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This article is a preprint. Please cite the published version:

https://doi.org/10.1016/j.rser.2019.05.053

DE-RATING OF WIND AND SOLAR RESOURCES IN CAPACITY MECHANISMS: A REVIEW OF INTERNATIONAL EXPERIENCES

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Abstract

Non-conventional renewable energy technologies are already a key element in the expansion of many power systems. These resources, whose deployment was fostered through different types of support mechanisms in the last decades, can now enter the market, in many jurisdictions, without the need of any specific economic aid, beyond the one that conventional technologies may need or may be benefitting from. Therefore, where capacity mechanisms are in place, non-conventional renewable technologies should be involved in these markets as any other technology, thus not only being able to receive a capacity remuneration, but also being subject to the commitments that a capacity contract entails. A key and challenging design element to allow this participation is the definition of a methodology to evaluate the actual (or expected) contribution to reliability from renewable technologies. This article presents a comprehensive review of international experiences on this design element, encompassing eleven power systems from the United States, Latin America, and Europe.

Keywords

Capacity mechanisms; De-rating; Firm capacity; Firm energy; Capacity credit; Reliability.

1 INTRODUCTION

In the last decade, capacity mechanisms have climbed the regulatory agenda on both sides of the Atlantic ([1] [2] [3]). This trend is more evident in Europe, where these regulatory instruments have gained momentum due to (among other reasons) the sustained deployment of intermittent renewable technologies, which has increased long-term uncertainty. Beyond the specificities of each context, capacity mechanisms are generally introduced when the regulator (or the government) estimates that the expansion of the system that would be obtained if market agents are only exposed to the price signals from the energy-only market is not optimal in the long term. Optimal refers here to the fulfilment of reliability criteria defined by the regulator, which can encompass different dimensions of the security-of-supply problem (adequacy, flexibility, etc.). Capacity mechanisms are therefore implemented to introduce a further signal [4] that is supposed to “adjust” the direction of system expansion.

Historically, the main target of these mechanisms, particularly in the United States and in Europe, were thermal power plants, which were assumed to be the default solution to fulfil the reliability criteria set by the regulator. The reliability product was then related to the installed capacity of the plant, simply de-rated according to its expected forced outage rate. Only in the South American context (and, in a lesser extent, in some European country, e.g., Spain), where power systems are characterised by significant shares of hydropower (and where capacity mechanisms were included, in most cases, in the original market design [3]), more complex methodologies had to be designed to estimate the contribution of hydroelectric facilities to reliability.

In the last decade, however, the problem has got significantly more complex. The expected deployment of a vast range of different technologies, especially intermittent renewable energy sources, is forcing regulators to reconsider and “sophisticate” the design of capacity mechanisms. Until now, two parallel investment tracks could be identified: non-conventional renewable energy technologies were promoted through specific support schemes [5] and capacity mechanisms were used to attract investments in conventional technologies in charge of guaranteeing reliability. Nonetheless, these two tracks must now converge. Non-conventional renewable technologies are a key, commonly predominant, and already mature element in the system expansion of most power sectors [6]. These resources can now enter (and are entering) the market without any specific incentive and they must therefore be involved in capacity mechanisms as any other technology.

A widespread misconception depicts renewable technologies as unable to provide any significant contribution to the security of electricity supply. On the contrary, these resources are proving their ability to contribute to the reliability of the system[1] [8]. Renewable technologies may offer a complementary availability with respect to conventional energy resources and their construction time may be significantly shorter than that of other technologies [9]. Beyond this, their contribution to the security of supply varies greatly depending on the characteristics of the system and the type of scarcity conditions it faces. In hydro-dominated systems, where their intermittency can be easily absorbed, renewable technologies can significantly contribute to improve reliability (see the case of Brazil). Also in capacity-constrained systems, as those characterised by high shares of thermal power, these resources can still contribute to different extents to improve reliability depending on the correlation between their availability and the occurrence of scarcity conditions (see the case of PJM). Therefore, in principle, there is no justification to impede renewable participation in capacity mechanisms. In recent years, many renewable power plants had access to capacity remuneration, mainly, but not only, in the United States.

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[1] At the same time, some empirical evidence from international experience suggests that estimating the contribution of thermal power plants to reliability considering only their expected forced outage rate may be inefficient. In recent years, natural gas supply crises have put capacity mechanisms to a test, especially in Colombia and ISO New England [7].

A central design element of capacity mechanisms is the definition of the capacity that is to be subject to remuneration. In the case of the energy market, this problem can be solved through a simple measure of the electric energy injected in the network, but for a capacity market, the answer is not so obvious and depends on the regulatory objective (or objectives) pursued through the capacity mechanism. If the goal of the latter is, as in most cases, to guarantee electricity supply during present and future system-stress events, the capacity recognised to each resource commonly reflects the expected contribution of that resource to such objective and is, therefore, related to the probability that the resource will be producing during stress events. Thus, the installed capacity is de-rated to include such probability.

A broad variety of de-rating methodologies have been used since the inception of capacity mechanisms (dating back to the Chilean market design of 1982). Most of these methods were developed for power systems that were very different from modern ones (not to say from future ones) and, initially, they did not consider methodologies to de-rate capacity from renewable technologies. Nonetheless, de-rating methodologies progressively evolved in many systems to include, at least, the most widespread non-conventional renewable resources. The objective of this paper is to present a comprehensive review of international experiences on de-rating methodologies for wind and solar photovoltaic power plants[2], in order to identify the different approaches currently applied to estimate the contribution of

[2] The focus is restricted to these technologies because they have monopolised the regulatory debate on this topic. Furthermore, among the rest of non-conventional renewable energy technologies, geothermal, solar thermal, and biomass resources are subject to a de-rating methodology similar to the one used for conventional thermal plants, while small- and mini-hydropower plants are treated, with minor differences, as hydropower units.

these resources to the reliability of the system, a pivotal element that will define their capacity remuneration.

Section 2 presents a review of relevant literature on the topic and identifies the contribution of this article. Section 3 contains the actual review of international experiences, grouped by region and then compared. Section 4 draws conclusions.

2 LITERATURE REVIEW

The impact of intermittent renewable resources, especially wind power, on system reliability is not a novel subject in literature. The first studies were published in the early 1980s ([10] [11]) and an extensive literature has been produced since then. Some of these analyses present theoretical dissertations that review or propose methodologies to calculate the so-called capacity credit or capacity value of wind ([12] [13] [14] [15] [16] [17]); other articles review methodologies actually implemented in different jurisdictions, commonly in the United States ([18] [19] [20]), or focus on a specific power system ([21] [22] [23] [24] [25]). Literature on solar photovoltaics is less extensive, but follows a similar pattern ([26] [27] [28] [29] [30]). There are also articles that try to shed a light on the interaction of wind and solar resources and how the installed capacity of one technology influences the capacity credit of the other ([31] [32]).

Most of the studies mentioned above have a clear geographical focus, analyse wind and solar technologies separately, and all of them present reliability studies for long-term adequacy planning. Capacity credits used for reliability studies may or may not coincide with those used to de-rate resources participating in a capacity mechanism, thus, the two subjects must be distinguished. At the best of the authors knowledge, the only publication that focuses on the crediting of renewable resources in the framework of capacity markets is the one by Bothwell and Hobbs [33], who compare wind de-rating methodologies applied in capacity markets in the United States.

The objective of this article is to fill this gap in the current literature, through a study that:

- Centres the attention on de-rating methodologies that affect the capacity remuneration in those systems implementing a capacity mechanism.
- Gathers experiences from all those regions where capacity mechanisms have been introduced (United States, Latin America, and Europe).
- Analyses wind and solar de-rating formulas together and sees whether they are subject to the same methodology or to different ones.

2.1 Terminology

Before presenting the actual review of international experiences, it must be remarked that the terminology used on this topic differs significantly among the regions analysed in this article. In the United States, the concept of capacity value or credit applies also to capacity mechanisms; another term commonly used in the Northern America context is the qualifying capacity, i.e., the capacity assigned to each resource during a qualification phase of the capacity mechanism. In Latin America, the region that pioneered the introduction of capacity markets, resources are remunerated for their so-called firm capacity or energy, intended as the fraction of the installed capacity that really contributes to security of supply. In Europe, the most-widespread concept is the already mentioned de-rating of capacity. Finally, two terms largely and equivalently used in this article are de-rating factor and capacity factor, i.e., percentage factors that, multiplied by the installed capacity, permit to calculate the firm capacity that can be remunerated in the capacity mechanism[3].

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[3] A minority of documents use a “complementary” definition of de-rating factor, according to which installed capacity must be multiplied by one minus the de-rating factor in order to calculate the firm capacity to be

3 REVIEW OF INTERNATIONAL EXPERIENCES

3.1 United States

The United States count with several capacity mechanisms and it is definitely the region with the largest experience in renewable participation in capacity markets.

3.1.1 PJM

PJM (Pennsylvania-New Jersey-Maryland Interconnection) relies on a capacity market organised around centralised auctions. The capacity that renewable resources can offer in the auctions, and for which they are remunerated, is obtained by multiplying their installed capacity by their capacity factor.

Wind and solar capacity factors, in PJM, are calculated analysing the production of each unit during the 368 summer peak-demand hours (from 2 to 6 PM of days in June, July, and August) of the last three years [34]. The average production during these hours is divided by the installed capacity to obtain the capacity factor. If, in some of the peak hours, the unit is not producing due to an instruction from the system operator, such hours are not considered in the calculation.

New renewable energy projects and units with less than three years of historical data are assigned a class average capacity factor, based on historical data from units of similar technology.

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remunerated. In this article, the term de-rating factor is used with the meaning specified in the body of the text; therefore, the higher the de-rating factor, the higher the firm capacity.

3.1.2 ISO New England

ISO New England operates a centralised capacity market. Also in this case, qualified capacity for wind and solar resources is obtained from historical production data. Its calculation considers the median value (50th percentile) of the production of each unit during summer peak hours (1 to 6 PM of days from June to September), winter peak hours (5 to 7 PM of days from October to May), plus hours with scarcity conditions as declared by the system operator, in the last five years [35]. This allows to calculate a qualified capacity for summer and one for winter. New wind and solar projects, on the other hand, must provide information on the availability of the renewable resource (wind speed, solar irradiation, etc.) and calculate a tentative winter and summer qualified capacity based on these data, which will be then confirmed by the system operator [35].

It must be remarked that ISO New England included in the capacity market design a specific cap for renewable technologies receiving subsidies. If renewable qualified capacity exceeds such cap, the qualified capacity of each unit is decreased proportionally until reaching the cap.

3.1.3 MISO

MISO (Midcontinent Independent System Operator) operates a capacity market based on centralised auctions. In this case, the methodology used to define the capacity factor for wind and solar resources is completely different.

Starting from 2009, the wind capacity factor is calculated through a complex methodology based on the Effective Load Carrying Capability, or ELCC[4]. First, an ELCC value is

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[4] The ELCC is a probabilistic method that allows estimating the additional demand that could be supplied through an increase in the installed capacity of a certain technology (located in a certain node of the grid, if a

calculated for the entire wind installed capacity, considering all wind turbines as a whole. Second, this combined firm capacity is distributed among wind resources according to their production during the eight yearly peak-demand hours in the last eleven summer periods [36]. The second part of the process creates important differences in the capacity factors assigned to different resources.

As regards solar resources, even if the possibility of applying ELCC is under study, the current methodology is still based on historical data. Solar capacity factors are calculated according to the average production of each unit during peak hours (2 to 5 PM of days from June to August) in the last three years [37]. New solar projects and solar resources without a three-year production series are assigned an average class capacity factor, calculated through a solar irradiation simulation model.

3.1.4 New York ISO

New York ISO relies on a capacity market based on short- and medium-term centralised auctions. Wind and solar resources are assigned two capacity factors, one for summer and one for winter, based on their average production during peak hours (2 to 6 PM of days from June to August and 4 to 8 PM of days from December to February) in the last year [38]. Being a short-term market, either the summer or the winter capacity factor is applied depending on the delivery month.

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spatial differentiation is applied). The first step is the definition of a reliability target (for instance, a Loss of Load Expectation, or LOLE, equal to 0.1 days per year). A resource mix that achieves exactly such target is taken as a reference and then the installed capacity of a certain resource or technology is increased. This will improve the reliability of the system (e.g., the LOLE will decrease to 0.08 days per year). Then, demand is increased until reaching the initial reliability target. Such demand increment represents the effective load carrying capability of the resource or technology being assessed.

For new renewable projects with no historical production data, average production factors are calculated through probabilistic simulation models (similar to the ELCC [39]). Tables are published each year with capacity factors that discriminate, for instance, between on-shore and off-shore wind or among different solar tracking technologies.

3.1.5 California ISO

The Californian capacity market is decentralised. The regulator fixes reliability requirements for load serving entities, who are in charge of achieving these targets by procuring capacity, commonly through bilateral contracts. Wind and solar resources can trade their net qualifying capacity, which varies month by month. The calculation of the monthly net qualifying capacities is based on the historical production during peak hours (1 to 6 PM of days from April to October and 4 to 9 PM of days from November to March) in the last three years [40]. The statistical measure used in California is not the average nor the median, but rather the 70% exceedance level (70th percentile). Resources that do not have data available for one or several months during the last three years are assigned a net qualifying capacity for that month proportional to the one assigned to resources of the same technology. The same applies to new resources.

An additional complexity of the Californian de-rating methodology stems from the need for distributing the so-called diversity benefit. If hourly productions of a group of resources of a given technology are summed and the 70% exceedance value is calculated for such series, this value will be always higher or equal than the sum of the 70% exceedance values calculated for each resource individually. The difference between these two values is defined as the diversity benefit, which represents a capacity contribution that resources of a given technology as a whole are providing to the system, but which is not being recognised to them through their net qualifying capacities. Therefore, the methodology includes a second step, in which the diversity benefit is redistributed among resources of the same technology according to their historical production in the period under study.

3.2 Latin America

Latin America pioneered not only power sector liberalisations, but also the introduction of specific mechanisms for system adequacy. However, in Latin America, these schemes do not always target capacity. In hydro-dominated, energy-constrained systems, scarcity conditions occur in dry years and may last for large periods of time. The system could certainly satisfy peak demand during a few hours, but would not be able to supply the demand during the remaining hours, days or months of the dry period. For this reason, many adequacy schemes in the region are based on firm energy[5] (as Colombia and Brazil) rather than on firm capacity (as Chile).

3.2.1 Chile

The Chilean capacity mechanism is based on an administrative capacity price, calculated by the regulator, which is multiplied by the firm capacity assigned to each resource to obtain its remuneration. Firm capacity is calculated through a complex methodology that involves several steps. As regards wind and solar resources, the first step consists in defining their initial firm capacity, obtained as the installed capacity multiplied by the lowest between [42]:

- Lowest yearly plant factor in the last five years
- Average plant factor registered during the 52 peak hours in the last year

[5] For details on how the concept of adequacy varies between energy- and capacity-constrained power systems, see [41].

The latter can be clearly seen as capacity factors; the first one used to be more restrictive than the second one for solar resources, while for wind resources it is not possible to identify a factor that is systematically lower than the other. The capacity factor for new resources, which cannot rely on historical data, is set equal to the average capacity factor of plants of the same technology that are located in the same area[6].

Initial firm capacities are used to build the joint probability distribution of the system, which combines all possible states of all power units, in order to calculate the preliminary firm capacity of each resource. The latter is defined as the expected contribution of each resource to the supply of peak demand. The probabilistic process used in this phase is a convolution that calculates the firm capacity that the system can provide with a certain probability, with and without the resource under examination. The difference between the two values represents the preliminary firm capacity of that resource.

Finally, each year preliminary firm capacities are proportionally reduced for their summation to be equal to the peak demand in the system. The capacity market is settled ex-post and this operation allows to balance capacity charges from demand with capacity payments provided to generators.

3.2.2 Colombia

As mentioned in the introduction to this subsection, Colombia can be considered an energy-constrained system. The scheme in charge of guaranteeing system adequacy is the so-called firm energy obligations (*Obligaciones de Energía Firme*, or OEF, in Spanish) mechanism. The

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[6] In 2017, a technical report commissioned by the Chilean regulator [43] proposed to modify these capacity factors in order to recognise a higher initial firm capacity to wind and solar resources and to reduce the volatility of this factor. The report proposes to increase from five to ten years the time horizon for the yearly plant factor and from 52 to 876 the number of peak hours for the calculation of the average plant factor.

system operator launches centralised auctions for the procurement of firm energy[7], defined as the daily energy that a resource can provide to the system with a certain probability (percentiles 95th and 100th [8], based on historical production series).

In 2006, when the OEF mechanism was introduced, no methodology for firm energy calculation was established for wind and solar resources. The methodology for wind projects was defined in 2011 [45] and was subsequently modified in 2015 [46]. Regulation differentiates between units and projects depending on whether they possess a 10-year wind speed series. If such series is available, the firm energy is calculated through a formula that translates wind speeds into daily energy values that would have been produced by such plant in the last 10 years; Such values are ordered from lower to higher and the already-mentioned percentiles (95th and 100th) are applied to this series. Wind projects without a 10-year wind speed series, on the other hand, are assigned a firm energy based on two administrative de-rating factors: 6% for the 100th percentile and 7.3% for the 95th percentile. These administrative factors are quite lower than those used in other contexts (see section 3.4) and are far from the average load factors of this technology.

The methodology for solar power plants was established in 2016 [47]. The firm energy of a solar resource can be calculated only when historical data on horizontal irradiation and temperature are available for the last ten years. The legislation considers a formula that, based on these time series, permits to calculate the potential daily energy output of the plant

[7] The reliability product is a financial option with a predefined strike price; reliability providers selected in the auction receive a yearly premium, but must return to demand any positive difference between the spot and the strike price. See [44] for details on the OEF mechanism.

[8] The base firm energy of a resource is calculated applying the 100th percentile, but the agent has the right to offer up to the firm energy of the 95th percentile, if it provides some additional warranties.

during the same time period, considering factors as the tilt of the panel, forced outages, and degradation. Once again, these daily production values are ordered from lower to higher and the 95th and 100th percentiles are applied.

One of the most controversial points of these methodologies is the need to count on 10-year time series, a requirement that is very limiting for several projects. An alternative, under study at this writing, is the permission to complement measured data (that must cover at least one year) with synthetic data generated by internationally-recognised weather models (only in those cases when a correlation between measured and synthetic data higher than 85% can be observed).

3.2.3 Brazil

The Brazilian wholesale electricity market is totally organised around long-term auctions. All demand, both captive and free must be covered by long-term contracts and the spot market is used only for settlements among generators. Auctions fix the price for both demand and generation and guarantee the security of electricity supply. In fact, the amount of energy that each resource can trade in long-term auctions is limited by the regulator through the emission of firm energy certificates. The computation of firm energy certificates to be assigned to conventional technologies is based on a complex probabilistic model (the same that is used for the hydro-thermal dispatch), which simulates the operation of the system as a whole and calculates the expected yearly production of each resource [44].

Nevertheless, firm energy certificates for wind and solar projects are not computed through the same simulation model. Wind and solar resources can use either historical production data or wind speed and solar irradiation time series in order to calculate the yearly energy production that their facilities can provide to the system with a probability equal to 90% for wind and 50% for solar [48].

3.3 Europe

Many power sectors in Europe that originally opted for an energy-only market are now introducing capacity remuneration mechanisms [1]. Renewable participation in these schemes has been very limited until now. In some cases, this participation is directly forbidden because it is considered incompatible with the remuneration already being provided by renewable support mechanisms. However, some countries do allow renewable participation in their capacity mechanism and have designed specific de-rating methodologies for wind and solar resources. In this subsection, the cases of Ireland, Italy, and France are analysed.

3.3.1 *Ireland*

Ireland is in the process of introducing a capacity remuneration mechanism based on reliability option contracts with multiple reference markets. Renewable resources are not obliged to participate in the capacity market, as for conventional power plants, but they can ask for permission, take part in the auction and have access to the resulting remuneration.

According to the documents available at this writing ([49] [50]), the firm capacity of each resource is obtained through de-rating factors calculated with a methodology very similar to the ELCC used in some systems in the United States. A generation reliability model is used to simulate the performance of the system. First, the installed capacity of a certain technology is increased and, second, demand is incremented until reaching the initial reliability target (in Ireland, this is a LOLE equal to 8 hours per year). The de-rating factor will be equal to the demand increment divided by the installed capacity increase. However, in a small system as the Irish one, a large power plant provides a lower contribution to security of supply than several smaller power plants summing the same installed capacity (due to outage correlations). Therefore, the probabilistic model considers different increments in the installed capacity and computes several de-rating factors for the same technology. The result is the construction of a marginal de-rating curve, which permits to assign different de-rating factors to units of different sizes within the same technology.

The same approach is applied to wind and solar resources[9]. Nonetheless, for these technologies, no marginal curve is computed to differentiate among plants of different sizes; the de-rating factor is unique for the entire technology. As already mentioned, the Irish territory is relatively small, and there is a high correlation in the availability of different power plants that rely on the same renewable source. If there is no wind in a specific hour, it is likely that the wind will be missing in the entire island and not just in one site. The same apply to solar power plants. Due to this high availability correlation, the contribution to security of supply of these technologies do not depend on the size of power plants.

3.3.2 Italy

Similarly to Ireland, Italy is reforming its capacity payment to introduce a reliability-options scheme with multiple reference markets. Renewable participation was not considered in the initial design, but, after a negotiation with the European Commission, the Italian regulator introduced some features to allow wind and solar power plants to bid in the capacity auction. Nonetheless, the commitment required to these technologies is very different from the one required from conventional power plants and so does the de-rating methodology.

Conventional power plants (thermal and hydropower) have their installed capacity de-rated according to their equivalent forced outage rate or to their availability during past peak-demand hours. The de-rating is carried out plant by plant. On the other hand, wind and solar resources are assigned a zonal de-rating factor, which aggregates all the units of one

[9] Actually, the methodology is slightly different, since the joint half-hourly production of all the units of each one of these two technologies is considered as a whole in the simulation, without marginal increments [49].

of the two technologies in a capacity zone (Italy operates zonal capacity auctions). De-rating factors consider the median value (50th percentile) of the production of all the units within a zone during peak hours in the last five years [51]. The latter are identified year by year by the system operator as the hours in which the system is more likely to suffer a reliability problem.

3.3.3 France

In 2016, France introduced a decentralised capacity market, in which load serving entities with capacity obligations have to procure capacity from certified resources. The certified capacity assigned to each resource depends on its production during winter peak-demand hours. The latter are defined as the hours from 7 AM to 3 PM and from 6 to 9 PM of days that the operator identifies as critical (these are notified to reliability providers one day ahead). According to the standard procedure, resources estimate in advance their expected production during these peak hours (self-certification) and this forecast is then verified ex-post according to the actual production, in order to calculate possible unbalances to be settled [52].

Wind and solar resources can opt for two different certification processes:

- The standard procedure, as described above; in this case, they are subject to the risk of forced outage of their facility as well as to the risk of unavailability of the primary energy source.
- The so-called normative procedure, in which their certified capacity is calculated by the system operator in a conservative way; in this case, they are exempted from the risk related to the unavailability of the primary energy source.

The normative certified capacity is computed from the historical average production of each resource during peak hours. This value is then multiplied by a so-called contribution coefficient which is different for each technology [53]. Contribution coefficients are calculated through a methodology similar to the ELCC: the installed capacity of the technology under study is incremented in a reference system and the resulting LOLE is computed; some capacity of a "perfect resource"[10] is added to the same reference system until reaching the same value of LOLE. The capacity of the perfect resource divided by the capacity increment of the technology under study represents the contribution coefficient.

3.4 Comparison

International experiences presented in this section show a large variety of different approaches for the calculation of wind and solar de-rating factors in the context of capacity mechanisms. This variety should not surprise, since, as mentioned in the introduction, these methodologies (as the entire design of the capacity mechanism) must be tailored to the system characteristics and to the regulatory objectives pursued through the capacity market. Most of the methods analysed in this review estimate the average contribution during a predefined period, based on historical data. However, several examples of more complex methodologies, based on marginal contributions and probabilistic approaches, could be observed. Table i presents a summary of the methodologies presented in this section.

Table i. Summary of methodologies for the calculation of de-rating factors of wind and solar resources

System	Wind	Solar
PJM	Capacity factor based on the average production during summer peak hours in the last 3 years; class average capacity factors for new power plants	
ISO NE	Capacity factor based on the median production (50th percentile) during summer and winter peak hours in the last 5 years	
MISO	Firm capacity of all wind units considered as a whole computed through ELCC and redistribution of such firm capacity	Capacity factor based on the average production during summer peak hours in the last 3 years

[10] A perfect resource does not have forced outages nor technical restrictions.

	according to the production of each plant during the 8 highest daily peak demands in the last 11 years	
NYISO	Capacity factor based on the average production during summer and winter peak hours in the last year; capacity factor base don ELCC for new power plants	
CAISO	Monthly capacity factors based on the 70% exceedance value of the historical production during monthly peak hours in the last 3 years	
Chile	Capacity factor equal to the lowest between: i) lower yearly plant factor in the last 5 years and ii) average plant factor in the 52 peak-demand hours in the last year	
Colombia	With wind speed information: potential historical production through a formula based on wind speed and application of the 95th and 100th percentiles; without wind speed information: 6% administrative factor	With solar irradiation information: potential historical production through a formula based on this information and application of the 95th and 100th percentiles
Brazil	Self-declared capacity factor based on historical production (or wind speed data) through the application of the 90th percentile	Self-declared capacity factor based on historical production (or solar irradiation data) through the application of the 50th percentile
Ireland	Unique capacity factor for each technology based on a ELCC analysis	
France	Two different alternatives: i) standard procedure, self-certification and ex-post verification; ii) normative procedure, average production during winter peak hours de-rated through a contribution coefficient computed through ELCC	
Italy	Zonal capacity factors for each technology based on the median production (50th percentile) during peak hours in the last 5 years	

This diversity among methodologies is amplified when comparing de-rating factors actually being applied to wind and solar resources worldwide. Even if de-rating factors cannot be compared without considering the peculiarities of each power system, Table ii tries to condensate the information collected for each system in a single capacity factor for each technology[11].

[11] This exercise could not be carried out for all the systems under study, either for the lack of data or for the impossibility of identifying a single value that was representative for the entire technology. In Colombia, no new auction was launched since the publication of the new methodologies for wind and solar technologies, thus no real value is available. The same applies to Italy, where no capacity auction has been launched yet. ISO New England does not publish qualified capacities for existing resources. The Brazilian adequacy mechanism is so different from the others presented in this article that mentioning an equivalent capacity factor here would be misleading.

Table ii. Wind and solar de-rating factors in systems with different generation mixes

System	Thermal capacity [a]	Hydro capacity [a]	Wind capacity [a]	Solar capacity [a]	Wind de-rating factor	Solar de-rating factor
PJM [b]	94%	5%	0,6%	0,4%	13%	38%
MISO	90%	2%	8%	0%	15,6%	50%
NYISO [c]	80%	14%	5%	1%	10% - 30%	2% - 46%
CAISO [d]	64%	18%	11%	7%	2% - 33%	0% - 80%
Chile [e]	61%	29%	5%	5%	20%	25%
Ireland	75%	3%	22%	0%	10,3%	5,5%
France [f]	66%	20%	9%	5%	70%	25%

Notes
[a] Data from [54] [55] [56] [57] [58] [59] [60] [61]
[b] Class average capacity factors; subclasses within a same technology have been proposed recently, with higher values for some subclass
[c] Summer and winter capacity factors for on-shore wind and solar PV with tracking technology; factors for new power plants
[d] Monthly capacity factors (maximum and minimum) for new power plants
[e] Capacity factors used for the calculation of the initial firm capacity; average factor within each technology
[f] Contribution coefficients to be multiplied for the historical production during peak hours, not comparable with the rest of de-rating factors

The most evident result of the comparison presented in Table ii is probably the difference between American systems, in which de-rating factors are usually higher for solar than for wind resources, and the two Northern European systems analysed in this section, where the opposite occurs. This disparity is likely to be due to the different kind of scarcity conditions expected in these systems.

4 CONCLUSIONS AND POLICY IMPLICATIONS

According to recent studies [62], levelised costs of wind and solar resources already fell in the so-called fossil fuel-fired cost range and the decreasing trend will last at least until 2020, opening the door to a second phase in the deployment of renewable energies. The latter is supposed to be based on an increasing integration of renewable technologies in the electricity market, on the removal of rules and exemptions that implicitly or explicitly favoured until now these resources, and on a progressive elimination of support mechanisms. In these context, renewable and conventional technologies will have to compete in the same markets, subject to the same rules.

If the regulatory trend observed in the last two decades continues, capacity mechanisms will be one of the pillars of future power markets. Until now, wind and solar participation in these schemes have been limited, mainly due to the assumption that they were not mature enough to be exposed to the same long-term risks as conventional technologies (and that they were therefore in need of targeted promotion mechanisms). Nevertheless, future renewable capacity will have to be treated as any other technology and enter the market in the same way as conventional resources. Beyond avoiding market segmentation, this participation has the advantage of exposing renewable resources to the efficient signal conveyed by the performance incentives that modern capacity mechanisms will encompass.

For this reason, it is essential that all the systems that complement the energy market with a remuneration for capacity, adequacy, or reliability establish a methodology for the de-rating of wind and solar capacity, which is the very first step to allow their participation in these schemes. This article presented a comprehensive review of international experiences, covering three regions, United States, Latin America and Europe, where most of the empirical evidence on capacity mechanisms can be found. De-rating methodologies currently under use for wind and solar resources in more than ten different power systems have been analysed.

A great variety of different methodologies has been observed, reflecting the different objectives pursued by regulators through capacity mechanisms. Even if many studies in literature highlight the benefits of probabilistic methodologies ([15] [16] [17]), as the effective load carrying capability, this review shows that the utilisation of the historical production during peak hours as a proxy of the contribution to system reliability is still prevalent, especially in the United States. Among the systems applying methodologies based on historical productions, large differences can be observed in the period of time used for the assessment (from one year in New York ISO to five years in ISO New England). This approach is also common in Latin America, where, however, the discussion is completely changed in some country by the presence of huge hydropower reservoirs, which move the focus from firm capacity to firm energy. On the other hand, in Europe, some new capacity market designs seem to opt for more complex probabilistic approaches, as those implemented by Ireland and France, while Italy preferred a method based on the historical production during peak hours.

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