PHOTOVOLTAIC PROJECTS ON ENERGY AUCTIONS

Characteristics of PV projects on auctions from 2013 to 2018

Empresa de Pesquisa Energética

MINISTÉRIO DE MINAS E ENERGIA

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FOREWORD

This Technical Note belongs to a series of documents that have been elaborated by EPE in order to discuss some trends, relevant aspects, and to disseminate relevant information about the PV projects that participate on the energy auctions in Brazil. The aforementioned documents are available on EPE's website and are listed below:

- 2º LER/2016 (EPE-DEE-NT-030/2017-r0) – 05/22/2017;
- 2º LER/2015 (EPE-DEE-NT-023/2016-r0) – 02/24/2016;
- 1º LER/2015 (EPE-DEE-127/2015-r0) – 09/24/2015 (Portuguese only);
- LER/2014 (EPE-DEE-NT-150/2014-r0), de 11/21/2014, (Portuguese only).

The first three documents present the characteristics and some discussions focused exclusively on the projects that have had their energy contracted on the respective energy auctions. The most recent Technical Note refers to an auction that has been cancelled and it is focused on the analysis of the historical data from all the PV projects that have been qualified for the energy auctions.

In this study, a mixed approached of the previous Technical Notes was taken. First, a general overview of the most recent auctions (A-4 2017 and A-4 2018) is presented. In this overview, a summary of the submitted projects is shown, as well as a discussion of the technical acceptance process for the auctions and the main reasons that have prevented the participation of some of the projects.

The second part of the Technical Note contains an analysis of the evolution of the characteristics of the PV projects that have submitted to the energy auctions. These results are based on a 6-year historical database of the energy auctions and the data is always presented on an aggregated form and through statistical results so that the confidentiality of the project owner's information is maintained.

Finally, the last part of the technical note shows a summary table with the main characteristics of the contracted projects, as well as a brief discussion on its technical and economic aspects, and a summary of the prices and the contracted amounts on each auction in which PV projects have been contracted.

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SUMMARY

1. INTRODUCTION

Ordinance MME n. 293/2017, from August 4th, 2017, and Ordinance MME n. 465/2017, from November 30th, 2017, have established the guidelines of the New Energy Auctions A-4 from 2017 and 2018. Besides PV projects, these auctions included projects from wind, hydro and thermal power plants. However, this technical Note only discusses the rules associated to PV plants.

Among the established guidelines, the following aspects should be highlighted:

- electricity supply from the contracted projects must begin on January 1st, 2021, for the A-4/2017 auction, and on January 1st, 2022, for the A-4/2018 auction;
- energy was negotiated on "availability contracts";
- 20-year power purchase agreement;
- projects under 5 MW were not accepted;
- electricity prices adjusted annually based on the Brazilian Consumer Price Index – IPCA (inflation index);
- on the A-4/2018 auction, it was determined that the projects should sell at least 30% of their qualified energy (on the A-4/2017 there was no restriction).

The A-4/2014 and the A-4/2018 were both strongly influenced by the publication of Ordinance MME 444/2016, which has established the general guidelines for the definition of the transmission system capacity of the National Interconnected System (SIN). With the publication of this ordinance, some of the main premises, criteria, and procedures generally used for the assessment of the transmission system capacity have been determined. It has also settled the milestones for the Technical Notes publications that subsidize EPE's technical analyses.

It is important to note that MME Ordinance 444/2016 contains fundamental regulations for the auctions where the transmission system capacity is assessed since it unifies the rules for obtaining the system capacity, it makes the process more transparent and predictable, and it allows project developers to perform their own estimates before the publication of the ONS Technical Note.

2. SUBMISSION AND TECHNICAL ACCEPTANCE

2.1. Submission

The submission and the technical acceptance of the projects were performed by EPE following the MME guidelines, as well as the Ordinance MME n.102, from March 22th, 2016, and EPE's instructions ("Instruções para Solicitação de Cadastramento e Habilitação Técnica com vistas à participação nos Leilões de Energia Elétrica") published on EPE's website.

By the time of the respective auctions, EPE published summaries with the number of submitted projects and the total submitted power per State. This information is presented on the Tables 1 and 2 below, on which the power may differ slightly from the previous values due to adjustments during the analysis process.

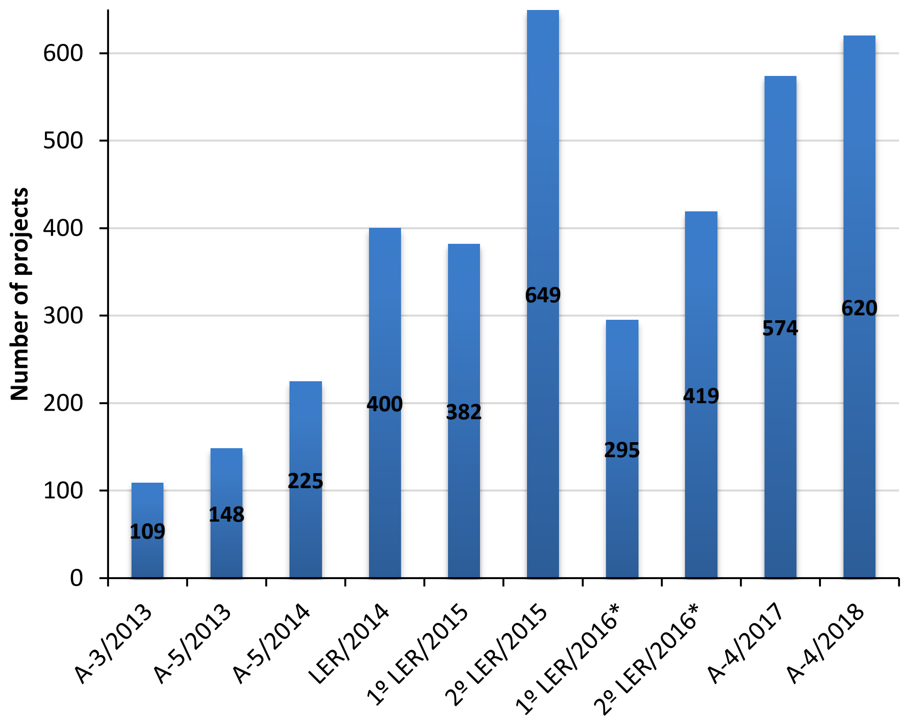
In comparison with previous auctions, the number of projects has increased, getting close to the record of 649 submitted projects on the 2nd LER/2015. It is important to remember that by that time, the one-year solar measurement campaign on the project site was not mandatory, a requirement that reduced the number of projects in the year of 2016 as it can be noticed on Figure 1.

Table 1 – Submitted projects on the A-4/2017 auction

State	Projects	DC Power (MWp)	AC Power (MW)
Alagoas	2	65	50
Bahia	162	5,955	4,699
Ceará	50	2,019	1,575
Minas Gerais	29	1,473	1,145
Mato Grosso do Sul	21	1,685	1,220
Paraíba	23	786	613
Pernambuco	40	1,566	1,201
Piauí	104	5,012	3,354
Rio Grande do Norte	89	3,698	2,978
São Paulo	42	1,549	1,243
Tocantins	12	322	215
Total A-4/2017	**574**	**24.131**	**18.293**

Table 2– Submitted projects on the A-4/2018 auction

State	Projects	DC Power (MWp)	AC Power (MW)
Alagoas	4	143	110
Bahia	177	6,699	5,212
Ceará	50	2,150	1,687
Minas Gerais	40	1,896	1,414
Mato Grosso do Sul	20	1,701	1,184
Paraíba	26	879	694
Pernambuco	38	1,457	1,123
Piauí	114	5,661	3,829
Rio Grande do Norte	98	4,185	3,350
São Paulo	40	1,488	1,198
Tocantins	13	337	225
Total A-4/2018	**620**	**26.596**	**20.026**



***Even though there was submission and technical acceptance for the following auctions, they did not occur for PV projects.**

Figure 1 – Number of projects submitted on each energy auction

As it has happened on previous auctions, most of the submitted projects are located on the Northeast subsystem (84% on both auctions). The remaining 16% belong to the Southeast/Center-West subsystem, divided on three States: Mato Grosso do Sul, São Paulo and Minas Gerais.

2.2. Technical acceptance

The technical analysis and acceptance of the submitted projects comprises several aspects of the projects and of the technical documents received by EPE, with the goal to select those that demonstrate their technical feasibility and their capacity to deliver the amount of energy to be contracted.

For the A-4/2017 auction, EPE qualified 55% of the submitted PV projects, which includes 315 projects, while on the A-4/2018 auction 422 projects were qualified. A summary of the quantity of qualified projects and their installed capacity, aggregated by State, is presented on the Tables 3 and 4.

The graph on *Even though there was submission and technical acceptance for the following auctions, they did not occur for PV projects.

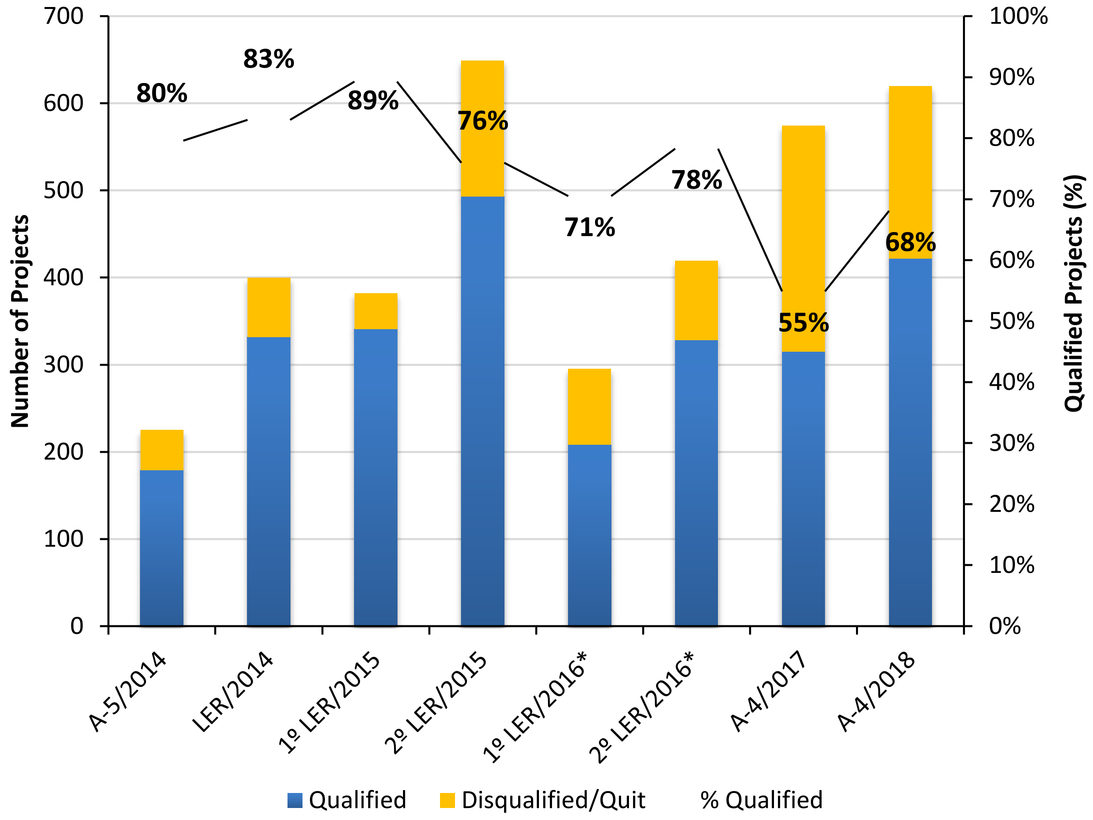
Figure 2 presents the data from the Energy auctions since 2014. In comparison, the percentage of qualified projects decreased, especially in 2017, and it increased a little in 2018.

Table 3 – Qualified PV projects for the A-4/2017 auction

State	Projects	DC Power (MWp)	AC Power (MW)
Bahia	50	1.883	1.486
Ceará	18	568	460
Minas Gerais	21	1,060	825
Mato Grosso do Sul	20	1,629	1,180
Paraíba	20	709	555
Pernambuco	40	1,566	1,201
Piauí	100	4,866	3,244
Rio Grande do Norte	11	461	360
São Paulo	35	1,287	1,033
Total A-4/2017	**315**	**14,030**	**10,344**

Table 4– Qualified PV projects for the A-4/2018 auction

State	Projects	DC Power (MWp)	AC Power (MW)
Alagoas	4	143	110
Bahia	65	2,459	1,935
Ceará	39	1,533	1,183
Minas Gerais	32	1,582	1,165
Mato Grosso do Sul	13	1,105	784
Paraíba	26	879	694
Pernambuco	31	1,169	913
Piauí	100	5,031	3,439
Rio Grande do Norte	67	2,484	1,974
São Paulo	32	1,194	958
Tocantins	13	337	225
Total A-4/2018	**422**	**17,916**	**13,380**



***Even though there was submission and technical acceptance for the following auctions, they did not occur for PV projects.**

Figure 2 – Technical qualifying historical results

On both auctions, there were 4 projects with invalid submission, though by different reasons. Also, 8 projects dropped out of the A-4/2017, and 29 of the A-4/2018. Quitting the process occurred for different motives: (i) projects that have already awarded the A-4/2017 and therefore quit the A-4/2018 and (ii) projects that had problems that could not be solved during the analysis process.

The disqualified projects (247 in the A-4/2017 and 165 in the A-4/2018) could not participate the auctions due to the motives exposed on Figure 3. The sum may exceed the number of disqualified projects because some of them may have been disqualified for more than one reason.

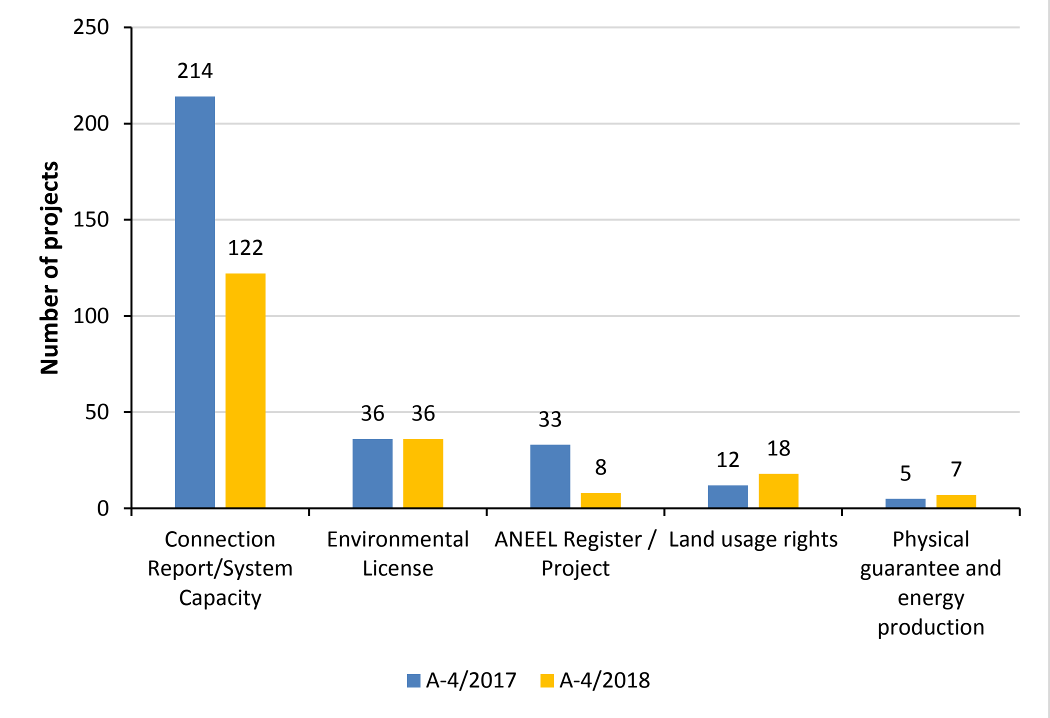


Figure 3 – Disqualifying reasons on the A-4/2017 and A-4/2018 auctions

On both auctions, the main disqualifying motives are related to invalid distribution grid connection feasibility study reports (whenever the project's connection is in the distribution grid, the distribution company must provide a document stating the feasibility of the connection), or insufficient transmission grid capacity, which is assessed by the ONS (National System Operator). In the A-4/2017 Auction 214 projects were disqualified while 122 were on the same situation for the A-4/2018 Auction.

The National System Operator (ONS) assessed the available transmission system capacity and published the result of this assessment on the Technical Notes 0118/2017 and 0016/2018. These documents presented the available capacity of the transmission grid on each busbar that was indicated as a connection point for the submitted projects.

Based on the results presented on these Technical Notes, several connection points had no additional capacity, or a remaining capacity that was lower than the individual installed capacity of the submitted projects. It is important to remind that the results of ONS simulations, which have defined the remaining grid capacity for new projects, were strongly influenced by the delays on construction of the transmission assets granted to ABENGOA, CHESF and ELETROSUL. The absence of these transmission assets have substantially influenced the capacity for the busbars located in the States of Bahia, Rio Grande do Norte and Rio Grande do Sul.

Additionally, it should be noted that despite of the lack of remaining capacity in several connection points, resulting in several disqualifications, there is an expectation for the reduction of the restrictions identified by ONS for the next competitions. This reduction is due to the conclusion of several planned transmission lines that should go into operation in the near future.

Finally, according to the Guideline Ordinances from the A-4/2017 and A-4/2018, requests for changes on the connection point that have been indicated during the project submission were not allowed.

Another important disqualifying reason on both auctions was regarding the environmental licensing. For the technical qualifying, a valid Environmental License must be presented and it has to be compatible with the technical characteristics of the project as well as the stage of the licensing process. In addition, Environmental Studies submitted to the respective licensing institution in the licensing process must be provided to EPE. On the A-4/2017, from the 36 projects disqualified for this reason, 26 did not submit the Environmental License, while 10 had inconsistencies between the project data submitted to EPE and the provided Environmental License. On the A-4/2017 auction, all 36 disqualified projects failed to present a valid Environmental License.

3. RESULTS AND EVALUATIONS

On this chapter, the results of the technical analysis regarding all the qualified projects for A-4/2017 and A-4/2018 are presented in comparison with the historical project database. It is worth mentioning that the assessments presented here were based on the projects submitted to EPE by project developers for the purpose of technical acceptance in the auctions. They do not necessarily represent the final configuration that would be actually built since developers are allowed to promote changes in the technical characteristics of their projects. Naturally, all these changes should be in accordance with current rules and they should be authorized by the MME. Such changes are natural, since before the auction the project is in a stage of "feasibility study". Afterwards, the detailed design can be defined considering equipment suppliers, technical and economical optimization, and more reliable information.

For further details about concepts and terminologies used in this document (DC Power, AC Power, Enabled Power, Generating Unit, etc.), refer to EPE's Technical Note EPE-DEE-NT-150/2014-r0 (EPE, 2014) and ANEEL's Normative Resolution 676/2015 (ANEEL, 2015), both available in Portuguese.

3.1 Aspects related to the solar resource

Since 2016, on-site measurements of the solar resource are required, as instructed on Article 6th of Ordinance MME n. 102/2016:

> *"Art. 6º Project developers must meet the conditions for Registration and Technical Acceptance, established in Art.4 and also the following requirements:*
>
> *(...)*
>
> *II – (…) a record of continuous measurements of global horizontal irradiance, for a period no shorter than twelve consecutive months, carried out at the site of the project (…) for photovoltaic projects without irradiation concentration technology".*

This requirement aimed to increase the reliability of the solar data used on the calculation of the certified energy production, and it was expected that it would result on lower global uncertainty on the projects. It should be mentioned that the "site of the project" is defined as a radius of 10 km around the measurement station.

For the auctions in analysis on this Technical Note, some changes on EPE's Instructions for PV projects were carried on, regarding the use of the local irradiation data. On the item 5.9.1.2, the new text is as follows:

> *"c) Evaluation of the data correlation between the local measurement and long term irradiation data (historical of at least 10 years) in hourly or shorter intervals, as well as the description of the data adjustment methodology, if used;*
>
> *d) Description of the procedure used to obtain the typical meteorological year from the adjusted long term data from item c)."*

In addition, on item 5.9.2, an adjustment was proposed:

> *"The calculation of the Certified Production must be performed using the typical meteorological year described on the Solar Data Certification".*

The goal of these changes was to point out the minimum methodology expected for the usage of the measured data. This consist on comparing the measured data with data obtained from a reanalysis or satellite data, with a longer time span, and, if deemed necessary, to use a data adjustment method for the long-term data. Details on adjustment methods, its necessity and its use on auctions are discussed in Ruschel and Ponte (2018).

Later, using the adjusted data, a typical meteorological year (TMY) is obtained, and it is used to calculate the long-term energy production. It should be noticed that other methods could be used, upon certifier's criteria, and these are evaluated on the technical acceptance process. For instance, instead of using the typical meteorological year, the certifier could simulate the energy production using all the adjusted long-term series, and from that, estimate the long-term energy production for the project.

After decreasing in 2016 with the start of the measurement requirement, the Solar Data Uncertainty has risen a bit again on the following auctions. The Standard Uncertainty, on the other hand, presented slight reductions, as shown on Figure 4.

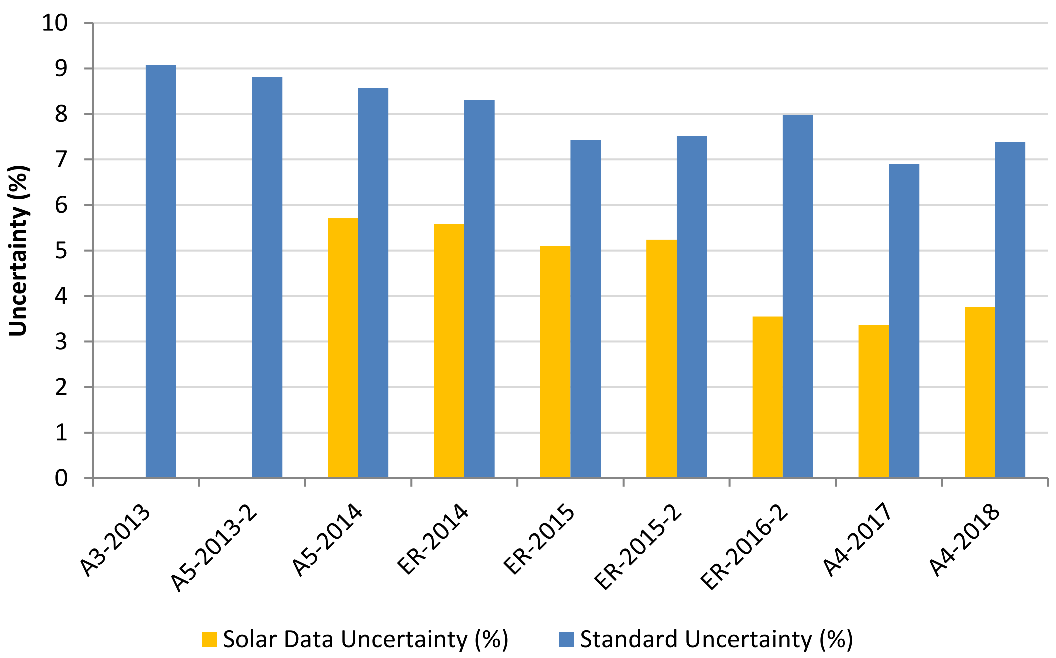


Figure 4– Historical mean uncertainties for PV projects on auctions

Since several projects share the same measurement stations (if inside a 10 km radius), the amount of installed measurement is lower than the number of submitted projects.

Appendix I presents the 104 measurement stations that were installed to fulfill the requirements to participate on the auctions.

The global horizontal irradiation (GHI) level considered on the energy production estimation ranged from 1,910 kWh/m².year to 2,334 kWh/m².year, same limits seen at the 2nd LER/2016, which was presented on a prior Technical Note (EPE, 2017). Historically, the GHI levels did not change significantly, except for some extreme values, as it can be seen on Figure 5, which shows the minimums and maximums (bars), means (orange points), and the first and third quartiles (blue boxes) for the GHI considered for the projects on each auction.

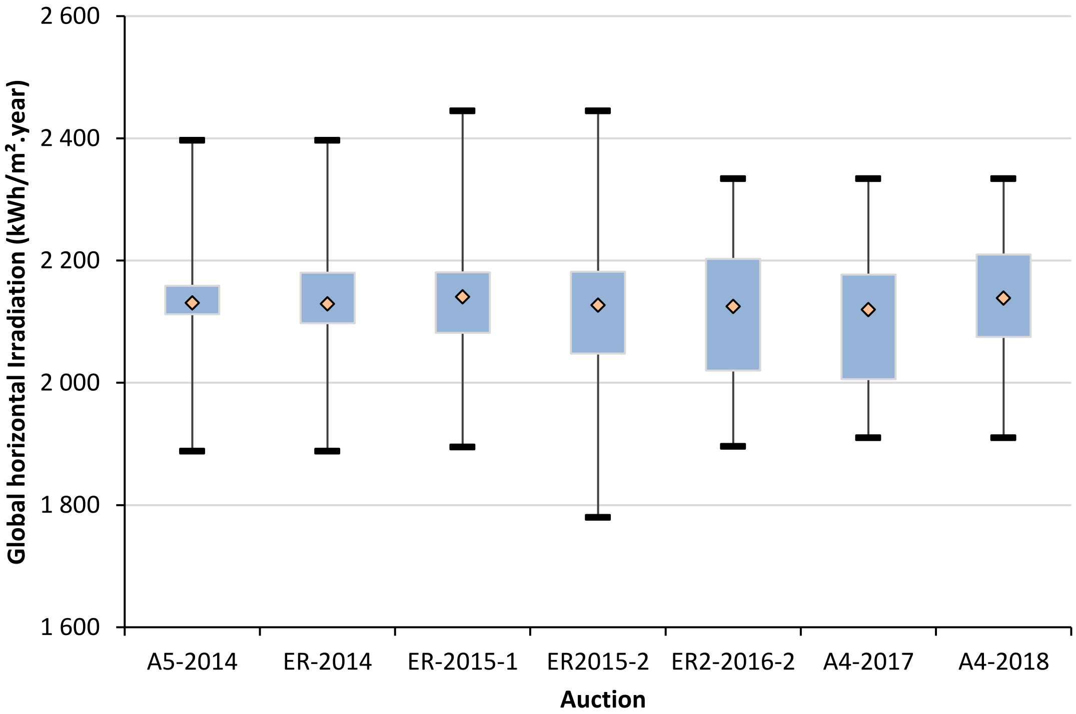


Figure 5 – Historical GHI variation on auctions

Since 2016, there was a reduction on the maximum levels, which may be correlated to the start of the use of local measurement. The mean values were kept approximately constant, and the quartiles have suffered some oscillation, which may be related to the variation on the number of projects, the diversification of the sites, among other factors. It should be pointed out that, even though the GHI is a good indicative of the future production of a PV plant, this correlation is not direct, since the power plants have non-horizontal tilts, and on the case of single-axis tracking, variable tilts.

3.2 Equipment

3.2.1 PV Modules

Crystalline silicon technology, as it happens on international markets, were the dominant choice for project developers. On the A-4/2017 and A-4/2018 auctions, they represented around 95% of the sum of the DC Power of the qualified projects. The only thin film technology that still presents submitted projects is Cadmium Telluride (CdTe), which since 2016 has maintained around 5% of the DC Power of the submitted projects. Among other technologies, on the 2nd LER/2015, just over 0.5% of the DC power used CIGS modules, and amorphous silicon technology never surpassed 0.1% of DC power for qualified projects. Figure 6 summarizes this historical.

It is always important to remind that this data do not necessarily correspond to the market share of each technology, since it relates to projects still on qualifying phase, and the final choice of equipment in general is confirmed only after the auction.

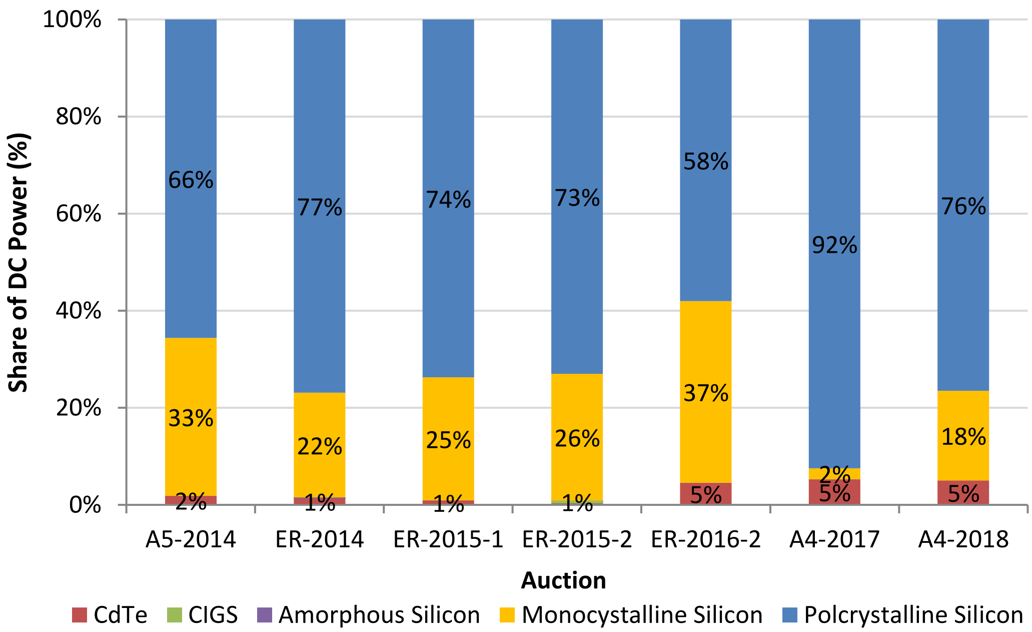


Figure 6 - Share of DC power by technology of the qualified projects on each auction

Among the crystalline silicon modules, in 2016 there seemed to be a trend to increase the number of cells on the modules. However, on the most recent auctions, there was actually a 72-cell modules dominance, which accounted for virtually all the (silicon) submitted projects on the 2017 auction. In 2018, their share decreased to 95% while the other 5% were 96-cells modules. Figure 7 presents the share of the DC power of the qualified projects by number of cells for crystalline modules.

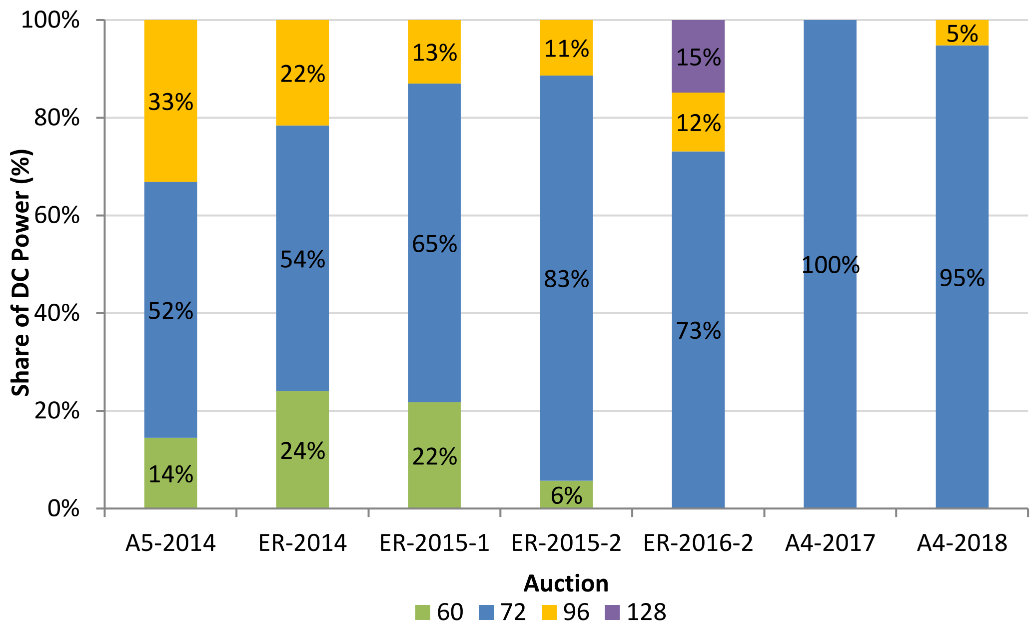


Figure 7 – DC power of the qualified projects by cell quantity

Another trend seen on recent auctions was the increase of the maximum admissible voltage of the systems, as shown on Figure 8. A recent migration has been occurring, from modules with 1000 V limit to the ones that endure 1500 V, allowing the use of longer series, reducing the system currents and cabling costs. On the other hand, higher voltage systems are more prone to PID (potential induced degradation), especially on sites with high temperature and relative humidity, and this effect should be monitored.

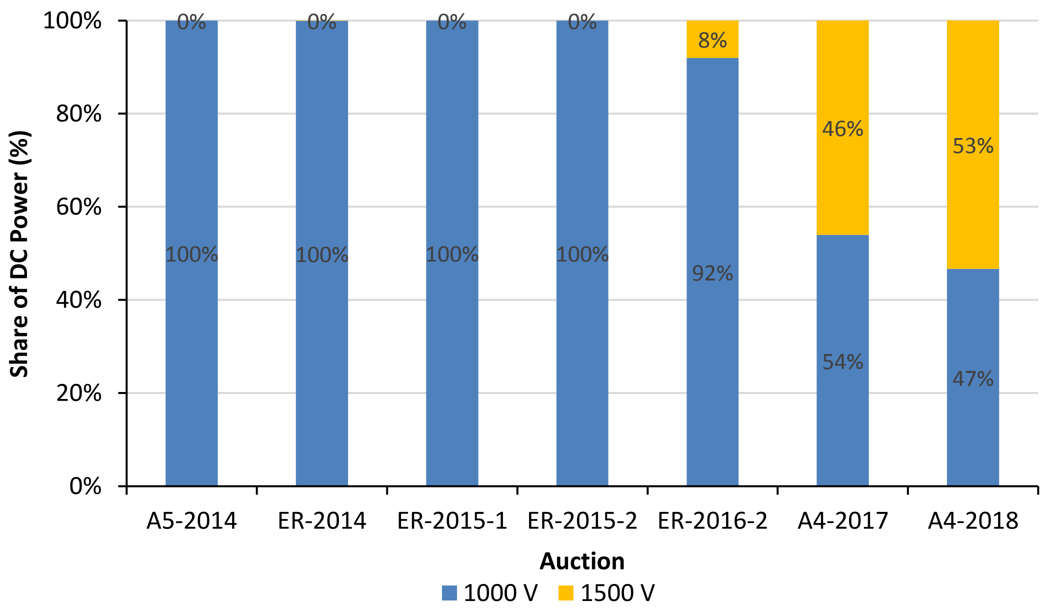


Figure 8 – Share of DC power of qualified projects by maximum voltage

3.2.2 *Inverters*

As on previous auctions, the inverter power for most projects ranged between 1000 kW and 2500 kW. On the A-4/2018 auction, however, there were submitted projects with more diverse inverter powers than on previous competitions. The larger inverter had around 4250 kW, and was used on 4 projects, while the smaller was a string-type inverter, with 48 kW. The use of string-type inverters, instead of the usual central inverters is under discussion on the PV sector, with its advocates claiming advantages as reduction on DC cabling, higher production on rougher terrain or partial shading, since it has more MPPT's, and easiness to replace faulty equipment, and that these attributes would compensate for the higher investment cost. Figure 9 presents the share of projects by inverter size.

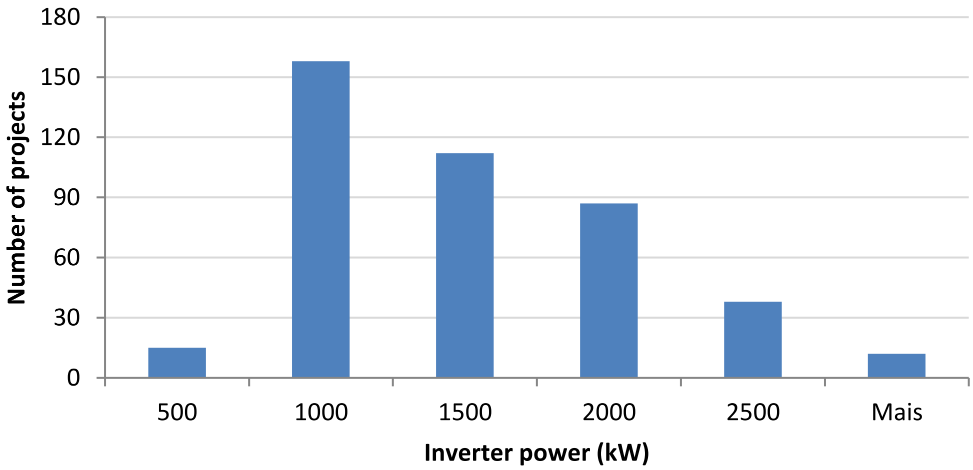


Figure 9 – Inverter power on the A-4/2018 auction

As for the sizing of PV projects, it is a common practice to use a larger DC than AC power. Such strategy is used because the laboratory irradiation and temperature test conditions are rarely verified on operation, and, therefore, the PV modules should not reach their peak power for most of the time. Therefore, the oversizing of the DC array enables a more efficient inverter operation close to its nominal conditions. On most cases, the Qualified Power by EPE is the same as the AC power. On the A-4/2017 and A-4/2018 auctions, that was the case for all qualified projects.

Each project developer chooses, as a project criterion, an inverter sizing factor (ISF), which is the ratio between the AC power and the DC power. The chosen ISF depends on a cost benefit evaluation, since it means, on one hand, lower investment and a better inverter operation, and on the other, the "waste" of a share of the energy provided by the PV modules due to inverter capacity limitation.

Project with an overloaded inverter tend to present a steadier power production during the day, as illustrated by Figure 10, which presents a simulation for the power produced on a sunny winter day, with two different ISF's, fixed 1000 kW inverter and single-axis tracking.

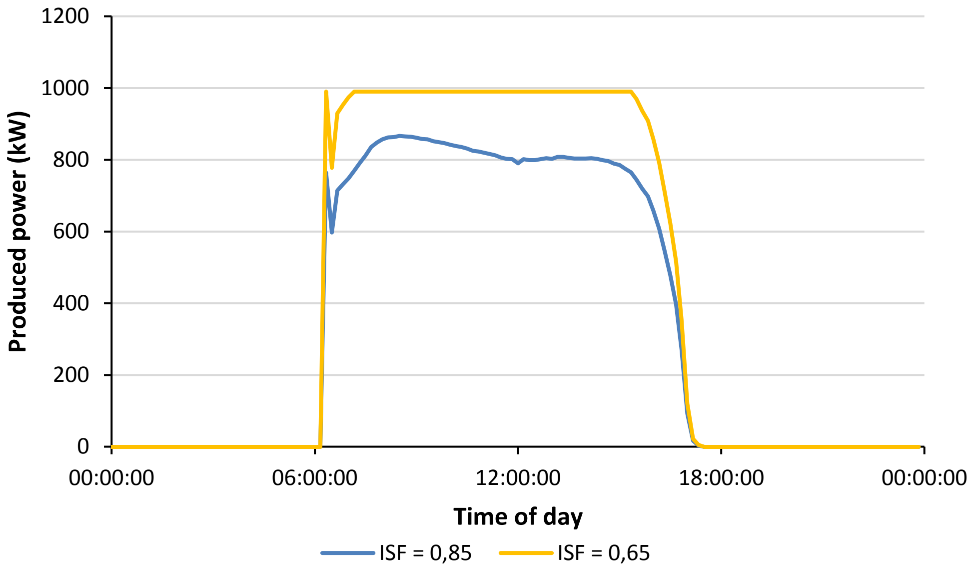


Figure 10 – Inverter overload effect on a sunny day

Moreover, on cloudy days, the variability inherent to the solar resource tends to be attenuated, and some of the fluctuations no longer have effect on the power production. An example of this behavior is presented on Figure 11.

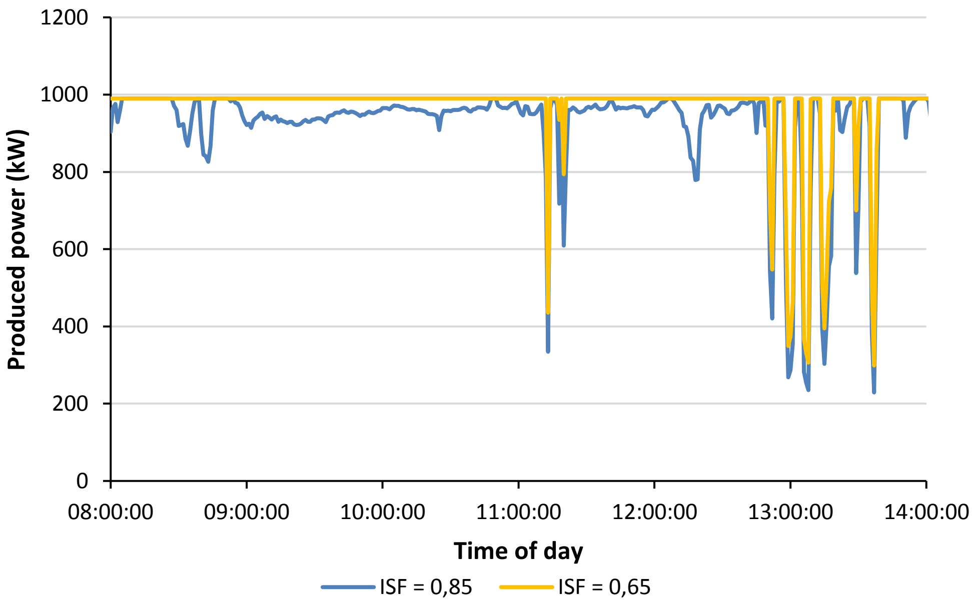


Figure 11 – Inverter overload effect on short-term variability

This inverter overload is becoming higher in recent auctions. Figure 12 exposes this trend, with the mean ISF values in orange, the 1st and 3rd quartiles in the light blue boxes, and the maximum and minimum on the bars. This decrease on ISF may be associated to the drop on the price of PV modules on a faster pace than on the rest of the components, which makes advantageous to install more DC power, even if the curtailment losses on the inverter increase.

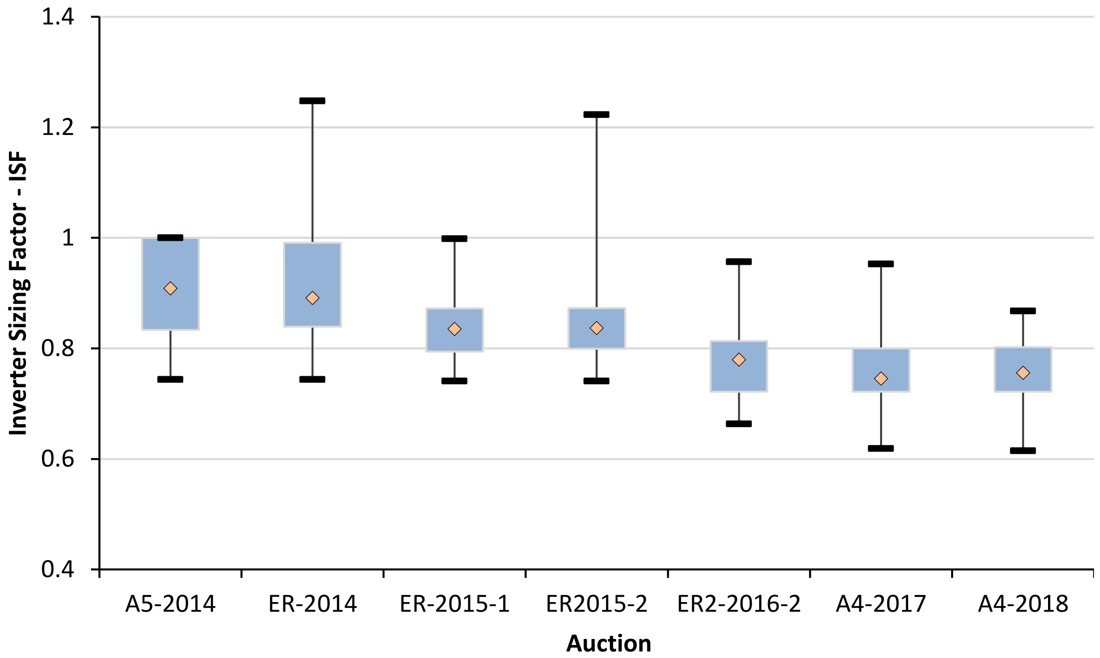


Figure 12 - Historical ISF on auctions

Even though the sizing is a particular technical-economical optimization for each project, there is some discussion on the literature regarding the limitation of this practice. In Bürger and Rüther (2006), for example, it is discussed how the use of hourly simulation on power production estimates may overestimate the benefit of a larger DC power, since this simulations underestimate the moments of high irradiance, and therefore underestimate the curtailment on the inverter.

3.2.3 Mounting structures

The trend of using single-axis tracking, discussed on the previous Technical Note (EPE, 2017), was confirmed. On the A-4/2018 auction, 96% of the qualified projects used this mounting type, versus 97% on the 2017 auction, as shown on Figure 13.

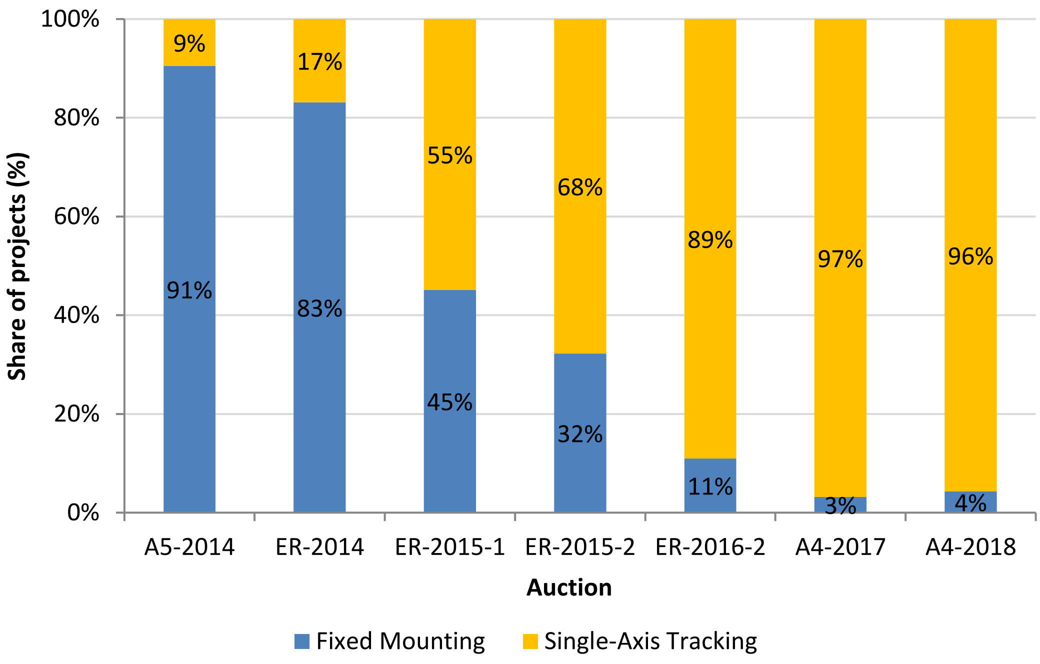


Figure 13 – Share of projects by mounting type

The use of tracking allows better use of the local solar resource for a same installed capacity, increasing the plant capacity factor, as it is discussed on the following chapter.

3.3 Capacity Factor

The capacity factor of a power plant is the ratio, at a given time interval, between the plant energy production and the energy that potentially could be generated if it operated continuously at its rated power. In this document, considering the regulated market rules, the capacity factor is defined as the ratio between the expected energy yield[1] of the power plant, in MWa[2], and its installed capacity, in MW.

In order to allow the comparison with international data and reports (either DC or AC based), the capacity factor is shown in terms of both Qualified Power and DC Power of the projects. As the AC and the Qualified Power are usually lower than the DC Power, AC-based capacity will normally be higher than the DC-based capacity factors.

[1] In accordance with MME Ordinance n. 258/2008, for PV plants the physical guarantee of the project corresponds to the expected energy production in the long-term.

[2] MWa (average megawatt) is an unit of energy and is equivalent to the energy produced by a 1 MW source during a certain period of time. Considering a 20-year supply agreement: 1 MWa = (8.766 hours x 20 years) = 175.320 MWh (megawatt-hour).

Regarding DC Power, the capacity factors of the plants were within the range of 18% to 25% on the A-4/2017 auction, while on the A-4/2018 only the lower value was different, of 19%. As for Qualified Power based capacity factors (on both auctions the qualified power was always equal to the AC Power), on the A-4/2017 they were comprised in the range of 20% to 35%, and in the 24% to 37% range in 2018.

As in previous auctions, projects with single-axis trackers had higher capacity factors than fixed mounting plants. Figure 14 illustrate with a histogram the range of capacity factors for qualified projects on the A-4/2018 auction, with separate colors for fixed-mounted and single-axis tracking projects.

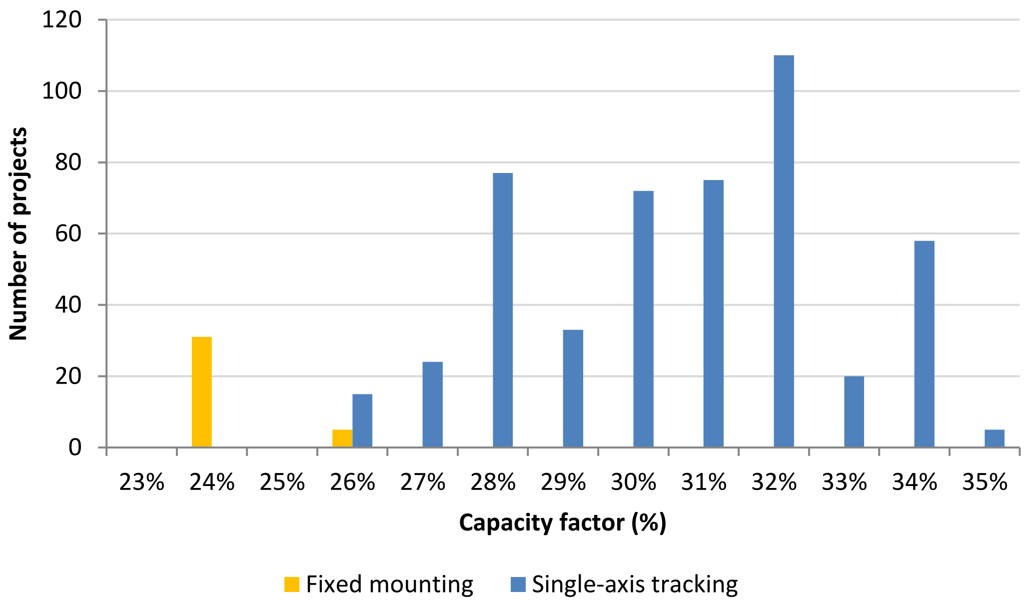


Figure 14 – AC-based capacity factor for qualified projects on the A-4/2018 auction

Figure 14 presents the mean (in orange), maximum and minimum values (bars), and the first and third quartiles of the Qualified Power-based capacity factor, for auctions with PV projects participation since 2014. A significant increase on the mean capacity factor, from 20% in 2014 to 30% in recent projects, and on the quartiles can be noticed. The Figure shows also that since the first auctions, the maximum values always reached the 30% mark, and on the last one it surpassed the 35% level. This historical growth is related mainly to the two reasons discussed previously: a higher inverter overload (lower ISF) and the use of single-axis tracking. The choice of sites with higher irradiation level could also contribute, but, as shown on section 3.1, it did not occur, as the GHI of recent projects is similar to the one on previous auctions.

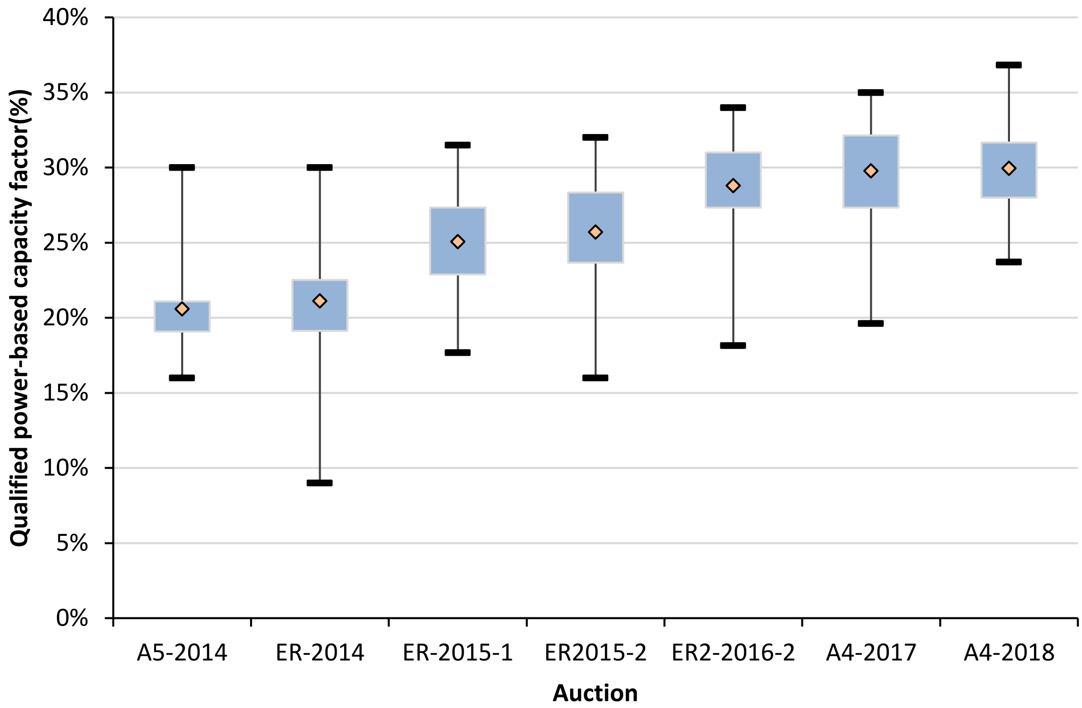


Figure 15 - Historical capacity factor (Qualified Power-based)

3.4 Investment Costs

Even though several international reports show a strong cost reduction on PV projects on recent years, the analysis of the CAPEX that is informed by the project owners regarding their plants indicate mean values approximately constant (in R$/kWp). While on the A-4/2017 auction the mean value was on the same level as in past years, on the A-4/2018 auction there was a reduction of about 14%, as shown on Figure 16.

It shows also that, after a drop on the variability in terms of maximum and minimum values in 2016, the difference between the extreme values has risen significantly. However, the quartiles indicate that the variability in terms of the median 50% projects has decreased by a small amount. It should be emphasized that these investment amounts do not consider interest during construction and are based on the December prior to the year of the auction.

The CAPEX of PV projects is presented usually in R$/kWp, since the PV modules represent the larger share of the cost. However, from the point of view of the electric system, it effective power is its AC power, and therefore in section 3.3 the AC-based capacity factors were presented. For the same reason, it is deemed important to analyze the costs also on AC-based power, and that analysis is presented on Figure 17.

The conclusions are similar to the DC-based cost analysis, but an even higher growth of the maximum values is seen, due to the lower ISF values, meaning larger differences between AC and DC powers, as discussed on chapter 3.2.2.

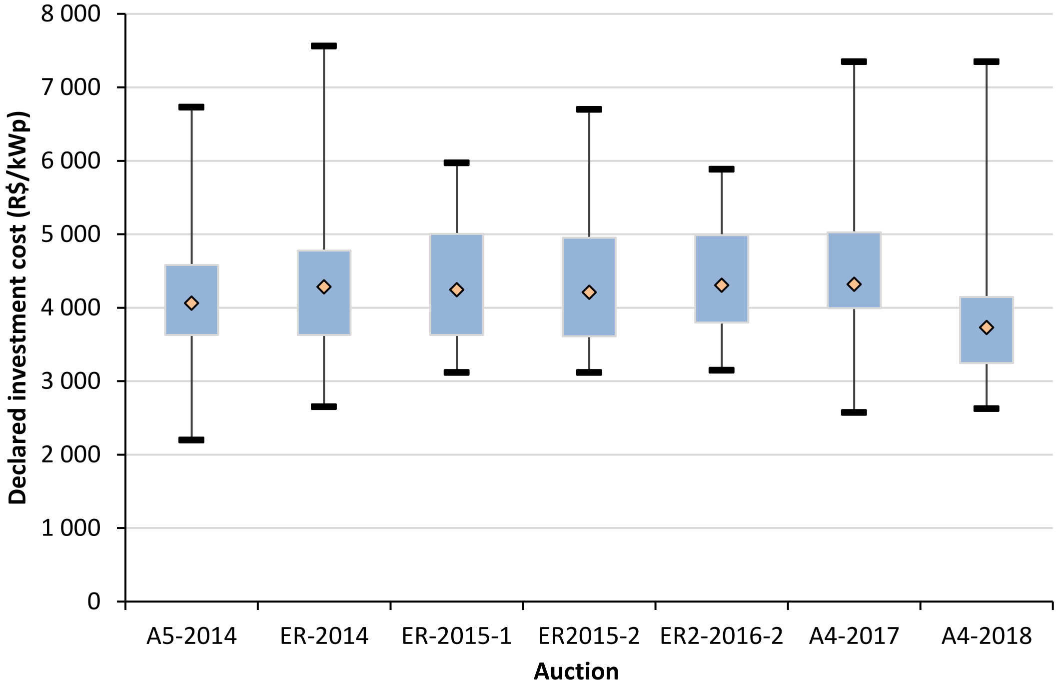


Figure 16 – CAPEX for PV projects in R$/kWp on each auction

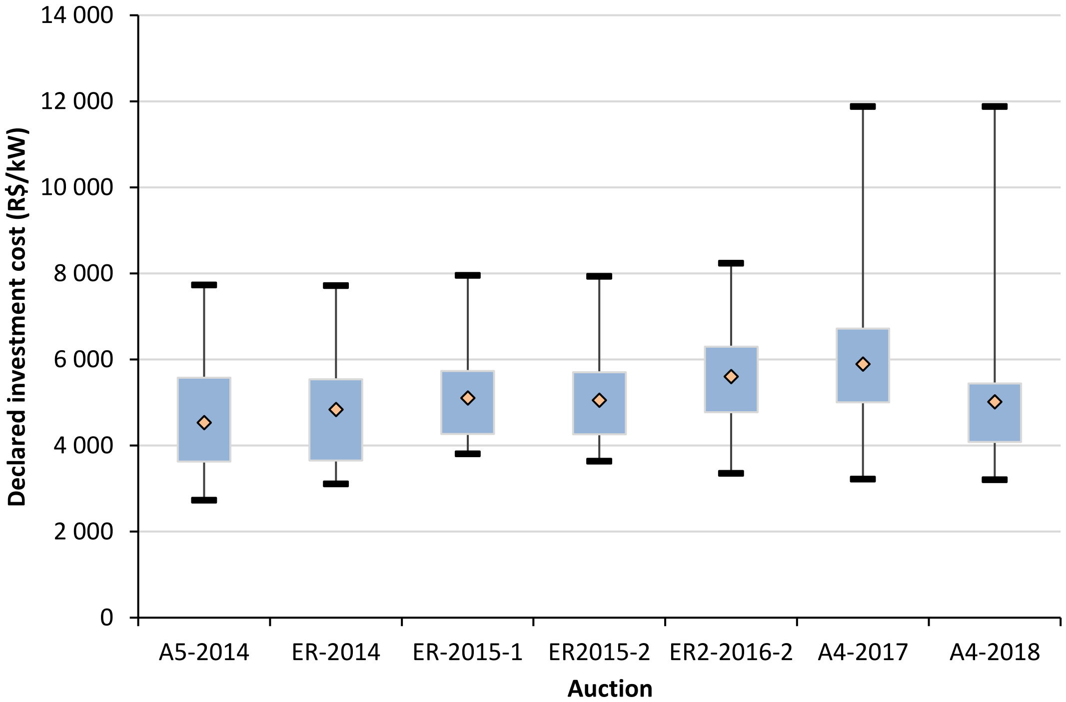


Figure 17 - CAPEX for PV projects in R$/kW on each auction

Another interesting point regarding the declared CAPEX is that it presented only a slight decrease in comparison to previous years, while the price of energy was substantially reduced, as it will be shown in section 4.2. A higher capacity factor contributes to this reduction, since a plant with the same capacity can produce more energy if it has a higher CF. However, the growth in the capacity factor discussed in section 3.3 is not enough to explain this mismatch, since it occurred on much lower level than the drop in prices.

Due to the fact that the CAPEX for PV projects is strongly related to the American Dollar, Figure 18 shows the CAPEX variation in US$/kWp. The declared values, in Brazilian Reais, were converted to US$ using the mean commercial exchange rate for the month of December prior to the respective auction[3]. This analysis show a CAPEX reduction for the last three auctions, in line with international reports.

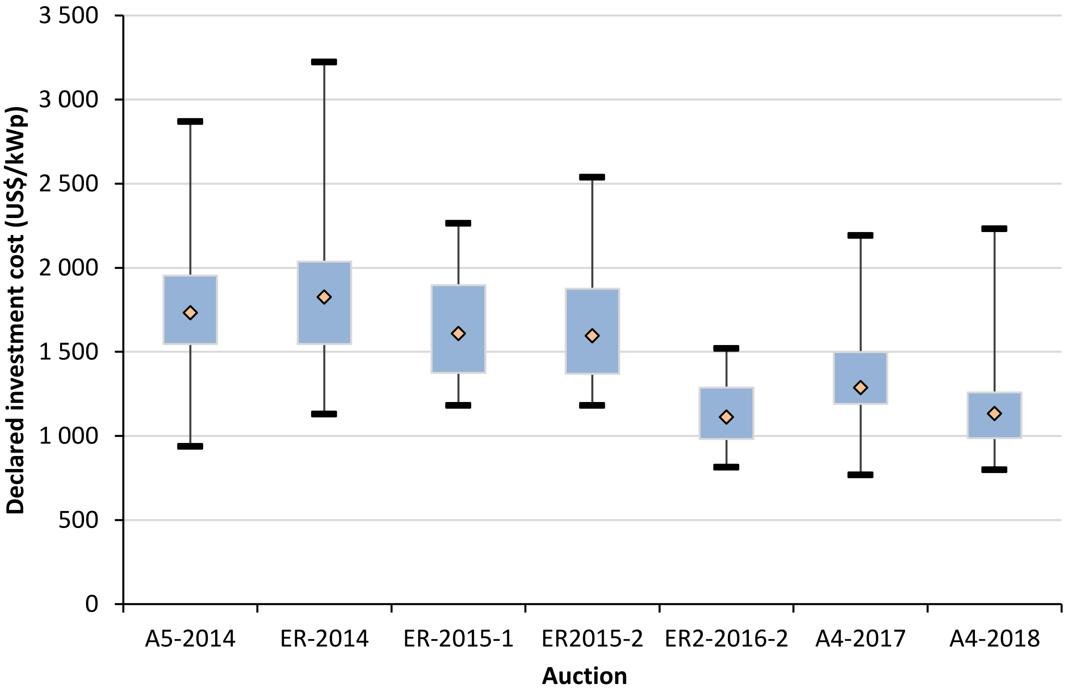


Figure 18 - CAPEX for PV projects in US$/kWp on each auction

In 2016, due to the higher value of the US Dollar in comparison to the Brazilian Real in December of 2015, the values were nominally lower. With a lower US Dollar on following years, the CAPEX in US$/kWp have risen again, but stayed on a lower level than the one from the auctions before 2016.

[3] Exchange rates for the month of December prior to the auctions 2014, 2015 e 2016, 2017 e 2018 in BRL to USD, respectively: R$ 2.3455; 2.6394; 3.8711; 3.3523 and 3.2919/US$. Source: http://www.ipeadata.gov.br (comercial exchange rate for sale – monthly mean).

The larger share of costs is equipment, which historically responds for around 70% of the CAPEX, with some fluctuation. The transmission and connection costs, and the construction costs also represent important shares, as shown on Figure 19. The cost identified as other includes several costs, as: land, socio-environmental compensation, indirect costs, logistics, mounting, tests and insurance.

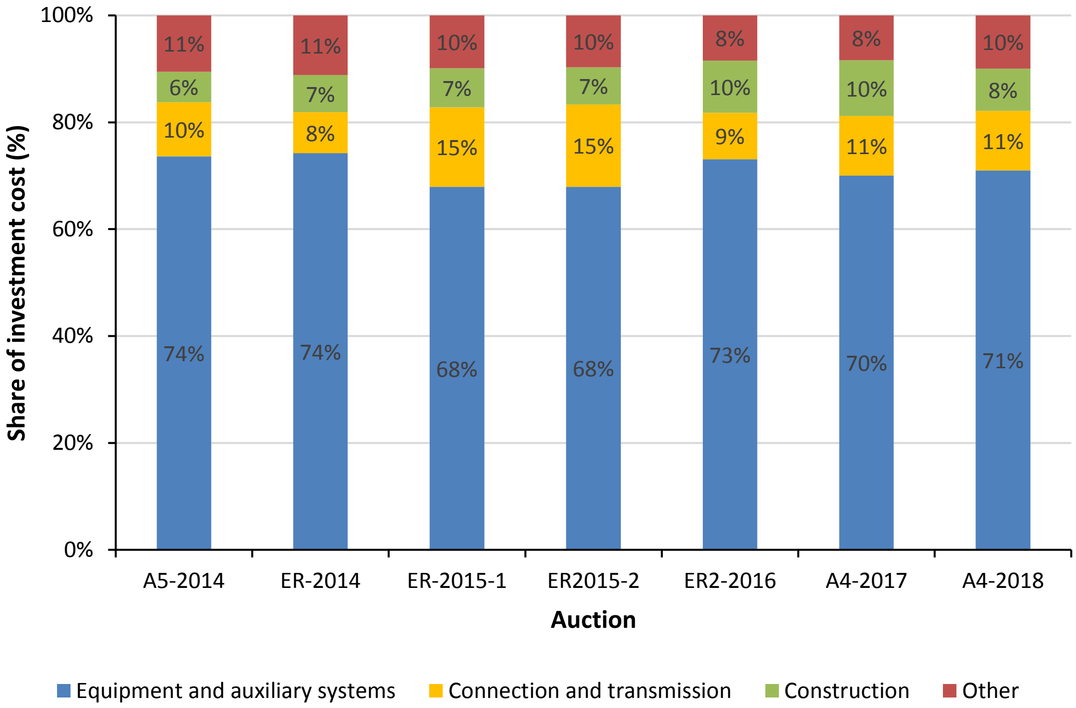


Figure 19 – Share of costs on total investment

Since 2016, EPE requires the equipment cost to be detailed in PV Modules, Inverters, Mounting Structures (including trackers) and Others. Figure 20 shows a slight decrease on the share of module costs, with an increase of Others, which includes cabling, junction boxes, protection equipment, SCADA, among others. Another highlight is the mounting structure and tracker costs, which has been higher than the cost of inverters.

Therefore, the CAPEX decrease is mainly due to the drop on the price of PV modules. Figure 21, Figure 22, and Figure 23 present respectively the declared CAPEX for modules, inverters and mounting structures. It is clear that there is a trend of decrease for the PV modules, while the mounting structures had only a slight decrease in 2018. As for inverters, the costs stayed relatively stable on the 3 auctions. PV modules and mounting structure costs are DC-based, since they are directly related to the DC-power, while inverters costs are AC-based.

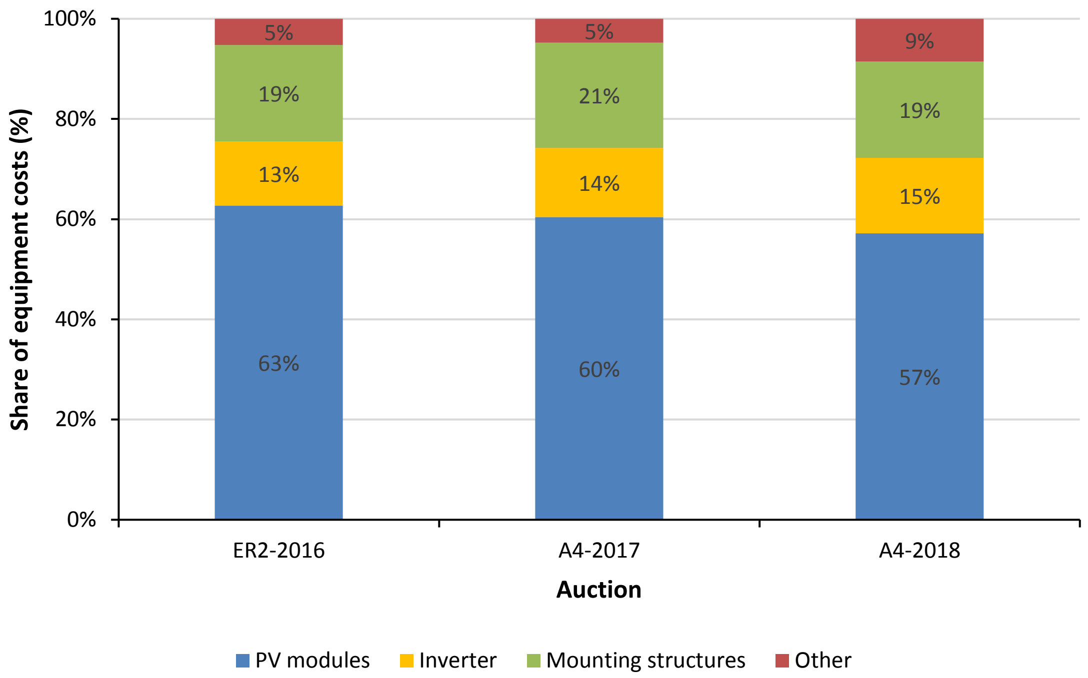


Figure 20 – Share of each component on equipment cost

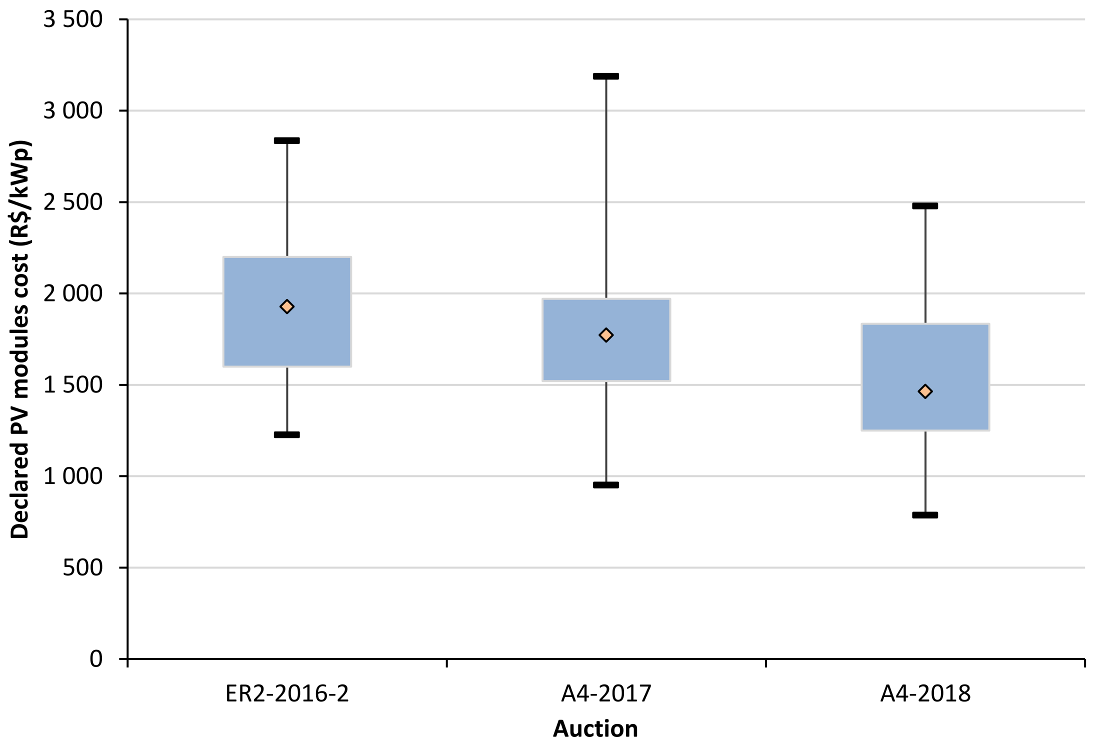


Figure 21 – Declared cost for PV modules (R$/kWp)

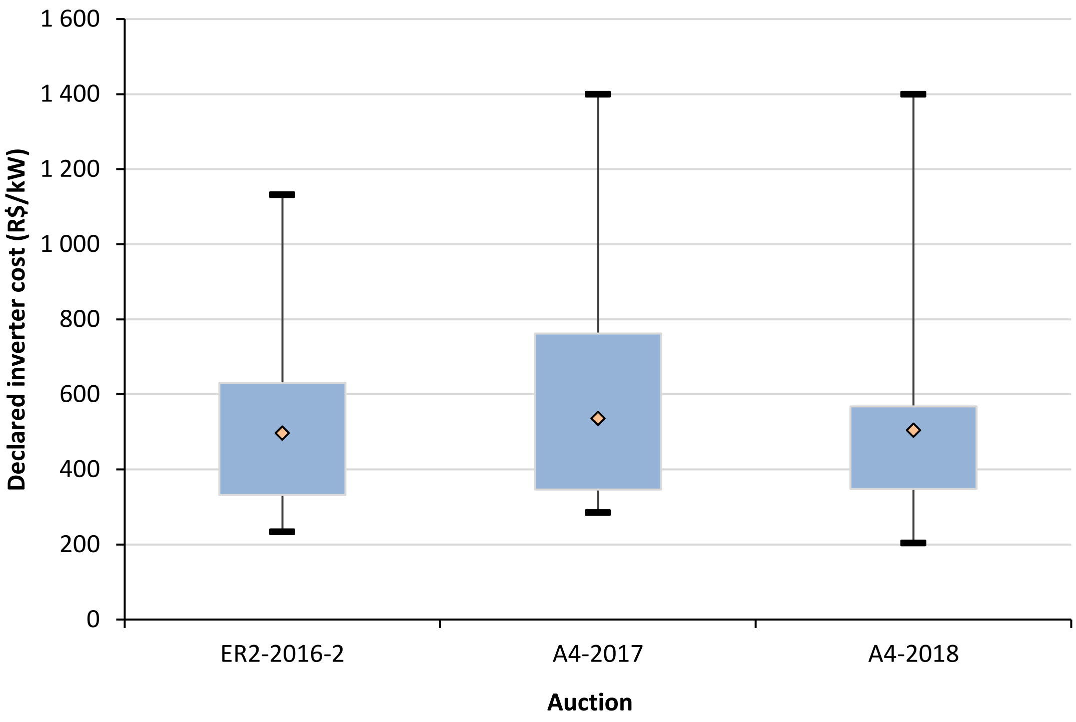


Figure 22 – Declared cost for Inverters (R$/kW)

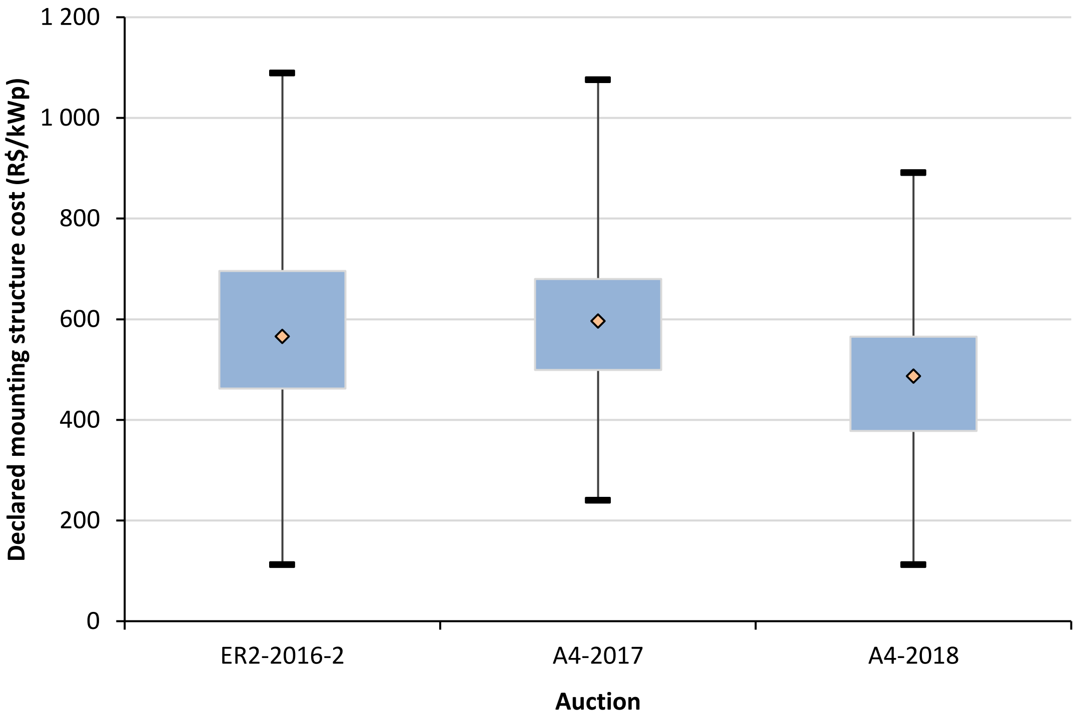


Figure 23 – Declared costs for structure and trackers

The figures show also a large dispersion on the declared values. During the analysis, EPE requests ratification or revision for the declared costs that are farther from the usual values, in order to have the correct values for the projects and to maintain the consistency of the database. In several cases, project owners correct the values, since typing errors are also common on the submission process. However, except for large differences (in orders of magnitude), the declared and ratified values are kept, since the project owners are the responsible for the informed data.

4. CONTRACTED PROJECTS

This chapter presents a summary of information regarding the contracted projects on the New Energy Auctions A-4/2017 and A-4/2018. Following, some relevant characteristics are commented, and finally the selling prices are evaluated in comparison with the contracting history, discussing possible causes for the strong decrease.

4.1 Summary of information

On the sum of both auctions, 398.7 MWh of energy were contracted, of 413.1 MWh available from the contracted projects. This represents 96.5% of contracting for the regulated market, while 3.5% of the energy remains uncontracted.

Table 5 and Table 6 present, respectively, projects that sold energy on the A-4/2017 and A-4/2018 auctions, aggregating the main information regarding these projects.

Appendix II presents the map with the location of the contracted projects, with plant capacities aggregated by city, including also the projects contracted on previous regulated market auctions.

Table 5 – Contracted projects on the A-4/2017 auction

Project	State	DC Power (kWp)	AC Power (kW)	ISF	Physical Guarantee (MWa)	AC-based capacity factor (%)	Contracted energy (MWa)	Mounting structure type	PV Module technology	Connection type	Total declared cost (R$x10^3)	Energy price (R$/MWh)
Água Vermelha IV	SP	18748	15000	0.80	4.0	26.7%	4.0	Single-axis tracking	Polycrystalline silicon	OTF	87 173.01	145.49
Água Vermelha V	SP	37498	30000	0.80	7.9	26.3%	7.9	Single-axis tracking	Polycrystalline silicon	OTF	174 346.01	145.49
Água Vermelha VI	SP	37498	30000	0.80	7.9	26.3%	7.9	Single-axis tracking	Polycrystalline silicon	OTF	174 346.01	146.66
BRIGIDA	PE	37417	27000	0.72	8.9	33.0%	8.9	Single-axis tracking	Polycrystalline silicon	Distribution	190 470.79	144.90
BRIGIDA 2	PE	41571	30000	0.72	8.9	29.7%	8.9	Single-axis tracking	Polycrystalline silicon	Distribution	212 700.77	143.60
SÃO GONÇALO 1	PI	48478	30000	0.62	10.2	34.0%	9.9	Single-axis tracking	Polycrystalline silicon	Basic Grid	243 678.80	146.67
SÃO GONÇALO 10	PI	48478	30000	0.62	10.2	34.0%	9.9	Single-axis tracking	Polycrystalline silicon	Basic Grid	243 678.80	145.50
SÃO GONÇALO 2	PI	48478	30000	0.62	10.2	34.0%	9.9	Single-axis tracking	Polycrystalline silicon	Basic Grid	243 678.80	146.67
SÃO GONÇALO 21	PI	48478	30000	0.62	10.2	34.0%	9.9	Single-axis tracking	Polycrystalline silicon	Basic Grid	243 678.80	145.99
SÃO GONÇALO 22	PI	48478	30000	0.62	10.2	34.0%	9.9	Single-axis tracking	Polycrystalline silicon	Basic Grid	243 678.80	145.00
SÃO GONÇALO 3	PI	48478	30000	0.62	10.2	34.0%	9.9	Single-axis tracking	Polycrystalline silicon	Basic Grid	243 678.80	146.67
SÃO GONÇALO 4	PI	48478	30000	0.62	10.2	34.0%	9.9	Single-axis tracking	Polycrystalline silicon	Basic Grid	243 678.80	146.67
SÃO GONÇALO 5	PI	48478	30000	0.62	10.2	34.0%	9.9	Single-axis tracking	Polycrystalline silicon	Basic Grid	243 678.80	146.67
Sertão Solar Barreiras I	BA	29388	28000	0.95	6.8	24.3%	6.8	Single-axis tracking	Polycrystalline silicon	Basic Grid	154 652.00	143.50
Sertão Solar Barreiras II	BA	29388	28000	0.95	6.8	24.3%	6.8	Single-axis tracking	Polycrystalline silicon	Basic Grid	154 652.00	143.50
Sertão Solar Barreiras III	BA	29388	28000	0.95	6.8	24.3%	6.8	Single-axis tracking	Polycrystalline silicon	Basic Grid	154 652.00	146.60

Sertão Solar Barreiras IV	BA	29388	28000	0.95	6.8	24.3%	6.8	Single-axis tracking	Polycrystalline silicon	Basic Grid	154 652.00	146.60
Solar Salgueiro	PE	37498	30000	0.80	8.6	28.7%	8.6	Single-axis tracking	Polycrystalline silicon	Distribution	149 000.00	143.70
Solar Salgueiro II	PE	37498	30000	0.80	8.8	29.3%	8.8	Single-axis tracking	Polycrystalline silicon	Distribution	149 000.00	145.98
Solar Salgueiro III	PE	37498	30000	0.80	8.8	29.3%	8.8	Single-axis tracking	Polycrystalline silicon	Distribution	149 000.00	146.66

Table 6 – Contracted projects on the A-4/2018 auction

Project	State	DC Power (kWp)	AC Power (kW)	ISF	Physical Guarantee (MWa)	AC-based capacity factor (%)	Contracted energy (MWa)	Mounting structure type	PV Module technology	Connection type	Total declared cost (R$x10^3)	Energy price (R$/MWh)
ALEX I	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	146 000.00	118.00
ALEX III	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	137 500.00	118.00
ALEX IV	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	137 500.00	118.00
ALEX IX	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	137 500.00	118.39
ALEX V	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	137 500.00	118.00
ALEX VI	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	137 500.00	118.00
ALEX VII	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	137 500.00	118.39
ALEX VIII	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	137 500.00	118.25
ALEX X	CE	41 796	30 000	0.72	10.2	34.0%	10.0	Single-axis tracking	Monocrystalline silicon	Basic Grid	137 500.00	118.39
ETESA 17 São João do Piauí I	PI	34 848	29 976	0.86	8.4	28.0%	6.7	Single-axis tracking	Polycrystalline silicon	Basic Grid	169 885.00	117.80

ETESA 18 São João do Piauí II	PI	34 848	29 976	0.86	8.4	28.0%	6.7	Single-axis tracking	Polycrystalline silicon	Basic Grid	169 885.00	117.80
ETESA 19 São João do Piauí III	PI	34 848	29 976	0.86	8.4	28.0%	6.7	Single-axis tracking	Polycrystalline silicon	Basic Grid	169 885.00	117.80
ETESA 20 São João do Piauí IV	PI	34 848	29 976	0.86	8.4	28.0%	6.7	Single-axis tracking	Polycrystalline silicon	Basic Grid	169 885.00	117.80
ETESA 21 São João do Piauí V	PI	34 848	29 976	0.86	8.4	28.0%	6.7	Single-axis tracking	Polycrystalline silicon	Basic Grid	169 885.00	117.80
ETESA 22 São João do Piauí VI	PI	34 848	29 976	0.86	8.4	28.0%	6.7	Single-axis tracking	Polycrystalline silicon	Basic Grid	169 885.00	117.80
FRANCISCO SÁ 1	MG	40 734	30 000	0.74	9.1	30.3%	9.1	Single-axis tracking	Polycrystalline silicon	Distribution	131 323.43	117.91
FRANCISCO SÁ 2	MG	40 734	30 000	0.74	9.1	30.3%	9.1	Single-axis tracking	Polycrystalline silicon	Distribution	131 323.43	118.35
FRANCISCO SÁ 3	MG	40 734	30 000	0.74	9.1	30.3%	9.1	Single-axis tracking	Polycrystalline silicon	Distribution	131 323.43	118.35
LAVRAS 1	CE	28 944	24 000	0.83	6.2	25.8%	6.2	Single-axis tracking	Polycrystalline silicon	Basic Grid	171 967.15	118.01
LAVRAS 2	CE	28 944	24 000	0.83	6.2	25.8%	6.2	Single-axis tracking	Polycrystalline silicon	Basic Grid	171 967.15	118.01
LAVRAS 3	CE	28 944	24 000	0.83	6.2	25.8%	6.2	Single-axis tracking	Polycrystalline silicon	Basic Grid	171 967.15	118.01
LAVRAS 4	CE	28 944	24 000	0.83	6.2	25.8%	6.2	Single-axis tracking	Polycrystalline silicon	Basic Grid	171 967.15	118.01
LAVRAS 5	CE	28 944	24 000	0.83	6.2	25.8%	6.2	Single-axis tracking	Polycrystalline silicon	Basic Grid	171 967.15	118.01
São Pedro e Paulo I	PE	30 225	25 000	0.83	6.7	26.8%	6.7	Single-axis tracking	Polycrystalline silicon	Distribution	125 911.25	117.63
SÃO PEDRO E PAULO V	PE	26 434	20 952	0.79	5.5	26.3%	5.5	Single-axis tracking	Polycrystalline silicon	Distribution	105 523.70	118.23
SÃO PEDRO E PAULO VI	PE	26 434	20 952	0.79	5.5	26.3%	5.5	Single-axis tracking	Polycrystalline silicon	Distribution	105 523.70	117.63
SOLAR JAÍBA 3	MG	36 480	29 940	0.82	8.4	28.1%	8.4	Single-axis tracking	Polycrystalline silicon	Distribution	160 381.25	118.40
SOLAR JAÍBA 4	MG	36 480	29 940	0.82	8.4	28.1%	8.4	Single-axis tracking	Polycrystalline silicon	Distribution	160 381.25	118.40
SOLAR JAÍBA 9	MG	24 320	20 000	0.82	5.5	27.5%	5.5	Single-axis tracking	Polycrystalline silicon	Distribution	106 920.83	117.81

All the contracted projects use single-axis tracking, confirming its dominance over fixed-mounting projects. Polycrystalline silicon also dominated, with 100% of the contracted projects in 2017 and 69% of the number of projects in 2018, while the remaining 31% used monocrystalline silicon. The ISF reduction trend was also reflected on the contracted projects, with minimum values of 0.62 in 2017 and 0.72 in 2018. As for the mean ISF's, in 2017 the value was 0.78, and in 2018 it was 0.72. Therefore, the capacity factors were also high, with means of 30.1% in 2017 and 29.8% in 2018, and maximum of 34.0% on both auctions.

Appendix II presents the map with the location of contracted projects, with powers aggregated by city, and includes also the contracted projects on previous regulated market auctions.

4.2 Energy price

The greatest highlight of the A-4/2017 and the A-4/2018 auctions were the energy prices, substantially lower than on previous auctions. Table 7 indicates the contracted quantities and energy prices on each auction that bought PV projects energy, as well as the cap-price on each competition.

Table 7 – Contracted quantities and Energy prices on each auction

Auction	Contracted projects	Contracted power (MW)	Cap-price (R$/MWh)	Mean energy price (auction day) (R$/MWh)	Mean price (corrected)[4] (R$/MWh)
LER/2014	31	890	262.0	215.1	272.5
1º LER/2015	30	834	349.0	301.79	351.85
2º LER/2015	33	929	381.0	297.75	341.72
A-4/2017	20	574	329.0	145.7	150.5
A-4/2018	29	807	312.0	118.1	120.6

In nominal terms, the mean prices on the last two A-4 auctions were lower than half the ones of the 2015 auctions. Correcting with IPCA (Brazilian inflation rate), the mean 2018 price was around 1/3 of the one with the highest price auction, the 1st LER in 2015. Figure 24 summarizes this information.

[4] Corrected by the IPCA index to August of 2018.

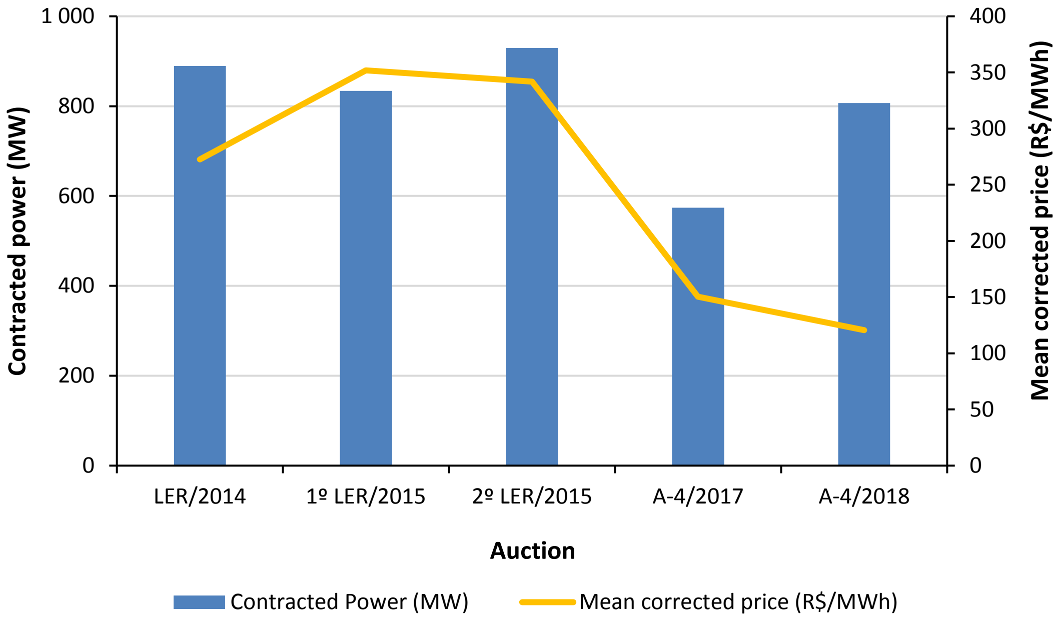


Figure 24 – Contracted power and mean price on each auction

The price reduction relates to the reduction on CAPEX and the increase on the capacity factor of the plants, discussed on chapters 3.4 and 3.3. Other factors that may contribute are: a better national conjuncture, leading to lower interest rates by the time of the A-4/2017 and A-4/2018 auctions in comparison with the 2015 auctions, the strong competition, with supply much higher than demand, new financing strategies by the project owners, and a certain "bet" in a higher cost reduction before the energy supply deadline.

5. FINAL REMARKS

After six years with PV projects, there was a constant evolution on the submitted projects. Among the trends, two highlights are the use of single-axis tracking, and the decrease of the AC/DC ratio, resulting on higher inverter loads. Both these practices increase the plants' capacity factors, and lead to a more constant energy generation during the day. As for the solar resource on the projects' sites, there was not much variation, just the decrease of the variation of the extreme values, which indicate that there was not much change on plant location during this time.

The declared costs presented a slight drop, mainly on the last auction. The magnitude of this reduction was small in Brazilian Reais, being closer to international trends when analyzed in American Dollars. Among the detailed costs, the only component that presented clear trend of reduction were the PV modules, while the declared inverter and mounting structure costs stayed in similar levels (per kWp/kW) on the three auctions for which this information is available.

The energy prices, however, were significantly lower on the last two A-4 auctions, 2017 and 2018, in comparison to previous contracting. This reduction is a reflex of both the factors discussed before, lower CAPEX and higher capacity factors, as well as the high competition, the economic conjuncture and financial aspects.

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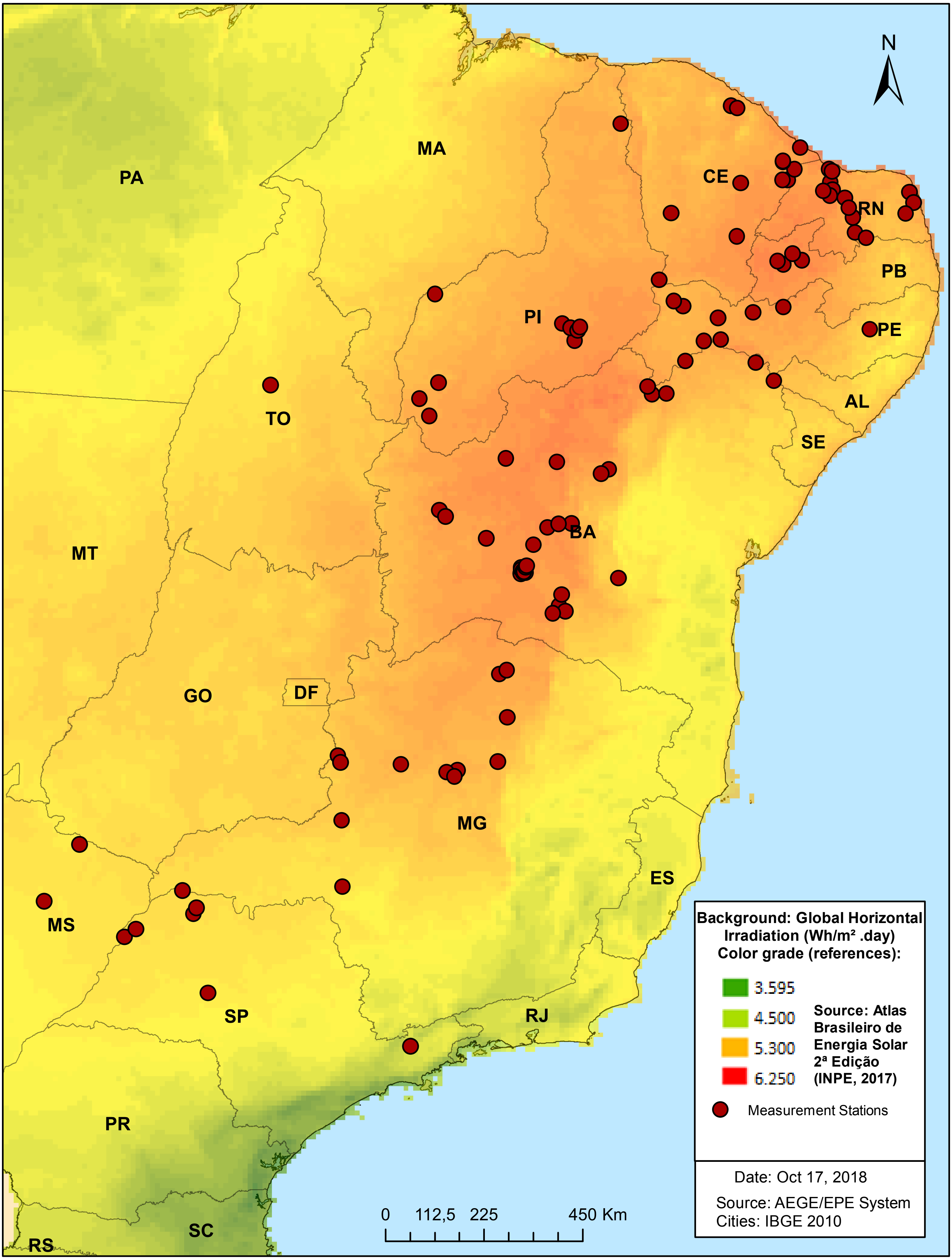
EPE-DEE-NT-091/2018-r0
APPENDIX I

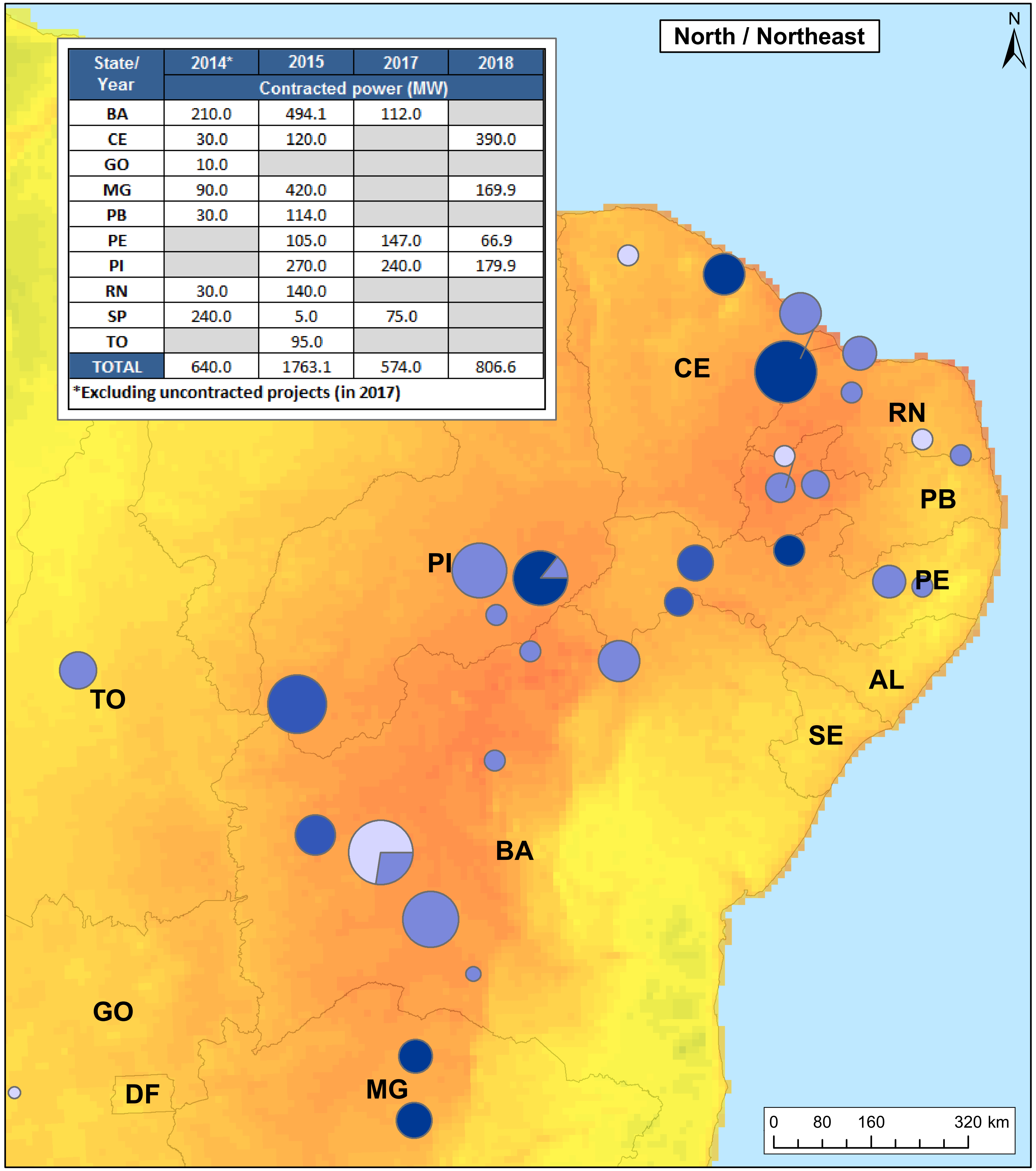
Solar Resource Measurement Stations installed to comply with energy auctions requirements



EPE-DEE-NT-091/2018-r0
APPENDIX II

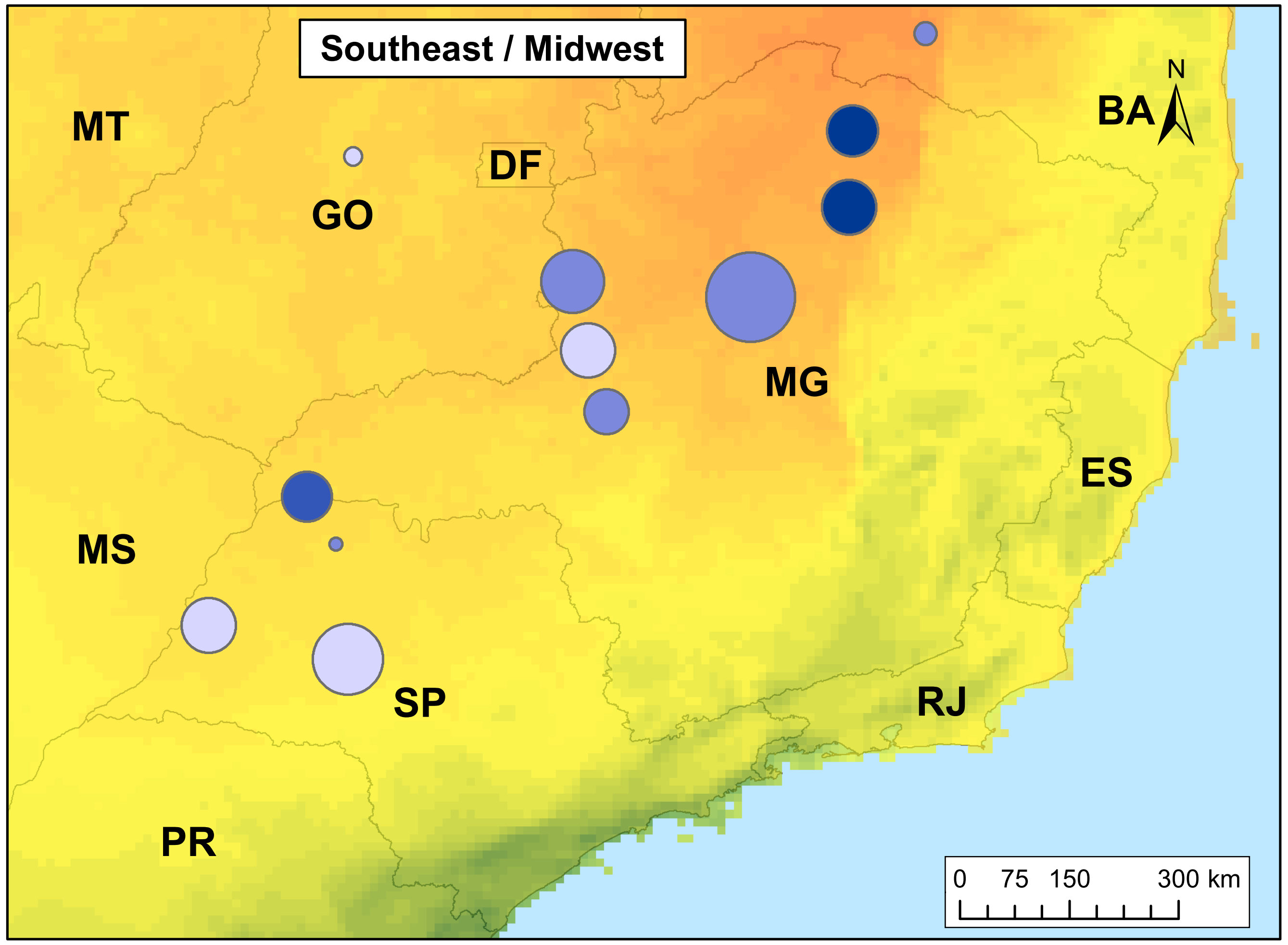
Contracted Photovoltaic Power Plants in Energy Auctions
(Sum of Installed Capacity by city)

Empresa de Pesquisa Energética



State/ Year	2014*	2015	2017	2018
	Contracted power (MW)			
BA	210.0	494.1	112.0	
CE	30.0	120.0		390.0
GO	10.0			
MG	90.0	420.0		169.9
PB	30.0	114.0		
PE		105.0	147.0	66.9
PI		270.0	240.0	179.9
RN	30.0	140.0		
SP	240.0	5.0	75.0	
TO		95.0		
TOTAL	640.0	1763.1	574.0	806.6

*Excluding uncontracted projects (in 2017)



Contracted Power Sum of Installed Capacity by city (MW)

200.

2014

2015

2017

2018

Background: Global Horizontal Irradiation (Wh/m² .day)

Color grade (references):

3.595

4.500

5.300

6.250

Source: Atlas Brasileiro de Energia Solar (INPE, 2017)

Date: Oct 17th, 2018

Source: AEGE/EPE System

Cities: IBGE 2010