accidents) due to fluctuations on the demand side (economy, climate and other specificities). At present, with exacerbated effects, the difficulties of adjustment between supply and demand have become more intense due to the intermittence of renewable sources and whose resources cannot be stored such as coal, oil, gas and hydroelectricity.

Another highlight is that this intermittence and seasonality are greatly aggravated by the difficulty of forecasting systems. Just to give a single example we can cite Ackerman and others [19] quote that on 29 March 2013, the forecasting systems indicated a potential supply of 11 GW of wind power plant capacity in the Spanish system, but what was available in practice was only 2 GW. It is known that the production predictability techniques of these IRRs are being implemented with significantly progress, but are still subject to large deviations.

The predictability of the load has a good assertiveness of its forecast, with errors in the order of 1.5% for the following day and 5% for the following week as pointed in the previous section. The biggest source of errors is caused by temperature fluctuations. Contingencies are in these cases adjusted by base generation, intermediate response plants and finally by rapid response sources.

It should be noted that reserves have always been required for adjustments; however, the intermittence of renewable sources (not dispatchable) has made these needs more drastic. Not only are these adjustment requirements becoming more and more frequent, but the speed of adjustment required has been more and more intense. The ‘duck curve’ is an excellent example of this intensity. The famous curve, which identifies the variance of the load in California in the face of the increasing insertion of photovoltaic generation in the timeline, shows that in 2020 projection there is a need for a 13 GW ramp in just 3 hours [20], as we can see in Fig. 17.5.

In specific situations, these ramps can be even more drastic. The EPE official Brazilian energy planning entity reports the occurrence in August 2018 when it was necessary to climb 9079 MW in a single hour [1].

These challenges have changed the dynamics of operators’ time. In the book by Madrigal and Porter [21], the timescale is portrayed as being established in three scales of order of magnitude, namely, seconds to minutes, hours and the following day.
The dimension of the Electric Regulation is that where the Operator continuously requests adjustments for increase or decrease of the generation, generally in a scale that goes until a few minutes (generally 10—15 minutes). Sometimes, these adjustments are even made automatically by Automatic Generation Control (AGC) systems. Settings that transcend this short-term interval require the input (or output) of units that are available as pre-prepared reserves or those that can be quickly triggered. Finally, they require those units that can be triggered with a response time that can transcend a few hours and even the next day. Table 17.3 presents a summary of these timescales in selected countries.

Reserves are usually defined as the additional capacity that the System Operator needs to have (‘on line’ or ‘off line’) to meet energy demand and ensure reliability whenever the load or generation differs from previously planned. The insertion of IRRs has made this task more difficult.

Although this issue is preponderant in the impact of additional costs, it has such a fundamental aspect in the operation of the interconnected system that it must be treated separately. The basic problem concerns the predictability of the IRRs’ production and how much assertiveness can be obtained. It is always possible to minimize generation problems at very short intervals (seconds to hours), but predicting the next day can be much more difficult.

The existence of different prices at different times of the day encourages the production of energy in the right quantity, at the right time as a result of the greater economic pressure of the settlement of the difference between the contractor and the actual consumption. Therefore the economic dimension represents an incentive to improve the forecasting assertiveness of the agents.

FIGURE 17.5 The duck curve. Source: Reproduced from CAISO-California ISO. What the duck curve tell us about managing a green grid. <http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf> [accessed 09.02.20].
The literature also indicates that regulatory status can make a difference in these definitions, and the ‘obligation to serve’ on the part of distributors ends up inducing higher costs than those where there is an environment where the competitive market is compulsory.

The problem, so important as it is, has led many ISOs to adapt their operating codes to accommodate the growing insertion of IRRs. Despite this perception, in many cases, the adaptations focus much more on ‘ancillary’ services than on the operation itself. This is due to the geographical dispersion of the IRRs and the dependence on the portfolio of pre-existing plants before the massive insertion of renewable energies.

The quality of the assertiveness of this task (prediction of reserves) depends on the size of the control areas (submarkets) and the capacity of exchange between different regions (i.e. how robust the transmission system is) and finally the balance between supply and demand.

The problem of defining the required reserves is still dependent on the speed of entry into operation of the available plants ‘on line,’ the level of available automation (AGC) and the number of plants considered inflexible in that interconnected system (technical or commercial inflexibility).

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**TABLE 17.3 Reserve time in selected countries.**

| Country     | Fast reserves                                      | Medium time reserves                      | Reserves in long time |
|-------------|----------------------------------------------------|-------------------------------------------|-----------------------|
| Germany     | Primary reserves available in 30 s, Dispatched by the RTO | Secondary reserves – 5 min dispatched by RTOs | Secondary reservations required up to 15 min | N.A. |
| Ireland     | Primary Reserves – required in 15 s (inertial or quick response) | Secondary Reserves – 15–90 s | Tertiary Reserves – Above 90 s | N.A. |
| United States | 1–5 s 1 min–1 h                                     | 1-h horizon, but in increments of 5 in 5 or 10 in 10 min | Response time. 1 h to 1 week with hourly increments |

Source: Elaborated from Madrigal M, Porter K. Operating and planning electricity grids with variable renewable generation. World Bank; 2013. p. 125.

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8. A nuclear power plant could be a good example of technical inflexibility and Natural Gas power plants with contracts take or pay represent a commercial inflexibility.
This theme is still developing and at the frontier of knowledge. The operators have found many alternatives, but none of them has yet been consecrated as a definitive experience. The California ISO, incidentally the first to express concern about the massive expansion of IRRs, uses as a basic rule that 1% of installed capacity should be added to the available reserves of dispatchable sources for every 100 MW of intermittent sources added to the system [21].

The Independent Transmission Operator of Germany considers the need for reserves with a primary capacity of 3 GW capable of going into operation in 30 seconds. Another 4.9 GW are available to be required in 5 minutes, basically backed by hydroelectric plants some of them reversible. A third block of plants made available for a reserve can even be composed of IRRs plants with an amount of 2.4 GW for which a start-up is expected within 15 minutes [21].

The interconnected system of Texas analyses the capacity of reserve plants actually used in the last 30 days and the same month in the previous year. It also makes the same analysis of the installed capacity of IRRs in the last 30 days and compare with the same month of the previous year. For each additional 1000 MW of installed IRRs capacity, a multiplier (>1) is used on the reserves actually used in the most relevant case (last month or the previous year) [21].

In Brazil, the discussion about operational reserves gains other strategic contours, since there are still unexplored hydroelectric plants with large storage capacity or, alternatively, for environmental reasons, the preferential choice for plants without reservoirs (run-of-river).

It is clear that these requirements ultimately demand greater technical and operational competence from the system operators, so more resources are required to cope with these demands. Consequently, there is also an increase in operating costs. These result from the greater demand for available reserves, greater computational resources, automation of the operation and more human resources, including greater intellectual competence to cope with the challenges required in this new context. In addition, the required safety levels tend to be amplified by the growing importance that electric energy is gaining in society and economy.

Recent studies indicate additional costs of up to 10 USD/MWh for up to 20% of installed capacity to be performed by IRRs [21–23].

The problem of additional costs in operating systems with high IRRs penetration is of extreme complexity, as there are criteria that need to be agreed on whether or not to consider some items. For example, there is a discussion if we should to whether or not considered the investment for more robust transmission systems, those are required by more frequent exchange between subsystems. The same applies to consideration of opportunity costs of generators that are required to remain in reserve by ISOs/RTOs requisition. They should be considered or not under this heading of additional costs?
Although these costs are real, usually only the operating costs of more qualified teams, complementary studies and different forms of operating interventions are computed as additional costs, such as the availability of short run reserves, entry into operation with more intense ramps and entry into operation without the proper optimization of the climbing process. Thus the cost can increase if the reservation requirements are also increased with a higher demand side escalation.

Note that not all costs are in principle from the IRR generator but they are the main cause of them, although eventually they may be borne by the back-up source generators. Obviously, at some point these costs will need criteria about their partition.

There are basically two alternatives for calculating the additional cost, as reported by the World Bank [21]. The first alternative contemplates modelling with different IRRs penetration scenarios and with different generation scenarios (stochastic generation models) comparing the expected operating cost for each of these scenarios compared with the same installed capacity without IRRs.

The difference between IRRs disregarded just for cost assessment can be made from a hypothetical capacity considering the same composition actually installed as traditional sources or considering a set of traditional sources with the best available technology.

The second alternative defines a period of time (e.g. 3 years) and models an analysis considering that the production of the IRRs of the last 3 years would have been deterministic and compared with the actual cost incurred. To minimize the hypothesis of total assertiveness, it can be adopted that a relevant percentage of intermittent production would have been assertively anticipated by the modelling. The additional cost is determined by the difference between the cost that actually occurred and that which would have occurred if the IRRs had been predicted with high assertiveness [21].

These alternatives face difficulties in their implementation, as data are not always available at short intervals (e.g. data every half hour), and the construction of coherent hypotheses of hypothetical complementary sources of IRRs substitution is also complex. The methods described here are generally intensive in data and team availability (often requiring several years to complete). This kind of experience is often postponed because of the inherent difficulties and costs. Rarely are developed with the insertion of IRRs less than 10%.

However, the problem is not only how to calculate the add-ons from IRRs, but also how to divide them among the agents. It is important to remember that some costs for thermal agents exist only because there are IRR agents. So what would be the fairest logic of cost apportionment:

- Individually?
- As a proportion of the impact of the plant on the subsystem where it is inserted?
- Isonomically among all the generators?
- Isonomically among all consumers?
- Any hybrid model of these alternatives?
- The same concept can be faced to share systemic benefits, such as the availability of avoided emissions certificates.

Finally, considering that there is an inevitable increase in costs, what would be the alternatives to reduce its impact? Although the answers may seem obvious, they are very difficult to implement, requiring increased predictability of intermittent production and conditions for energy storage.

The opportunities for more intense storage are still far from becoming viable, but even so, the theme is already on the radar of aggregating companies. The main theme will be the possibility of arbitrage of energy stored at very low or even negative prices. However, many questions remain to be addressed in the 5–10 years, such as the still high costs of storage in batteries, a better portability and a real understanding of whether its intense use could cause more exacerbated environmental impacts. What we can anticipate is that as the batteries advance in the market, probably due to an expansion of electric mobility, the limits discussed here may change drastically [24,25].

17.3.3 Economic effects

As it was already possible to foresee in the development of the previous section, the complexities pointed out, result inexorably in economic complexities, many of which are characterized by various controversies.

Wouldn’t accelerated expansion be an indication that renewable sources have become competitive and that they would not need more incentive regulations?

How much expansion would be possible given that intermittence will require a more complex operation, requiring operational reserves and complex ancillary services. A literature review usually indicates limits ranging from 20% to 30% of total installed capacity as a physical and economic limit to IRR penetration. There are many references in the literature, to nominate a few we can list Trainer [26], Mills [27] and Hirth [28]. This last one inclusive believes that the limits are under 20%.

On the other hand, there are even the understanding of some authors that technological advance could minimize the difficulties faced of this accelerated expansion and promote overpassing the limit of 30% and around [29]. For example, (1) the new digital controls of wind turbines allow them to contribute inertia, reactive support and even reserve to offset variability; (2) the geographical diversification of sources (portfolio effect) allows a ‘firm’ generation comparable to that of a thermal plant at the base; (3) the ‘binding dispatch’ in the price offer for the ‘day ahead’ led to an extraordinary
improvement in the forecasting capacity of wind production in Europe, greatly reducing the need for reserve.

In the specific case of Brazil, there is still an additional advantage to reinforce this conclusion. The Belo Monte hydroelectric power plant, the third largest hydroelectric plant in the world, has high seasonality and ends up allowing its production to be synergic with wind energy produced in its absolute majority in the Northeast region of Brazil once the cycles are very complementary. This phenomenon does reduce the risks of adequacy and also allows large transmission systems over 3000 km not to remain idle for much of the year. Although it is an obvious advantage, it is usually denied by environmentalists who needed in this case recognize a strategic advantage of a large hydroelectric plant located in the Amazon region, what they do not want.

One can also add to these possibilities of storage in HPPs, the development of more efficient and economical storage system-batteries. Apparently, this advance would be linked to an expansion of electric mobility that would promote the scale for the reduction of battery prices.

It happens that in the measure that the IRRs expand, either by reduced cost of equipment, for environmental reasons or the existence of incentives, and considering that these sources are not dispatchable, at many times the marginal costs of operation fall sharply and even negative prices can happen.

The main factor influencing short-term prices (spot prices) is still determined by demand (it should be noted that demand is an exogenous factor to the generation industry). The second main factor is already represented by the IRRs generation itself and its intermittence.

This phenomenon results from the excess supply of electricity with non-dispatchable plants associated with low demand situations. When this phenomenon occurs, it can even be further aggravated by the low flexibility of a series of conventional plants such as thermal plants (especially those of coal) and nuclear plants that can demand several hours for their adjustment. For this reason, in the occurrence of negative prices it is usual that they last for a few hours, at least 3–4 hours. A period that has been conventionally called ‘Downward Adequacy,’ that is, the lack ability of a system to adapt to the low demand in relation to the production of not dispatchable sources.

Although negative prices are very rare in the economy, they can be associated with the costs arising from the need to stock a product that has no demand in a given period and whose production cannot be interrupted. Economic history still records paradigms that can be associated with these negative costs, such as the destruction of products in order to avoid their depreciation in the market. During the crisis of the 1930s in the last century, the Vargas Government in Brazil burned coffee stocks in order to balance the price suitable for the market.

Occurrences of negative prices have already been registered in Germany, Denmark, Austria, Belgium, France, United Kingdom, Switzerland, Canada,
Australia, United States, and in regional markets such as NordPool (Barbour et al. [30], Davis [31] and Ambec and Crampes [32]). Ambec and Crampes also reported occurrences of 200 €/MWh in June 2016 in France a very high figure for this phenomenon [32].

An effect that once was cited as mere curiosity has been increasingly frequent. According to Davis [31], this situation has increasingly surpassing 100–150 hours/year while Götz et al. [33] estimate that these kinds of occurrences could surpass 1000 hours/year in 2022 in Germany.

One has to ask why plants having to pay to keep their operation active prefer to operate than to speed up their shutdown. The reasons can be multiple: (1) inability to change the plant’s status quo in the period in which negative prices are expected to be maintained,9 (2) because of obligations assumed in the supply of ancillary services,10 (3) obligations assumed in contracts for heat supply in district heating systems and/or contracts linked to cogeneration services, (4) plants with long-term contracts with a pre-established price and that do not face extra costs of operating on a flat basis (because of the specific conditions of these contracts) may not have the necessary incentives to reduce their generation, (5) in the existence of tariffs ‘feed in,’ the loss is supported by some government fund or by regulated tariffs, (6) why there may be contract conditions with ‘self-dealing’ conditions where a possible loss of one part of the production chain is compensated by the profits of another part of the same shareholder and (7) for hydroelectric plants that can not to stop for safety criteria. Although this is possible far from the point of view of flexibility, it may arise from the nonexistence of spillways (small run-of-rivers power plants) or from environmental restrictions that limit the use of spillways by excessive oxygenation of the water spilled (in both cases what remains is to turbine the water from the reservoirs).

It should also be noted that the effects are not restricted to microeconomic effects, but may have macroeconomic consequences. To exemplify this effect, we can refer to the effect that negative prices can have on energy exports (a kind of submarket risk11 that overpasses from one country to different others). The effect is not restricted to commercial transactions among agents of the electric industry when there is the phenomenon of negative prices. Countries with the relevance of IRRs like Germany influence the prices in the countries where the surplus could be destined [34] It is common

9. Some plants would take a long period of time to shut down. When the shutdown could be reached, probably prices would return to normal levels and demand a reverse and costly operation, not only due to the additional fuel spent on ramp-up (or ramp-down) but also due to wear and tear additional equipment.
10. This challenge will require greater ability of these conventional plants to price their ancillary service markets.
11. The submarket risk is usually the risk of congestion of transmission lines. But in its case is the flow of energy with unrealistic prices.
for negative prices in Germany to affect spot prices in France, aggravated by the fact that France being a country with a predominance of nuclear power plants, these do not have enough flexibility to reduce its production and take advantage of the possibility of importing from Germany.

This reduction in spot prices, induced by the penetration of IRRs, produces a rebound effect, as it creates a strong incentive for conventional plants (especially thermal plants that are not so flexible) to lose interest in developing new projects (which are essential for operation as safety reserves). Otherwise, if these are developed, investment metrics will require higher returns. As a consequence, the expansion of IRRs would find viability limits, being found in several publications, as pointed before, such as Milligan and others [35] that there would be a limit of the order of 30% as the upper limit of the percentage of insertion of these intermittent sources in relation to total installed capacity.

This effect has become known in the literature on the subject as merit order effect (MOE). Formally, the definition of MOE can be found in McConnel et al. [36]. These authors explain that the generation offers are ranked by the price of available options in the auction that will define the economic dispatch. This is a procedure that the ISOs use daily aiming at meeting the projected demand in the most economical way. This set of plants thus selected meet in principle the demand projected electricity for a specified period in future, usually the next day. The last source select in the auction defines the marginal operational cost that will be pay as a rent for all generators selected by this process. Since the operational cost of the IRRs is very low, this model ends up producing a reduction in spot prices.

Figs. 17.6 and 17.7 in a qualitative way evidence that when we have a IRR with a very small cost of operation the price that meet the equilibrium will reduce. In this single example, the sources of natural gas will be out of the portfolio defined by the auction and the spot price change for a less expensive value.

### 17.3.4 Externalities and the merit order effect

Although the presence of energy from IRRs being part of the auctions and have the ability to affect spot prices, it cannot be overlooked that the important presence of these alternatives resulted from previous incentive policies (PROINFA\textsuperscript{12} or Feed-in tariffs — for example) that represent a cost to society. If, on the one hand, consumers and traders operating in competitive markets end up having advantages with the MOE, consumers with regulated tariffs in many countries have higher tariffs because of cross-subsidies.

\textsuperscript{12} Alternative Sources Incentive Program developed in Brazil.
This effect exemplifies well the concept of externality when a cost or benefit\textsuperscript{13} affects the welfare of society without, however, affecting the direct costs of industry. In the study developed by the National Academies of Sciences, Engineering and Medicine\cite{38}, there is a large series of references on studies developed on externalities, from the pioneering work of Pigou\cite{39} to the contributions of Hohmeyer\cite{40} one of the first authors to exemplify environmental problems as externalities to be considered in the electric power industry.

In the same work, Cohon et al.\cite{38} draw attention to the fact that public policies affect IRRs in an intense way in the incidence of externalities. However, these externalities are not restricted to the expansion of generation capacity. For example, distribution utilities in Brazil, located in poorer regions, tend to have higher tariffs because of higher quotas of subsidies for discounts destined to the ‘low-income’ class and higher costs of works for the universalization of electricity in rural areas.

Energy markets are affected by externalities. For example, the existence of Feed in Tariffs leads to an increased supply of IRRs and consequently increases the MOE. In a recent work by Hildmann et al.\cite{41}, they identified that in many countries, the beginning of the encouraged insertion of IRRs occurred simultaneously with market release reforms and thus the price formation effects are often difficult to identify from the duality of causes and effects.

These complexities must be conceptualized from different perspectives, according to the role of each agent and it is clear that all these difficulties act as barriers to the expansion of IRRs.

\textsuperscript{13}Externalities can be positive or negative.
The question affecting producers focuses on how to maintain the viability of conventional projects in markets with high IRRs participation and consequently affected by MOE. One of the alternatives to address this problem is the development of a capacity market, separating the ‘ballast’ from the traded energy.

The issue that mainly affects consumer protection class entities focuses on how to avoid that incentive policies produce a very intense increase in regulated tariffs.\(^{14}\)

Distribution dealerships, on the other hand, need to live with the risk arising from the so-called ‘Death Spiral’.\(^{15}\)

It is worth noting, as Foster et al. have pointed out \(^{42}\), that the externalities associated with MOEs can have a transshipment effect from the energy industry to other related industries, such as the fuel industry.

As these authors explain \(^{42}\), as IRRs once achieve cost parities with conventional sources, so in theory they should no longer have subsidies. On this occasion, it is likely that there will be a competitive reaction of the prices of conventional plants (mostly thermal plants) due to the reduction of the spot price.

This trend may not be absolute in all cases, since an eventual price reduction in the search for competition would require the reduction of fossil fuels that represent the highest operational cost of traditional plants, but these

\(^{14}\) It is clear that regulated consumers actually finance the difference in volume traded with incentives (Feed in tariffs, for example) and that which would occur if these incentives did not exist.

\(^{15}\) Expansion effect of IRRs that lead to excess capacity in distribution systems (lines, substations and transformers and human resources and infrastructure for maintenance), which subsequently lead to the need for real tariff increases and consequently become an incentive for greater IRR penetration, especially for small-scale ones, causing a self-fed effect.
prices are normally linked to other market logics and eventually to other regulations that influence their price formation.

In the same context, Foster et al. remind that IRRs are priced down by technological advance and the learning curve of the industry, in particular wind and sunlight predictability techniques, while traditional plants have their cost very dependent on fuels. It should also be noted that fuels do not always have their prices formed through competitive processes. The International Gas Union report explains that in research conducted with producers in 2013 found that only 43% of prices were formatted by competitive processes, 19% by contracts linked to the price of oil, 33% by government decisions and 5% by other criteria [43].

Particular cases are affected by regional contingencies, for example, the influence in the MOE in several US states because of shale gas.

It should also be considered that the thermo plants will continue to be necessary to function as operational safeguards16 so that at a certain level of IRRs penetration these traditional plants must have their prices adjusted or otherwise no new investments will emerge.

There are a few studies of the influence of MOE in the long term, an exception is Li’s Master’s thesis which concludes that this effect tends to be minimized, probably by growth and costs associated with greater operational complexity [44]. Li also addresses the fact that the expansion of IRRs and the lower prices produced by the MOE also affect the price of carbon certificates, which intuitively should represent a percentage value of the total energy cost.

Some authors believe that long-term contracts signed by traditional plants need to be respected and that at the end of these new conditions should be renegotiated reflecting the MOE. However, the existence of relevant MOE may also create conditions for claims to be made while the contracts are still in force, as a kind of compensation for a new type of ‘stranded costs.’

The MOE can make short-term gains for consumers, but, according to Pham and Lemoine [45], these gains are not enough to finance the incentives developed to leverage the IRRs. In other words, the benefit produced for some would be less than what was invested by society as a whole.

The complexity of all these analyses makes the decision of what is the optimal expansion of IRRs for a given country increasingly difficult to achieve. Prof. Hirth teaches [28] that while these constraints are changing over time, the optimal penetration of IRRs will depend on the existing infrastructure, the regulatory framework in place, and the relative costs of investments in each generation alternative. He also notes that many of these costs are centralized (e.g. Treasury transfers for incentives to environmentally friendly sources) and the benefits are decentralized among market agents.

16. At least until demand response and storage alternatives are sufficiently structured and cost competitive.
These studies of the economic impacts of IRRs allow us to conclude that this expansion produces many effects, for example: (1) reduced spot market prices; (2) increased volatility in spot market prices; (3) generator income transfers to the market; (4) the existence of the MOE creates unfavourable arguments for IRR incentive policies; (5) there is no consensual evidence that the income lost by generators always reaches final consumers; (6) the MOE represents an excellent example of the risk of very long contracts based on increasingly volatile and unstable assumptions; (7) an expansion of deregulated markets will allow greater access for small consumers at prices affected by the MOE; (8) there are not many studies on the MOE in the long term, but the few that have been published consider the possibility of the effect being reduced and even cancelled in longer terms. This could be explained by the perspective that long-term prices reflect more the expectations of market agents about the fundamentals of the energy industry in this long-term perspective; (9) the ideal penetration of IRRs depends on endogenous conditions of the industry (installed infrastructure, equipment prices, consumer market and regulation), but also depends on exogenous factors such as availability of natural resources, substitute products and climate conditions.

17.4 Rebound effect – social acceptance of intermittent renewable sources – the opponents

The author understands that IRRs will not be accepted automatically by society. This idea may be surprising to the extent that they apparently have only favourable and virtuous attributes, such as being cheap and having strong environmental appeal. This section analyses that this automatic acceptance could be not true.

The acceptance must occur in three different plans: (1) socio-political acceptance where it is discussed how these policies and technologies are seen by the general public, (2) acceptance of the impacted community, which may become a relevant barrier, (3) acceptance of the market where investors and governments need to create favourable conditions economically and also it is necessary to occur the technical feasibility arising from the impacts on operation, energy security and reliability of the electricity system.

In the foreground, we can mention the devaluation of land around the plants, the decrease in local tourism, the increase in tariffs (due to the existence of subsidies for the IRRs), the eventual inability of the public authorities in their licensing, media opinion, noise, health risks, visual aspects related to the ecology of the landscape and memory links, and ecological debates that counteract clean energy with the impacts of fauna and flora (green × green) among other aspects.

17. No studies involving MOE were found in the Brazilian market.
In the dimension of the impacted community, the discussion points address experiences in their relationship with the project developers, the importance of community leaders in forming opinion about their convenience and the role of the media, advocacy and logistics arrangements, such as distance from the plant to the impacted agents. The definition of metrics for these impacts (e.g. sound impacts), the size and geometric arrangement of the generation plant and the political perception of the impacts in relation to major themes are also important, for example: how compensations and mitigations were implemented, and the ideological positioning in the face of climate change. Among the findings of this research, it is worth noting that the neighbourhood effect (NIMBY\textsuperscript{18}) has been identified as of little importance in the international literature \cite{46,47}.

The third dimension discusses how the conditions of governance provided by regulation and market players can foster full acceptance or resistance to these projects. One can exemplify the dimensions of regulatory safety and the impacts that the intensive penetration of these alternatives will provoke in the operation, direct costs, marginal costs of operation\textsuperscript{19} and of third parties (e.g. greater dispatch of thermal plants to cover intermittence), financing terms, impacts on the profitability of distributors,\textsuperscript{20} existence of lobbying for specific technologies such as coal or nuclear that would be displaced by the growing insertion of IRRs, among others. Specifically, denialist agents of the existence of Climate Change may want to defend more orthodox generation alternatives such as natural gas or coal on the grounds that climate issues are misused to subsidize the IRRs. All of these different factors are pointed in several papers \cite{48–51}.

The research carried out shows that while the very intense expansion of IRRs can be seen as a parameter of success, both by entrepreneurs and by institutional agents and public policy formatters, this success should not be seen as a tacit recognition that this expansion will continue without there being an emerging opposition, similar to what has already occurred in France and in other countries. This may cause delays and increases in the costs of new projects, because of the increasing difficulty of licensing and because of increased commitments to mitigate and compensate for the social and environmental impacts caused. This opposition could still arise if the expansion of the IRRs was lead to increased tariffs for electricity consumers, either because of incentive policies or because of increased operational complexity and the growing need for operational reserve plants to cope with intermittency as discussed in previous sections.

\textsuperscript{18} Not in my backyard.
\textsuperscript{19} Merit Order effect, for example.
\textsuperscript{20} Notably the so-called death spiral effect, where the reduction in network uses as a result of the growing use of distributed small generation ends up requiring an increase in tariffs and consequently increases the incentive for new users to join these systems.
17.5 Conclusions

The expansion of IRRs is a reality and should remain at a sustainable rate of expansion for its favourable attributes, however, the absolutist theses of a 100% IRR-based electricity industry should not happen. The technical, political, regulatory and economic complexities are very impactful and diverse affecting multiple players. This analysis indicates that the limits taught by contemporary literature are coherent when establishing limits (qualitative ones) of the order of 30% of all installed generation capacity in the next decade. In fact, this is the estimated penetration (order of magnitude) to happen in Brazil until 2030.

Some countries may go a little further, but without sufficient storage systems in place or with viable costs there will still be limits and the industry will persist for a long time to come depending on fossil fuels.

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