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RESEARCH ARTICLE

The Accuracy of PV Power Plant Scheduling in Europe: An Overview of ENTSO-E Countries

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ABSTRACT The dynamic increase of Europe's installed photovoltaic capacities does not leave any of the stakeholders of the electricity industry unaffected. One of the effects of the inevitable uncertainty of solar power generation, due to solar energy's variable nature, is the increasing significance of the provision of reliable power generation forecasts to make the integration and operation of grid systems including photovoltaic power plants possible, as well as to facilitate the related processes of decision making and planning. This study presents the accuracy of the daily and the intraday scheduling of energy generation in the PV systems of the member countries of the European Network of Transmission System Operators (ENTSO-E) in the period 2013 – 2022. The examined countries showed great variation regarding the accuracy of the scheduling of their PV power plants. Overall, it could be established that Germany and Spain were capable of producing more precise forecasts than the other nations in the study. In their case, the annual downward and upward regulatory needs, as percentages of the yearly energy generation, ranged between 5.6% and 2.3% for the daily, and from 6.1% to 2.6% for the intraday forecasts. In some countries the forecasts demonstrated less accuracy, e.g. in Estonia the annual need for downward regulation nearly reached 47% of the energy generated in 2020, while in Switzerland the yearly need for upward regulation exceeded 42% of the produced power in 2018. The novel, practical contribution of the research presented in this paper is that it determines and presents information related to the accuracy of the ENTSO-E countries' day-ahead and intraday PV forecasting activities that are relevant from a practical perspective to the transmission system operators (TSOs), the main actors of the energy market as well as the decision makers. Furthermore, this information is of help for investors investing in PV power plants not only from an economic perspective, but it may also significantly contribute to the market-related development of the management systems of energy storage solutions related to PV technology.

INDEX TERMS Solar energy, solar power forecasting, value of forecasting, PV grid integration.

I. INTRODUCTION

The introduction presents the subject matter of this study concentrating on five main topics, covering the global importance of variable renewable energy sources (VRES), the challenges of integrating VRES into the grid, the importance of energy storage in VRES integration, a brief overview of the electricity market and the related presentation of the electricity markets of European nations, and finally the challenges related to PV power forecasting.

First of all, it is necessary to briefly describe the significance that VRES have gained due to global processes and developments. Global warming, the process of the rise of average temperatures on Earth [1], is indisputably connected to Greenhouse Gases (GHG), among which carbon dioxide is the most significant [2]. As human activities, especially the burning of fossil fuels, are responsible for much of the GHG emissions [3], which drive the warming of the planet [2], human efforts to decrease these emissions is the key to

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combating climate change [4]. The Paris Agreement states that, instead of continuing to use fossil fuels, renewable sources of energy should be deployed as an alternative in order to prevent the rise in global average temperatures from reaching 2 °C [5]. The decarbonization efforts, of course, need to involve the fundamental reformation of the world's electricity systems [6], which, undoubtedly, requires a much greater proportion of renewable energy in the global electricity mix [7].

This trend of increasingly relying on renewable energy sources, however, has to overcome numerous challenges. A major inhibiting factor is the current power system itself, since it was designed as a vertical structure to serve a network consisting of facilities of centralized electricity generation and a vast transmission grid to supply the consumers with electric energy [8]. The renewable sources of energy that depend on weather and climate show great variation in both time and space [9], which makes their integration into the energy system difficult. Thus, in order to include a higher proportion of variable renewable energy (VRE) in the energy mix, the current energy systems must become significantly more flexible [10].

In spite of the great significance that VRES have in the process of energy transition, it needs to be noted that their integration in the energy networks poses great challenges. Various measures to promote the spread of variable renewable energy sources (VRES) in many countries, together with the decreasing costs of the technologies associated with them, have led to a dynamic increase in the deployment of solar and wind power around the world. This development, however, poses great challenges to the conventional design and operation of energy systems [11], which also means that it is becoming increasingly problematic to balance the supply of, and demand for electric power because of the variability of energy generation and the related geographical limitations [12]. While in the case of lower shares of VRES, the renewable energy produced is typically consumed directly upon its generation, in systems with high VRE proportions considerable imbalances may occur between energy production and demand, due to overproduction in more favorable weather and shortages of power under unfavorable weather conditions or increased demand. In the case of inadequate VRE generation, it is imperative that dispatchable generation or other flexibility solutions have to be immediately available [13] to make up for deficit [14].

An effective way to deal with the inherent uncertainties of VRE deployment is the forecasting of energy generation to facilitate the design, operation and planning activities connected to energy systems [15]. Nevertheless, the provision of accurate renewable energy forecasts is a difficult thing to do even today, because intermittent renewable energy is highly variable and hard to predict [16]. The issue is complicated even further by the fact that different renewable energy sources are characterized by different patterns of power generation, so they have their own typical problems in terms of balancing demand and supply, and integration into the grid. As PV power generation depends on the quantity of solar irradiation absorbed by the solar cells, it fundamentally follows the natural cycle of the changing seasons and that of day and night. Nevertheless, actual irradiation is also a function of a wide range of weather-related phenomena, such as cloud conditions and precipitation, which may demonstrate a high level of irregularity. In PV energy generation integration, the problem of balancing is not caused by the issue of predictability in itself but by scheduling power production. While solar irradiation and, consequently, PV power generation generally reach their highest levels around noon, residential customers' demand for electricity is normally greatest after sundown, which results in a discrepancy between supply and demand. The situation of wind power is, of course, rather different. On the one hand, the role of annual and daily rhythms is less important, while wind speed may show considerable variations within short periods of time, on the other hand, making the forecasting of power generation by wind turbines challenging [17].

The spread of VRES and the challenges associated with it have led to a range of various solutions, such as market adjustment, regulations on feeding power into the grid, grid developments, and innovative tools for demand and supply forecasting [18]. These responses, however, are only sufficient in the case of comparatively low VRES penetration and slower changes in the supply infrastructure, as they are mere reactions at the levels of TSOs and distribution system operators (DSOs), mostly involving provisioning. Structural solutions that are adequate to handle a high penetration of decentralized energy generation from VRES require a complex approach, the extent and methods of which are still being hotly debated, as it involves modifying policies, integrating systems, and cooperation between prosumers, DSOs and TSOs [19], [20]. The reformation of policy coordination is all the more pressing, since threats to system operation, e.g. capacity constraints and grid congestion, do occasionally occur [17], [21]. Another shortcoming in policymaking is that the micro and/or meso-levels rarely receive due attention. Although, at present, VRES deployment is more common at the macro-level, it does not mean that VRES balancing issues are not encountered at the lower levels too. Thus, all three levels need to be equally considered during the process of developing structural solutions to the issues of grid balancing [17].

Studying the present and potential role of VRES and the issues related to its integration naturally leads to the subject of energy storage, which can be significant for solving these problems. It follows from the above that a growing decentralized VRES penetration calls for considerable changes not only to the network but also to the manner it is used if the operational parameters of the grid are to be kept between the appropriate limits. The present practice to achieve this mostly involves limiting power generation to prevent excess electricity, and using dispatchable (non-renewable) reserves to avoid shortages [22], [23]. However, these two alternative actions may not be enough to manage systems with increasingly high shares of energy from VRES. In the future, the need for sufficient buffering potential may be met by the deployment of electrical energy storage (EES), according to many [24]. Nevertheless, the use of EES also has its constraints. It cannot handle all imbalances between power supply and demand. Moreover, how useful and effective its deployment is may greatly depend on various conditions, which at present do not seem to allow EES to be considered a universal solution to all imbalance problems. A policy for successful energy transition requires more in-depth knowledge of how and to what extent EES can be utilized to facilitate VRE integration [17].

Neither the present study, nor its subject matter can be meaningful without understanding the context of the electric energy market, in general, and the electricity market of European nations, in particular. In the sophisticated system of the electricity market, the total amount of energy supplied by the producers must meet an ever-changing load from the consumption side at any given moment. It is in the daily market where electricity exchanges are carried out first. The sellers and buyers have to make bids before the gate closure time for the next delivery period. The parties are responsible for any breach of the resulting contract financially. Some electricity pools also have intraday (ID) markets to allow corrective actions. System operators manage the so-called regulation markets to guarantee the balance of consumption and production in real time. Rapid changes in load and unexpected generation capacity problems are dealt with by system operators using reserves [25], [26]. EES has the potential to offer the electricity market a range of new possibilities [27], [28]. As the electricity market operates with different time-scales, a control algorithm with multiple layers is needed to fulfill a variety of tasks related to the following: preparing schedules for the daily market; various sessions in the ID market; the market to manage deviations; the market of regulation services, and load sharing in real time [26].

The characteristics of the structure of the European electricity market and those of the market integration are dealt with in the work of Hu et al. from 2021 in detail [29]. It gives an account of the liberalization process of the European electricity market, which began with the first European Directive on the liberalization of the electricity market in 1996. The liberalization of the market took place simultaneously in the European Union (EU) and its member states with a view to creating a single internal electricity market that would guarantee both the affordability and security of energy supplies [30]. According to the ENTSO-E, the present sequence of balancing markets in Europe consists of the following markets: forward market, day-ahead (DA) market, intraday (ID) market, balancing market, imbalance settlement [31].

The uncertainties inherent in the day-ahead market are mitigated by trading mid-long term products or electricity derivatives in the forward markets, whose liquidity in the different European countries varies greatly. For example, the bidding zones (the geographical regions that allow market actors to exchange energy without capacity allocation [32]) of France (FR), Germany-Austria-Luxembourg (DE-AT-LU, [DE-LU from October 2018]) and that of Great Britain (GB) have the greatest liquidity, while those of Poland and Spain are much less liquid [33].

In contrast with the mid-long term products of the forward markets, the DA market is the place where deals are made for the next 24 hours. The market clear prices of the DA markets are regarded to be the most significant reference in terms of energy prices in general. The system of Single Day-ahead Coupling (SDAC) in the European Union was created with a view to establishing a single cross-zonal day-ahead electricity market for the whole of Europe [34]. At present, the Price Coupling of Regions and Pan-European Hybrid Electricity Market Integration Algorithm (PCR EUPHEMIA) is widely used in Europe for the allocation of cross-border transmission capacity and calculating electricity prices [35].

During the periods when the DA market is closed, it is the ID markets where short-term adjustments can be made. ID markets operate either as collective auctions or they are based on continuous trading [29].

The third component of the system of electricity markets is the balancing market (also known as the ancillary services market), where ancillary services are offered and sold to the system operator by service providers, including demand response facilities, battery energy storage systems and power generators. The services provided by these are meant to enhance system dependability and security [36], and include black start services, frequency control, voltage support, automatic islanding, etc. [37]. It is important to note here that, in the imbalance settlement process, it is balance responsible parties (electricity producers and consumers) that are financially responsible for any imbalances they cause [31].

According to current regulation, wind and solar power generation (MW) forecasts are required for each bidding zone, and market time unit for the next day. The deadline for the provision of information is 18.00 Brussels time every day prior to the day of the actual delivery. The regular updating and publishing of the data is also mandatory at least once in the course of intraday trading with a deadline of 8.00 Brussels time of the actual day of delivery. The information provision is compulsory for all bidding zones only in those ENTSO-E Member States where the annual feed-in of solar or wind power production exceeds 1% or for those bidding zones whose yearly feed-in of wind or solar power generation is more than 5% [38].

As the challenges of forecasting PV power are at the core of the present research, it is necessary to enumerate some of these. With the growing penetration of renewable energy in the world's electric energy grids, it has become crucial for power system operation, management and planning to enhance the accuracy of forecasting renewable energy [39]. Although preparing precise forecasts for renewable energy continues to be a challenge due to its variable, often even capricious, character [16], a high rate of PV penetration is not feasible without the ability to accurately predict the electricity generation by distributed photovoltaic (PV) systems [40]. Based on the literature, there are numerous algorithms for the precise forecasting of renewable energy on a time horizon ranging from a couple of minutes to some days, which fall into one of the four groups: statistical, physical or artificial intelligence methods or the hybrids of these [16].

Day-ahead prognoses are mostly based on numerical weather prediction (NWP) [41], which uses real weather data to create mathematical models (by the non-linear solution of differential equations [42]) that can predict both local and global weather conditions. Twice a day, the European Centre for Medium-Range Weather Forecasts (ECMFW) runs 10-day deterministic forecasts using the IFS (Integrated Forecasting System) model, in the course of which the interactions between the ocean and the atmosphere, the land and the atmosphere, and the snow cover and the atmosphere are all taken into account [43]. It is the national and international meteorological services that provide the operators of solar power plants and the TSOs with the solar radiation forecasts that make it possible to make estimates concerning the expected PV power [44]. It is worth noting that systems predicting the real energy generation of PV power plants are capable of forecasting data on a horizon ranging from a few seconds [45] up to even two weeks [46] on the basis of forecasted weather data. From the perspective of the operation of solar power plants, those methods are relevant that can predict the expected energy generation of a given day on the previous one. Certain solutions estimate the expected energy generation of a PV system based on the latest forecast data together with information on the location, the nominal power, the orientation and tilt angle of the modules [46]. These approaches, however, do not take the individual energy characteristics of PV power plants that differ at the inverter level (e.g. shading resulting from inadequate spacing distances between strings) into consideration. Nevertheless, there are also methods that, apart from using the latest forecast information, deploy neural networks through PV power plant measurements [47], or artificial intelligence developments supported by machine learning [48].

Bearing the above in mind, it is little wonder that there has been a remarkable rise in interest in the advancement and deployment of solar forecasting by not only scientists and grid operators but also other actors of the electricity markets lately [49]. What defines what is expected of solar forecasting is always the goal of the user who needs the forecasted data [50]. In a great number of electricity markets worldwide, most of the electric energy is traded in the DA market (DAM), where, as a result, most decisions on the dispatch of generators are also made. Therefore, it is self-evident that PV system operators, especially those of many and/or large-scale systems (e.g. utilities and aggregators), wishing to optimize their bids in the market, have a great interest in PV power forecasting models producing DA generation forecasts as accurate as possible [40].

A. CONTRIBUTION

Besides being one of the most favorable renewable energy options, supporting measures by governments, such as feed-in tariffs and environmental benefits, have also greatly contributed to the dynamic spread of grid-connected solar farms recently. Their unprecedented proliferation, however, does pose technical challenges for the dynamics and operation of energy systems mainly because of the variability of solar power [51]. The negative effects of the increased share of distributed PV systems on power quality can be alleviated by accurate PV power generation forecasting, which is a useful management tool in the hands of the operators of power plants and utilities [52].

As it was stated in the introduction, a number of studies that describe PV power generation forecasting algorithms, systems or services are already available. However, their published results are incomplete; they do not offer adequate insight into national-level prognoses in terms of their accuracy. Thus, it is necessary to carry out research in this neglected field. This study is related to this problem, since nowadays it has become indispensable to conduct a detailed examination into this topic, to which the innovative novelty of the article is also connected. The contribution of this paper to the body of knowledge is that this is the first work that analyses the characteristics of the accuracy of the day-ahead and intraday PV forecasts of the ENTSO-E countries and their development over the examined years, from a practical point of view. Thus, thanks to the findings of this research, light is shed on the following:

- how long the examined countries have provided real and forecasted PV power data for the system of ENTSO-E;
- to what extent the data can be analyzed regarding the particular years;
- what the joint distributions of the real and forecasted power data of the examined nations were like in each year;
- how great the annual PV-based downward and upward regulation needs were compared to the yearly energy generation.

The main significance of this research is based on the fact that every commercial energy producer is obligated to submit daily and intraday schedules to the TSO. Empirical experience has demonstrated that it is not possible to prepare 100% accurate schedules for the TSOs for variable renewable energy sources, including the energy generation of solar power plants, because of the various natural effects, which may lead to unpredictable expenses for all involved parties. This issue prompted the formulation of the goal of this research, according to which it has become indispensable to investigate the accuracy of the daily and the intraday scheduling of energy generation in the PV systems of the ENTSO-E countries. The reason this information is important for the TSOs nowadays is that it can highlight the limitations of the forecasting methods in connection with several countries, it can contribute to the market-related development of the management systems of energy storage solutions and provide help for investors investing in PV power plants in connection with various economic aspects.

B. PAPER STRUCTURE

The structure of this paper is the following: Section two presents the methods related to this field, part number three introduces the results and discussions of the research, and finally the fourth section includes the conclusions.

II. MATERIALS AND METHODS

A. THE SOURCE DATABASE OF THE ANALYZED PV DATA

The data that the research was based on were sourced from the ENTSO-E Transparency Platform [53]. The recent years have seen a remarkable improvement in transparency in Europe. An important milestone in this process was Regulation (EU) No 543/2013 of 14 June 2013 [54] on submission and publication of data in electricity markets. The provisions of this Regulation mandate data providers and owners in the European member states (power exchanges, TSOs, and other competent third parties) to provide essential data on electric energy production, load, transmission and balancing to be published via the ENTSO-E Transparency Platform. The rationale of this information provision obligation is that without transparency it is impossible to implement the Internal Electricity Market (IEM) and to establish wholesale markets which are efficient, competitive and liquid at the same time. Other reasons are the need for fair market conditions for all participants and preventing the abuse of market power. The platform also makes vital electricity market information available for use in the future and to assist the further development of the European energy markets with a view to enabling their continuous evolution and integration It was on 5 January 2015 that the ENTSO-E Transparency Platform was started under Regulation 543/2013 [55], and, consequently, it was this historical fact that determined the starting year of this investigation regarding most of the examined countries too.

As the European TSOs are key figures in this study, it is essential to provide some basic information about them here. Fundamentally, it is the large-scale transmission of electricity via the high-voltage systems that these entities, which function independently from the other actors in the electric energy market, are responsible for. They also provide the other actors of the sector (i.e. those involved in the production, trade, supplying, and distribution of electric energy, as well as customers that are directly connected) with grid access. Their operation is subject to transparent and non-discriminatory regulation. They are also responsible for the security of supply, which they achieve by ensuring safe system operation and maintenance. In addition, in numerous nations they are also charged with the development of the electrical network. The ENTSO-E, the organization of European TSOs, has 34 member countries: Austria (AT), Albania (AL), Bosnia and Herzegovina (BA), Belgium (BE), Bulgaria (BG), Switzerland (CH), Cyprus (CY), the Czech Republic (CZ), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), Greece (GR), Croatia (HR), Hungary (HU), Ireland (IE), Iceland (IS), Italy (IT), Lithuania (LT), Luxembourg (LU), Latvia (LV), Montenegro (ME), the Republic of North Macedonia (MK), the Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Romania (RO), Serbia (RS), Sweden (SE), Slovenia (SI) and the Slovak Republic (SK) [56]. The examinations herein also included the United Kingdom, since this country had also submitted data to the ENTSO-E Transparency Platform between 2015 and the middle of June 2021 [53].

In the case of Belgium, the data were not sourced from the ENTSO-E Transparency Platform, but from the Elia Group (EG), the TSO of the country, because its database contains data on the real power of the PV power plants and the related DA and ID production forecasts from as early as 2013 up to the present day [57]. That meant an extra two years' analysis compared to the ENTSO-E database, which has data only starting from 2015.

The focus of the present study was on PV technology. Table 1 summarizes the changes in the capacities of the installed PV power plants in the examined countries over time. It is visible that, in the case of most of the countries studied, the energy generation of their PV power plants is becoming more and more significant. The PV capacities presented below represent the PV power plants that are obligated to provide data for the TSOs of the respective countries. To support the methodology used in the research, it seemed justified to examine the yearly changes in PV power plant capacities in the studied nations.

B. USING THE DATA FROM THE DATABASES

In the ENTSO-E Transparency Platform [53] it is possible to access 15-minute or 60-minute data in a yearly breakdown for numerous countries. Some countries have been submitting PV system data since 2015 (e.g. Germany and France), while other ones only since 2019 (e.g. Croatia and Hungary). Because of the different data series, the examined countries were separately analyzed and evaluated in section III/A. However, section III/B provides a summary of the results of the ENTSO-E nations. From the point of view of the investigations, the actual power of the PV systems as well as their DA and ID power generation forecasts, i.e. the schedule data, were relevant, so it was these that were analyzed. The ENTSO-E Transparency Platform differentiates between four main geographical concepts, such as countries, bidding zones (BZ), control areas (CA, where the network is operated by a single system operator) and market balance areas (MBA, areas with a uniform price for balancing energy) [58].

The research focused on country-level data according to the geographic concept used by the ENTSO-E, but in the case of France it was necessary to use BZ data to access the ID data. In France there is only one BZ (BZN|FR). In this case, the national and the BZ real power and DA generation forecast data are identical, in contrast to Italy, for example, where the annual availability of these data is not always the same. This may be due to the fact that there are 19 BZs in Italy.

TABLE 1. The yearly changes in the capacities of the installed PV power plants in the examined countries [53].

Country	PV capacity in the examined years (MW)									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
AL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	0
AT	N/A	N/A	587	723	1031	1 193	1 193	1 333	1 851	2 500
BA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BE	2 502	2 818	2 953	2 953	2 953	3 369	3 887	4 788	4 788	6 431
BG	N/A	N/A	275	1 041	1 046	1 052	1 059	1 084	1 246	1430
CH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CY	N/A	N/A	76	N/A	115	123	150	205	252	N/A
CZ	N/A	N/A	2 050	2 067	2 027	2 040	2 049	2 061	2 054	2 053
DE	N/A	N/A	37 271	38 686	40 834	42 804	45 299	48 206	53 302	57 744
DK	N/A	N/A	601	601	601	1 002	1 014	1 013	1 300	1 536
EE	N/A	N/A	1	1	1	1	33	123	164	370
ES	N/A	N/A	6 535	6 500	6 720	6 722	6 751	8 466	11 390	14 640
FI	N/A	N/A	N/A	N/A	N/A	N/A	3	7	7	7
FR	N/A	N/A	6 191	6 772	7 660	7 170	8 188	9 438	10 213	13 154
GR	N/A	N/A	2 429	2 441	2 441	2 441	2 441	2 606	3 055	3 820
HR	N/A	N/A	44	49	51	52	53	53	85	96
HU	N/A	N/A	6	29	70	336	936	1 407	1 829	2 524
IE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IT	N/A	N/A	4 980	4 768	4 659	4 719	4 717	4 874	4 979	5 137
LT	N/A	N/A	68	69	80	82	82	103	169	259
LU	N/A	N/A	1	1	1	1	136	170	236	258
LV	N/A	N/A	N/A	N/A	N/A	N/A	7	9	11	14
ME	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	22
NL	N/A	N/A	1 000	1 429	2 039	2 584	3 937	5 710	7 900	16 074
NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PL	N/A	N/A	14	77	187	231	430	1 310	3 473	6 664
PT	N/A	N/A	221	251	261	272	324	413	569	1 032
RO	N/A	N/A	1 101	1 152	1 210	1 211	1 150	1 163	1 145	1 160
RS	N/A	N/A	N/A	N/A	4	N/A	N/A	4	3	3
SE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SI	N/A	N/A	262	263	266	275	275	278	289	286
SK	N/A	N/A	532	530	530	531	531	N/A	N/A	N/A
UK	N/A	N/A	N/A	N/A	N/A	12 563	13 438	13 368	13 470	N/A

The analysis of the country-level data was also advantageous from the perspective of the research because it allowed seeing the real power and the forecasted values for each country in aggregate. With the help of these data, it is possible to gain adequate insight into the accuracy of the scheduling of PV power plants at the national level. In those cases where the real power, DA and ID generation forecast data were accessible in the ENTSO-E for the particular years they were downloaded and then combined in a tabular form in a yearly breakdown.

From the EG [57] database it is possible to download the Belgian real power, DA and ID energy generation forecast and also the monitored PV capacity data at a monthly level, in a 15-minute breakdown starting from 2013. Concerning any other countries, the EG does not publish data of this type. The downloaded data also contained weekly forecasts, but the investigations presented in this study did not use these but monthly data, which were combined to create databases for the examined years, and this input information was used for the analyses. It is worth mentioning that although the ENTSO-E database contains downloadable data for Belgium, they have a 60-minute breakdown, and they are only available starting from 2015. Therefore, regarding Belgium, the EG database, which has more detailed data, was used.

When a country had not only DA but also ID forecasts, both were separately compared with the real energy generation figures in the analyses, since the accuracy of both kinds of forecasts could be explored in this way. In some cases there was a lack of either 15-minute or 60-minute data in the downloaded information. In these situations the following guidelines were followed:

- missing real power data: in a given case when there were 15-minute and/or 60-minute forecasts but there were no real power data, the period in question was not taken into account in the analyses;
- missing DA schedule data: in a given case when there were real power data, but there were no DA power generation forecast data, the period in question was not taken into account in the analyses;
- missing ID forecast data: in a given case when there were real power data, but there were no ID power generation forecast data, the period in question was not taken into account in the analyses.

According to the above, it was established for each country what percent of the data allowed the analysis of the DA and ID time series in the periods with the DA and ID forecasts (Table 2). Table 2 also answers the question which nations provided data for the ENTSO-E or the EG, and in which year the publication of DA and ID type data was started in the case of PV power plants. The color coding in Table 2 is meant to help view and interpret all the data at once regarding every database and country:

- the color green indicates a complete database in the given year (100%);
- the color red shows that the database is extremely inadequate in the given year (e.g. Slovenia's ID database of 2018 is only 4.1% complete, since the data only became available in the ENTSO-E Transparency Platform from 17 December 2018 onwards);
- the darker the shade of yellow is (turning orange) in the cell of a figure, the more inadequate the database of the year in question was (e.g. in the case of Austria, ID data became

TABLE 2. The completeness of the DA and DI databases of the examined countries in the examined years (Dark green: complete database; red: extremely incomplete database. The darker the color of yellow, fading into orange, the less complete the database).

Country	Data resolution (min)	The completeness of the DA and DI databases in the examined years. (%)																			
		2013		2014		2015		2016		2017		2018		2019		2020		2021		2022	
		DA	ID	DA	ID	DA	ID	DA	ID	DA	ID	DA	ID	DA	ID	DA	ID	DA	ID	DA	ID
AL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
AT	15	N/A	N/A	N/A	N/A	100	N/A	99.5	N/A	100	N/A	100	58.6	100	100	100	100	100	100	100	100
BA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BE	15	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99.7	100	99.2	100	100	100
BG	60	N/A	N/A	N/A	N/A	58	N/A	98.1	N/A	99.5	N/A	99.3	N/A	98.1	N/A	98.6	N/A	94.6	N/A	97	N/A
CH	60	N/A	N/A	N/A	N/A	99.5	N/A	99.5	N/A	99.7	N/A	100	N/A	100	N/A	100	N/A	100	N/A	100	N/A
CY	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CZ	60	N/A	N/A	N/A	N/A	99.6	N/A	99.9	N/A	100	N/A	100	N/A	100	100	100	100	100	100	100	100
DE	15	N/A	N/A	N/A	N/A	100	100	100	100	100	100	99.4	99.2	100	97.5	100	99.2	100	95.9	100	99.2
DK	60	N/A	N/A	N/A	N/A	86	N/A	100	N/A	100	N/A	100	N/A	100	N/A	98.9	N/A	99.5	N/A	96.7	N/A
EE	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	33.1	N/A	100	N/A	97	N/A
ES	60 &15	N/A	N/A	N/A	N/A	99.8	N/A	100	N/A	100	N/A	100	88.2	99.9	99.9	100	100	100	100	99.9	99.5
FI	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FR	60	N/A	N/A	N/A	N/A	99.6	N/A	98.5	N/A	99.4	N/A	99.4	48	99.1	70.3	98.3	69.3	99.1	70.1	99.5	92.1
GR	60	N/A	N/A	N/A	N/A	99.9	N/A	99.7	N/A	99.9	N/A	100	N/A	89.6	N/A	91.5	N/A	100	43	100	99.7
HR	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	56.6	50.3	100	100	100	100
HU	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	100	100	100	100	100
IE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IT	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	94.8	N/A	91	N/A	92.1	N/A	99.2	N/A
LT	60	N/A	N/A	N/A	N/A	96.3	N/A	91.5	N/A	97.2	N/A	98.6	36.2	99.7	99.7	100	100	100	100	100	100
LU	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LV	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ME	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NL	15	N/A	N/A	N/A	N/A	98.6	N/A	100	N/A	100	N/A	99.7	N/A	100	100	100	100	100	100	100	100
NO	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PL	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	73	73	100	100	100	100
PT	60	N/A	N/A	N/A	N/A	97.5	N/A	97.3	N/A	98.6	N/A	80	80	92.3	98.1	98.6	99.5	98.3	99.7	99.4	99.4
RO	60 &15	N/A	N/A	N/A	N/A	98.8	N/A	99.9	N/A	99.9	N/A	99.3	N/A	100	N/A	100	100	96.8	96.8	97.8	97.8
RS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SI	60	N/A	N/A	N/A	N/A	100	N/A	100	N/A	96.7	N/A	99.7	4.1	100	100	99.2	99.2	99.6	99.8	99.6	11.5
SK	60	N/A	N/A	N/A	N/A	95.5	N/A	99.1	N/A	99.3	N/A	98.9	N/A	99.2	80	99.5	99.7	100	100	99.8	99.8
UK	60 & 30	N/A	N/A	N/A	N/A	99.5	N/A	99.9	N/A	99.6	N/A	100	4.9	99.7	92.2	100	92	44.8	31.9	N/A	N/A

accessible from 01 June 2018, which caused that the database was only 58.6% complete).

Concerning Table 2, it is also necessary to note that the UK provided 30-minute real power data, while its forecasted data were only hourly. Consequently, the real and the forecasted power data were compared in an hourly breakdown. In the case of Romania until 30 January 2021 and in the case of Spain until 23 May 2022, PV power plants were obligated to provide 60-minute data, which later changed to 15-minute figures, but this did not cause any problem concerning the analyses.

C. THE METHODS APPLIED IN THE ANALYSES

In the past, various researches used different methods for the verification of solar energy generation forecasts. As a consequence, the published scientific results were also difficult to compare, since the accuracy of the forecasts were established according to differing metrics [59].

In statistics the mean bias error (MBE) and the root mean square error (RMSE) indices are most commonly used for the description of model and forecast accuracy. The MBE can show the average of the differences of forecasted and real power generation. In the case of perfect forecasting MBE =0, but it may also occur that the negative and positive errors level each other out, thus producing a value close to 0 for both the sum and the average. The mean squared error (MSE) and root-mean-square error (RMSE) eliminate this feature of MBE. As RMSE weights the deviations of the forecasts detected at the examined points of time proportionally to their magnitudes, it is mainly sensitive to major errors. Nevertheless, since climates of the areas involved in the investigation of PV power generation forecasting show considerable variation, even the above-mentioned normalized indices (MBE, RMSE) are not fully suitable for an appropriate comparison of the different forecasting practices. The skill score method (awarding scores for forecasting skills) is also used for the comparative examination of the accuracy and quality (skillfulness) of forecasts. It is based on the comparison of the forecast to be analyzed with a benchmark forecast [60]. The 2020 study of Yang et al., which made an effort to standardize the verification of deterministic solar radiation forecasting, was a considerable step towards unifying different forecasting approaches [61]. In order to produce results that are comparable and can be widely interpreted, this study also follows the methods and suggestions presented in their paper [61], albeit with some minor modifications required in the practical realization of the research.

The factor that determines the irradiation of the sun the most is-of course-cloud cover, so most forecasting errors are also attributable to the false predictions of clouding. This also means that it is much easier to produce precise forecasts for locations with dry climates. Another important factor to be considered while examining the forecasting accuracy of different countries is the size of the territory in question. The larger the area where the solar power plants are located is, the more the errors resulting from wrong solar radiation forecasting may level one another out [60]. The above can be well illustrated with the example of Belgium, a West European nation with an area of 30 689 km2 and a moderate maritime climate, influenced by the North Sea and the Atlantic Ocean [62]. Due to the relatively small size of the country, the regional differences observable in its climate are

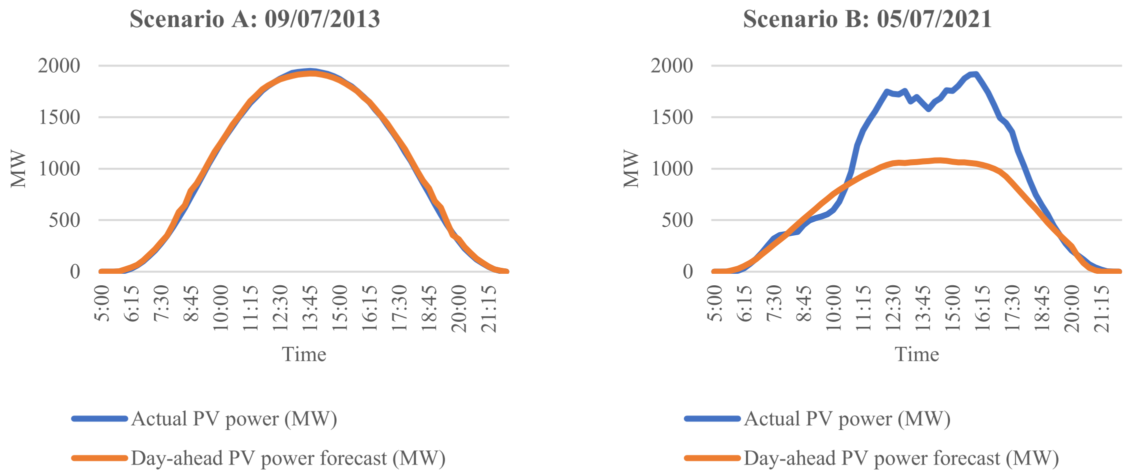

FIGURE 1. Two examples of DA power generation forecasting in Belgium: Scenario A: clear sky prediction, 09/07/2013, 2.5 GW total PV power plant capacity; Scenario B: cloudy sky prediction, 05/07/2021, 4.8 GW total PV power plant capacity.

TABLE 3. The average chance of clear sky in Belgium, based on [64].

Month	1	2	3	4	5	6	7	8	9	10	11	12
Chance of clear skies in Belgium, average (%)	30	36	39	45	46	51	57	56	50	40	30	27

insignificant, although the maritime influence lessens farther from the coast [63]. The average chance of clear sky in Belgium in each month of the year is shown in Table 3:

In the various parts of the country the average chance of clear sky only differs by a few percentage points. For example, in March this value is 36% in the south of the country at the Saint-Hubert Air Base, 39% in Brussels and 41% in Ostend, in the north [64]. This is also important for the EG's development of its solar PV power forecasting system, ongoing since 2013 in an effort to produce schedules as accurate as possible [57]. Figure 1 shows that, in terms of DA forecasts, the system of the EG could predict the energy generation of cloudless periods with a high precision already as early as 2013 (Scenario A). Another example in Figure 1, Scenario B, shows the extent of the deviation of the total energy generation by PV power plants compared to the DA forecast in a case when the predicted cloudy period did not occur. It is a clear illustration of the fact that the reason for the inaccurate DA forecast was the false prediction of cloud cover.

Although it was stated above that most forecasting errors are caused by the false prediction of cloud cover [60], it was important to examine whether the inaccuracies of the DA and ID schedules of the power plants in the research had really been caused by wrong radiation forecasts every time. To establish this, such methods were selected whose results can provide information that are easily interpretable from a practical perspective by TSOs, the decisive actors of the energy market and decision makers too. In the analyses performed in the course of this research, following the example of Yang et al. [61], the forecasting accuracy was scrutinized by deploying the method of the graphical representation of the joint distributions of the forecasted and the real power data. In this way, every time-independent characteristic of the forecasts could be visualized (see the Results section).

As for the practical aspects, the deviation of the real power from the forecasted one has an important role, as its value is equal to the amount of balancing energy, which occurs in the form of need for regulation. Nowadays, it is not without precedent in Europe any more that this discrepancy, in the case of using VRE technologies, results in increasing financial sanctions [28], [65]. This issue results in more and more severe financial sanctions, for example, in the case of Hungary, which is closely linked to the continuous rise in the price of regulatory energy. If a given PV system produces less electric energy than it was predicted to do, a positive regulatory need occurs, and if the real power generation exceeds the forecasted amount, a negative regulatory need emerges [28].

The minimization of the regulatory need, i.e. aiming for forecasts that are as precise as possible, has an enormous significance for the producers of electricity, since according to the regulations currently in force the responsibility for any imbalances in the electric energy system are to be born by the producer [66]. Practically, the mean absolute error (MAE) indicates the average amount of balancing power [67], which is calculated as shown below:

$$\mathrm{MAE} = \frac{1}{N}\sum\nolimits_{i=1}^{N} \left|P_{fc} - P_{act}\right| \tag{1}$$

where P_{fc} and P_{act} are the forecasted and actual PV power, and N is the total nuber of available data points.

Although this index cannot show the direction of the deviation, it is still essential, as negative and positive imbalances cause different issues and—consequently—require different solutions in practice. It also follows from this that the prices of the two types of balancing energy are also different in the markets. It is possible to divide the MAE index into a mean positive and a mean negative error, as follows:

$$\mathrm{MNE} = \frac{1}{N}\sum_{i=1}^{N} \min\left(0, P_{fc} - P_{act}\right) \quad (2)$$

$$\mathrm{MPE} = \frac{1}{N}\sum_{i=1}^{N} \max\left(0, P_{fc} - P_{act}\right) \quad (3)$$

As suggested by their names, MPE is positive and MNE is negative at all times MAE = |MNE |+MPE.

Table 1 shows the PV power plant capacities of the examined countries, from which, however, the amount of power generated in the monitored PV power plants differed to a high degree on numerous occasions [53]. By deploying the MNE and MPE indices, this research established the amount of downward and upward regulation as a percentage of the annual energy production for each country, from the 15- and 60-minute real power and DA and ID energy generation forecast data. In this method, the 15- and 60-minute power data were converted to values of the amounts of electric energy (i.e. from MW to MWh). This approach is of practical significance for a number of reasons:

- The positive and/or negative regulatory need can be determined for any PV capacity. This information is, however, important not only from the perspective of energy management but it may also influence trends related to network development.
- In the process of planning PV power stations, it becomes thusly possible to estimate the magnitude of the financial sanctions resulting from both the positive and negative regulatory needs, which may affect economic decisions [28]. In Hungary, for instance, due to an annually increasing surcharge for discrepancies between the 15-minute real generation and the schedules, there is a growing financial pressure on so-called scheduling groups, which prepare DA and ID schedules for TSOs, which charge the generation schedule groups for surcharges. The considerable costs of these surcharges are either shifted to PV power plant owners by the scheduling groups, or the groups pay them in return for a raised schedule preparation service fee [47], [68], [69].
- It provides the scheduling groups that manage PV systems, the TSOs, the dominant actors of the energy market and the decision makers with indices that are easy to interpret.
- It may influence the technical and economic aspects related to the integration of PV power plants into the electric energy system and the establishment of energy storage systems [28], [70].
- If it is an objective to deploy energy storage units to enhance the schedule accuracy of PV power plants, it can provide reference information not only for improving the negative and positive regulatory need figures, but it may also contribute to the feasibility of creating financial benefits related to better schedules [28], [65]. Closely related to this is the fact that the price of regulatory energy is constantly rising, which may also have an impact on such economic decisions.

III. RESULTS AND DISCUSSION

The results of the study were based on the visualizations of the joint distributions of the values of the actual power data and the forecasts made for the schedules of the PV power plants of the examined countries, and the needs for downward and upward regulation calculated from these figures (Equations 1-3), provided the data provision of the given country was reliable. For the sake of better visibility, the joint distribution figures containing the DA and ID schedule discrepancies related to the same periods were displayed side by side (Figures 2 – 23). The values of the annual downward and upward regulation requirements related to energy generation, are shown separately for the DA and DI forecasts to make the magnitudes of the downward and upward regulation linked to the forecasts easier to see (Tables 4 – 26). Due to the differences in data provision, several subsections were included in the study. Accordingly, the nations without data provision (Subsection I), countries with significantly inadequate or incomplete data provision (Subsection II) and those that were suitable for the comparative analysis of the scheduling characteristics of their PV power plants (subsection III) were dealt with separately.

A. THE ACCURACY FEATURES OF THE SCHEDULING OF PV POWER PLANTS IN THE EXAMINED COUNTRIES

1) THE NATIONS WITHOUT DATA PROVISION

After an examination of the database of the ENTSO-E Transparency Platform, it was established that there were some countries that did not provide data related to PV energy generation or generation forecasts, so their analysis was impossible. These nations were the following:

- Albania, Bosnia and Herzegovina, Ireland, Iceland, Luxembourg, Latvia, the Republic of North Macedonia, Serbia and Sweden.

2) THE COUNTRIES WITH SIGNIFICANTLY INADEQUATE OR INCOMPLETE DATA PROVISION

Generally speaking, scheduling is deemed perfect when the dots in the scatter plot of the joint distribution of the actual and the forecasted PV power data are located on the diagonal. Such an ideal situation, however, never occurs, which means that if the dots are situated on the diagonal, it indicates an anomaly in data provision.

In the research there were countries which supplied data related to PV energy generation and/or forecasted schedule data to the ENTSO-E Transparency Platform, but the results of their analysis suggested significantly faulty or incomplete data provision activities. These countries were the following:

- Austria, Cyprus, Finland, Croatia, Montenegro, the Netherlands and Norway.

a: AUSTRIA (AT)

In the case of Austria, Figure 2 shows that the real power data in 2015, 2016, 2017 as well as in most of 2018 and 2019 and in the first quarter of 2020 were identical with the DA schedule energy generation forecast data. In contrast to that, from the second quarter of 2020 till the end of the period examined, the DA schedule energy generation forecasts showed values exceeding the actual data two or three times, i.e. overscheduling occurred. This suggests that the actual data and the forecasted values were related to PV systems of different capacities, which is illustrated by the following:

- sunny period: 08.07.2020 11:45 – 12:00 (CET), real PV power: 528 MW, DA forecasted power 1080 MW;
- sunny period: 10.07.2021 12:30 – 12:45 (CET), real PV power: 528 MW, DA forecasted power 1408 MW;
- cloudy period: 17.09.2020 11:45 – 12:00 (CET), real PV power: 348 MW, DA forecasted power 628 MW;
- cloudy period: 21.09.2021 11:45 – 12:00 (CET), real PV power: 292 MW, DA forecasted power 540 MW.

Because of the scheduling problems presented above, the amounts of the downward and upward regulation requirements were not determined from the differences of the real energy generation and the forecasts.

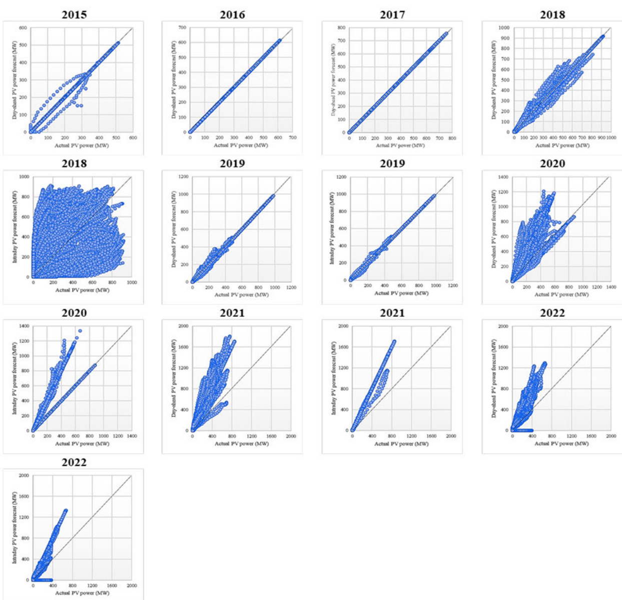

FIGURE 2. The joint distributions of the real and forecasted PV power data in the case of Austria in the examined years.

b: CYPRUS (CY)

In the case of Cyprus, there were certain years when there was data provision to the ENTSO-E system, albeit not appropriate. This is the reason why this country was classified as one of the 'countries with significantly inadequate or incomplete data provision'. Although during the period 2015 – 2021 there were no available real power data related to the PV power plants, there was data provision of only hourly DA energy generation forecast figures to the ENTSO-E Transparency Platform from 2016 to 2020. Consequently, no analysis could be carried out for this country.

c: FINLAND (FI)

Similarly to Cyprus, in the case of Finland, there were also some years when there was data provision to the ENTSO-E system, however not adequate. In the case of this nation, it was also this fact that put it in the group of 'countries with significantly inadequate or incomplete data provision.' In the examined years, there were no available real power data related to the PV power plants. Contrary to this, there was a provision of DA forecast data from the middle of August 2019 and that of ID generation forecasts from the middle of July 2019. Due to the above, no analysis could be carried out for this country.

d: CROATIA (HR)

In the case of Croatia, there were also some years when there was data provision to the ENTSO-E system, however not adequate. This is the reason why this country was also classified as one of the 'countries with significantly inadequate or incomplete data provision'. It can be seen in Figure 3 that the real power data were identical to the DA and ID schedule values in the majority of the cases in 2020 and 2021. Due to the scheduling inadequacies presented above, the amounts of the downward and upward regulation requirements were not determined from the differences of the real energy generation and the forecasts.

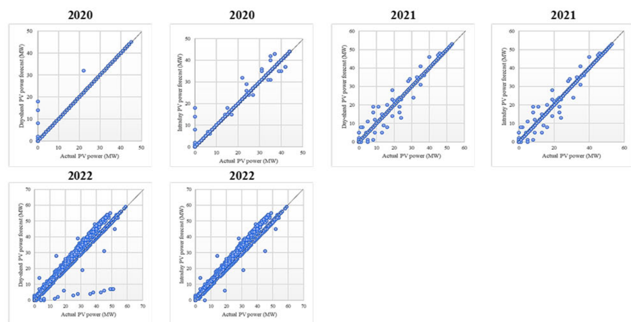

FIGURE 3. The joint distributions of the real and forecasted PV power data in the case of Croatia in the examined years.

e: MONTENEGRO (ME)

Montenegro's scheduling practice resembles that of Finland the most. There were some years when there was data provision to the ENTSO-E system, however it was not adequate. Thus, this country was also classified as one of the 'countries with significantly inadequate or incomplete data provision.' In the period 2015 - 2021, there were no available real power data related to PV technology. Conversely, there was data provision of DA and ID energy generation forecasts, which took place from the end of June 2020 and from the beginning of June 2019, respectively. Due to the above, it was not possible to perform an analysis for this country.

f: THE NETHERLANDS (NL)

In the case of the Netherlands, there were some years when there was data provision to the ENTSO-E system, however not adequate. Therefore, this country was also included in the category of the 'countries with significantly inadequate or incomplete data provision.' In most of the period 2015 – 2021 there is a value 0 in the database of real power related to PV power plants (Figure 4). This caused the situation that the analyses indicated overscheduling, as the forecasts exceeded the real data of 0 by far. The DA data were available from as early as 2015, while the ID forecasts from only the middle of April 2018. Due to the characteristics of scheduling presented above, the quantities of the downward and upward regulation requirements were not determined from the differences of the real energy generation and the forecasts.

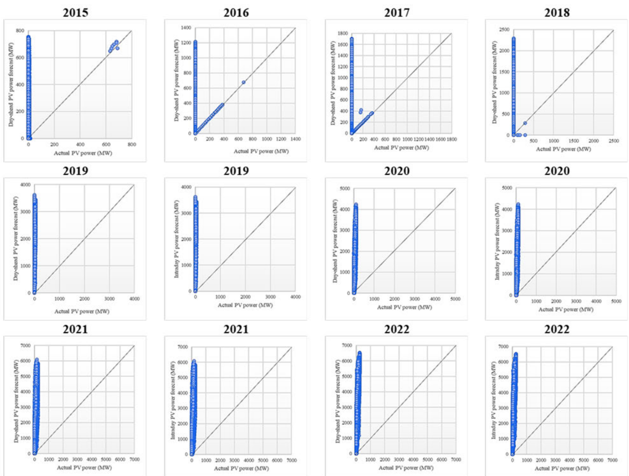

FIGURE 4. The joint distributions of the real and forecasted PV power data in the case of the Netherlands in the examined years.

g: NORWAY (NO)

The situation of scheduling in Norway resembles those of Montenegro and Finland the most. In the case of this nation, there were also some years when there was data provision to the ENTSO-E system, however it was not adequate. Thus, this country was also classified as one of the 'countries with significantly inadequate or incomplete data provision.' Although in the period 2015 - 2021 there were no available real power data related to PV power plants, the provision of DA power generation forecast data was already active from 2015, but the data assumed the value 0. Concerning ID forecasting, there was no provision of data. Due to the above, it was not possible to carry out any analyses for this country.

3) THE COUNTRIES SUITABLE FOR THE COMPARATIVE ANALYSIS OF THE SCHEDULING CHARACTERISTICS OF THEIR PV POWER PLANTS

Among the examined countries 18 (BE, BG, CH, CZ, DE, DK, EE, ES, FR, GR, HU, IT, LT, PL, PT, RO, SI, SK, UK) were suitable for the comparative analysis of the scheduling characteristics of their PV power plants. The analyses showed varying degrees of under- or overscheduling (clusters of dots below or above the diagonals of the graphs of the joint distributions). The next section presents an overview of the country-specific characteristics of PV scheduling and the amounts of downward and upward regulation requirements. The description of each country follows a similar logical structure for easier comparability.

a: BELGIUM (BE)

Belgium was the country where the most detailed data were available among the countries studied. As mentioned in section II/A, the database for the investigations for this nation was provided by the EG, for which high accuracy in PV scheduling is one of the most important goals [57]. Figure 5 demonstrates that the dots are located near the diagonal, which indicates precise forecasting. Compared to the DA schedules, ID ones produced more precise forecasts every year. This is also verified by the proportion of the annual downward and upward regulation requirements to the energy production (Table 4.):

- The proportion of the annual downward regulation need to the energy generation in the case of the DA forecasts was in the range of 9.0% – 7.0%, which could even be improved by a further few percent in the case of ID forecasting, as shown in Table 4.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts varied between 14.4% and 6.2%. The application of ID scheduling could enhance the accuracy compared to DA scheduling.

b: BULGARIA (BG)

In the case of Bulgaria, the results indicated (Figure 6.) that both under- and overscheduling characterized the DA forecasts made for the PV power plants. The explanation of the phenomenon may be that those preparing the prognoses did not have adequate information on the unfavorable, unexpectedly variable cloudy weather of the following scheduling periods. These trends are also shown by the proportions of the annual downward and upward regulation requirements to the energy production (Table 5.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 17.8% and 6.5%.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 22.5% and 6.5%.

c: SWITZERLAND (CH)

In the case of Switzerland, there were only two years when the data provision was not adequate. This is the reason why this country was not classified as one of the 'countries with significantly inadequate or incomplete data provision'.

During the period 2015 – 2019, it often happened that the forecasts overestimated the real power figures, which may be explained by the fact that those preparing the prognoses did not have adequate information on the unfavorable, unexpectedly variable cloudy weather of the following

TABLE 4. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Belgium.

Denomination	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	8.9	8.3	8.7	9.0	8.9	7.4	7.6	7.0	8.3	7.7
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	14.4	12.3	8.1	8.2	8.2	8.6	8.0	6.6	7.7	6.2
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	6.9	5.8	6.5	5.6	6.1	4.7	5.1	5.1	6.1	4.5
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	12.3	11.2	6.1	5.6	6.3	5.6	5.8	5.0	5.2	4.0
The improvement of the annual downward regulation requirement when using ID forecasting (%)	2.0	2.4	2.2	3.4	2.8	2.6	2.5	1.9	2.2	3.2
The improvement of the annual upward regulation requirement when using ID forecasting (%)	2.1	1.1	1.9	2.6	2.0	2.9	2.2	1.6	2.5	2.2

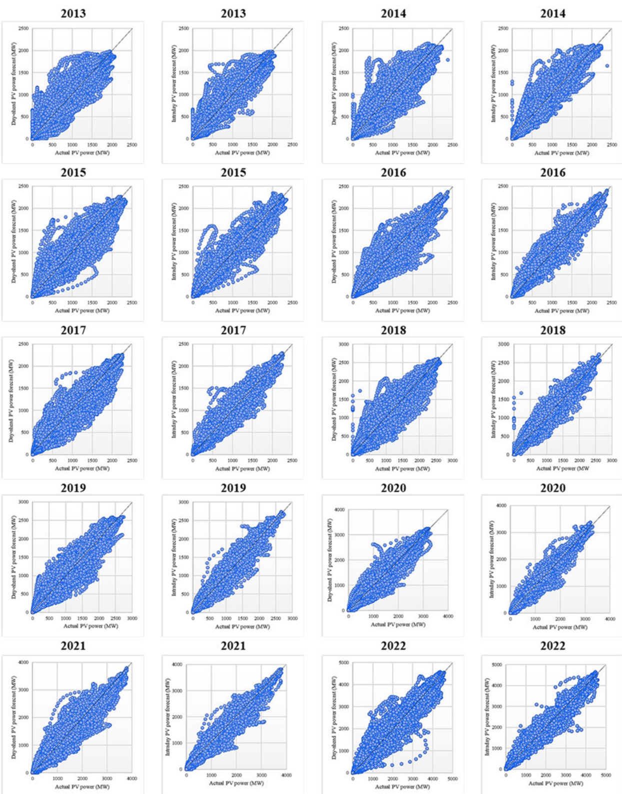

FIGURE 5. The joint distributions of the real and forecasted PV power data in the case of Belgium in the examined years.

TABLE 5. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Bulgaria.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	10.2	11.8	8.8	6.5	7.8	17.8	11.7	8.8
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	14.6	12.5	15.7	22.5	20.9	6.5	9.4	18.5

scheduling periods. It is worth mentioning that there were two occasions in March 2016 when, according to the data provided, the real power values were greater by orders of

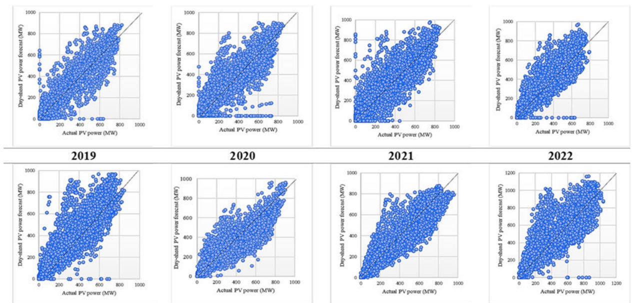

FIGURE 6. The joint distributions of the real and forecasted PV power data in the case of Bulgaria in the examined years.

magnitude than the forecasted ones. Presumably, the reason for this was that there were some recording errors; the decimal points were wrongly placed. This is illustrated below:

- 04.03.2016 15:00 – 16:00 (CET), real PV power: 22.0 MW, DA forecasted power 43.0 MW.
- 04.03.2016 16:00 – 17:00 (CET), real PV power: 1012.0 MW, DA forecasted power 20.0 MW.
- 04.03.2016 17:00 – 18:00 (CET), real PV power: 753.0 MW, DA forecasted power 6.0 MW.

The 2020 – 2021 data signal that the values of the real power data submitted to the ENTSO-E Transparency Platform changed significantly compared to the forecasts, and this caused the considerable discrepancies in the schedules. By that time underscheduling had become typical, as shown by the majority of the dots lying below the diagonal (Figure 7). This suggests that the actual data and the forecasted values were related to PV systems of different capacities in the period 2020 – 2021, which is illustrated by the following:

- sunny period: 22.08.2020 14:00 – 15:00 (CET), real PV power: 1349 MW, DA forecasted power 130 MW.

Because of these scheduling characteristics, the amounts of downward and upward regulation requirements were determined for the years 2015 – 2019 (Table 6):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 9.4% and 4.6%.
- Compared to the downward regulation needs, the annual upward regulation requirement posed a greater challenge in

TABLE 6. **The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Switzerland.**

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	9.4	8.5	4.6	4.6	5.3	data error	data error	data error
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	37.5	20.0	16.6	42.7	12.0	data error	data error	data error

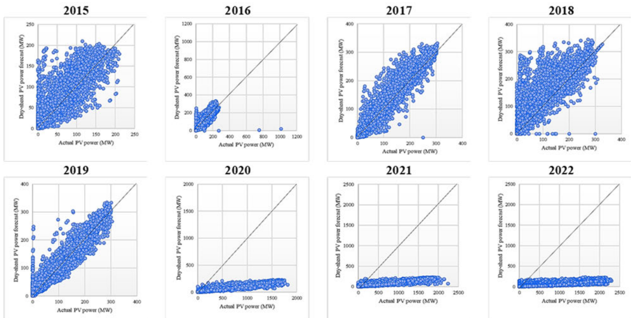

FIGURE 7. **The joint distributions of the real and forecasted PV power data in the case of Switzerland in the examined years.**

terms of the management of scheduling. The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 42.7% and 12.0%.

These values suggest that the prediction of PV power parameters in cloudy periods was more challenging.

d: THE CZECH REPUBLIC (CZ)

In the case of the Czech Republic (Figure 8), it can be observed that the dots are located near the diagonal, which indicates precise forecasting. In the period 2015 – 2017, the degree of the inaccuracy of the DA schedules was higher than in the subsequent years. The positive change seen in scheduling starting from 2018 suggests the deployment of an improved forecasting algorithm that was capable of a more sophisticated prediction of weather parameters. The use of ID scheduling resulted in a slight improvement compared to DA scheduling in some cases, while in others it decreased the forecasting accuracy. The proportions of the annual downward and upward regulation requirements to the energy production show the following (Table 7.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 10.4% and 3.6%.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 9.7% and 4.4%.

TABLE 7. **The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of the Czech republic.**

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	10.4	8.3	7.9	5.1	4.5	4.2	5.8	3.6
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	7.8	9.7	9.0	5.8	6.1	6.4	4.4	5.2
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	4.6	3.6	8.9	3.7
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	6.1	5.8	5.5	8.0
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	-0.05	0.64	-3.1	-0.1
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	0.04	0.62	-1.1	-2.8

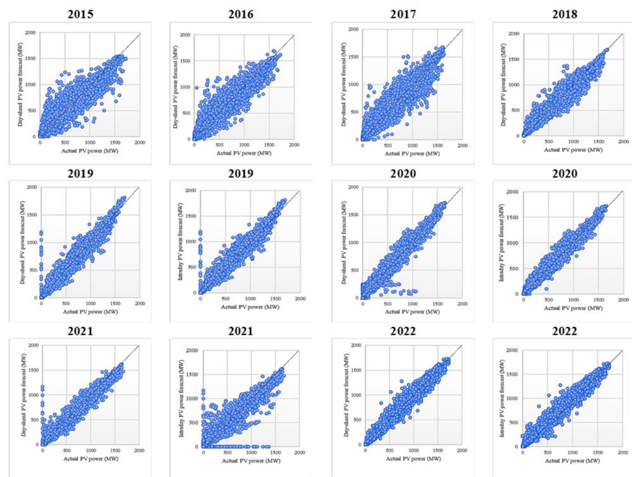

FIGURE 8. **The joint distributions of the real and forecasted PV power data in the case of the Czech Republic in the examined years.**

e: GERMANY (DE)

One of the most accurate DA and ID forecasting mechanisms connected to PV technology was observable in the case of Germany. It can be seen that, in the case of the DA forecasts, the dots are close to the diagonal, which indicates precise forecasting (Figure 9).

The ID forecasts have provided appropriate data since 2018, so the amounts of the downward and upward regulation requirements were established for the years 2018 – 2021. The ID forecasts from earlier than 2018 seem to be related to PV systems of different capacities, which resulted in under-scheduling. This is illustrated below:

• sunny period: 18.06.2015 13:00 – 13:15 (CET), real PV power: 9828 MW, ID forecasted power 3168 MW.

• sunny period: 12.07.2016 12:45 – 13:00 (CET), real PV power: 15344 MW, ID forecasted power 5449 MW.

• sunny period: 06.07.2017 13:00 – 13:15 (CET), real PV power: 25454 MW, ID forecasted power 10103 MW.

The proportions of the annual downward and upward regulation requirements to the energy production developed as follows (Table 8.):

• The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 4.2% and 3.2%, which showed minor improvements thanks to the deployment of ID forecasting in the overwhelming majority of the cases.

• The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 6.1% and 3.1%. The application of ID scheduling could enhance the accuracy compared to DA scheduling in this case too.

The high forecasting precision of Germany could be attributable, on the one hand, to the fact that among the examined ENTSO-E countries this country has the most PV power plants, distributed over a relatively large geographical area, and thusly they level out their inaccuracies to a certain extent and, on the other hand, to the more than 10 years' experience in the development of the energy generation forecasting of PV systems [71].

TABLE 8. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Germany.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	3.9	3.3	4.2	3.4	3.9	3.3	3.5	3.2
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	6.1	5.1	3.8	3.6	3.1	3.4	3.6	3.2
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	data error	data error	data error	5.6	3.3	2.7	2.8	2.4
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	data error	data error	data error	2.6	2.7	2.9	2.9	2.9
The improvement of the annual downward regulation requirement when using ID forecasting (%)	data error	data error	data error	-2.2	0.6	0.6	0.7	0.8
The improvement of the annual upward regulation requirement when using ID forecasting (%)	data error	data error	data error	1.0	0.4	0.5	0.7	0.3

f: DENMARK (DK)

Similarly to the state of scheduling in Bulgaria, the Danish results also indicate that the DA forecasts made for PV power generation were characterized by both under- and overscheduling (Figure 10). A possible explanation for this may be that the variability of the weather was not taken into consideration appropriately during the preparation of the prognoses. The proportions of the annual downward and upward regulation requirements to the energy production were as follows (Table 9.):

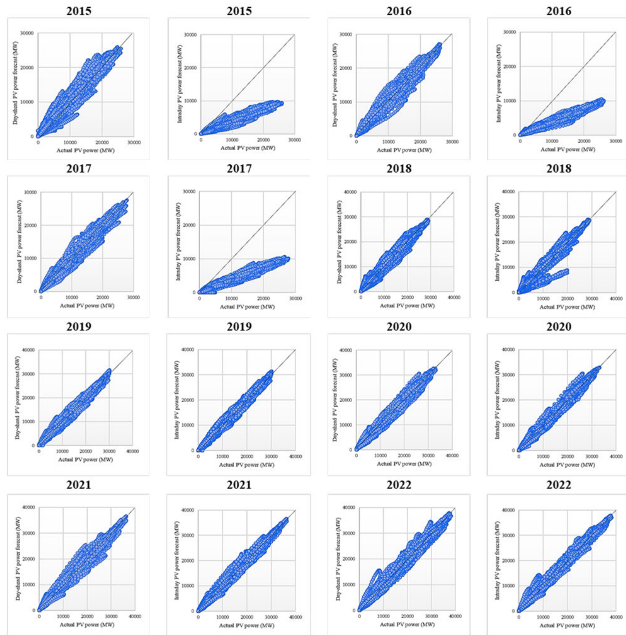

FIGURE 9. The joint distributions of the real and forecasted PV power data in the case of Germany in the examined years.

• The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 15.2% and 5.3%.

• The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 10.8% and 5.7%.

TABLE 9. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Denmark.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	10.0	8.9	6.8	6.0	5.3	11.5	11.5	15.2
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	6.4	7.2	7.1	8.0	10.8	5.7	6.8	8.1

g: ESTONIA (EE)

In the case of Estonia, the DA forecasts made in 2019 and 2020 underestimated the real power of the PV power plants (Figure 11). From the data it was not possible to determine without any doubt whether the actual data and the forecasted values were related to PV systems of different capacities. This is the reason why this country was not classified as one of the 'countries with significantly inadequate or incomplete

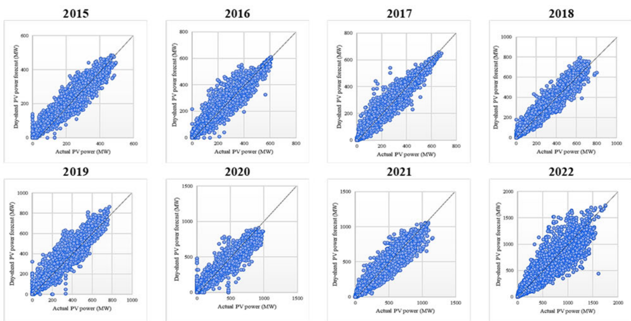

FIGURE 10. **The joint distributions of the real and forecasted PV power data in the case of Denmark in the examined years.**

data provision'. The explanation of the phenomenon could be that instead of aiming for the greatest precision, the PV schedules were optimized according to some other aspects. The proportions of the annual downward and upward regulation requirements to the energy production show the following (Table 10.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 46.8% and 32.3%.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 17.6% and 1.1%.

TABLE 10. **The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Estonia.**

Denomination	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	46.8	45.6	32.3
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	17.6	1.8	1.1

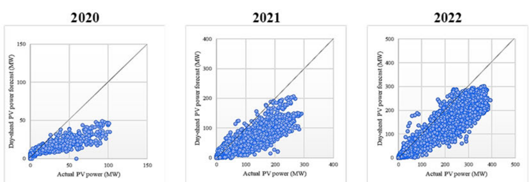

FIGURE 11. **The joint distributions of the real and forecasted PV power data in the case of Estonia in the examined years.**

h: SPAIN (ES)

Similarly to Germany, the Spanish results signal that this nation possesses one of the most accurate DA and ID forecasting mechanisms connected to PV technology. It can be seen that, in the case of the DA forecasts, the dots are near the diagonal, which indicates accurate forecasting (Figure 12). ID data are available from 2018 onwards. The proportions of the annual downward and upward regulation requirements to the energy production also confirm the above (Table 11.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 4.8% and 3.0%, which showed minor improvements by the deployment of ID forecasting.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 5.9% and 3.5%. The application of ID scheduling caused a maximum improvement of 0.5% of the annual upward regulation need, compared to the DA forecasts.

The high forecasting precision of Spain may be attributable, on the one hand, to the fact that among the examined ENTSO-E countries this country has one of the largest PV power plant capacities (14.6 GW in 2022), distributed over a relatively large geographical area with a rather dry climate in some areas [72], [73], and thusly the power plants level out their inaccuracies to a certain extent and, on the other hand, to the knowledge related to the energy generation forecasting of PV systems gathered since 2013 [74].

TABLE 11. **The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Spain.**

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	4.8	3.6	3.4	4.3	4.0	3.0	3.8	4.4
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	4.4	4.1	3.5	5.9	5.2	5.3	4.3	5.6
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	3.9	3.5	2.3	3.1	4.0
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	5.0	4.7	5.2	4.3	5.4
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	0.5	0.7	0.6	0.4
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	0.5	0.1	0.0	0.2

i: FRANCE (FR)

In the case of France, it can be seen that both under- and overscheduling characterized the DA as well as the ID forecasts made for the PV power plants (Figure 13). One of the probable causes of this may have been that new PV capacities installed after 2020 resulted in higher uncertainty in terms of scheduling. It may have also happened that a new forecasting algorithm different from that used in previous years was deployed, or a systematic operational error took place. Of course, it cannot be ruled out either that, simply, those preparing the prognoses did not have adequate information on the unfavorable, unexpectedly changeable cloudy weather

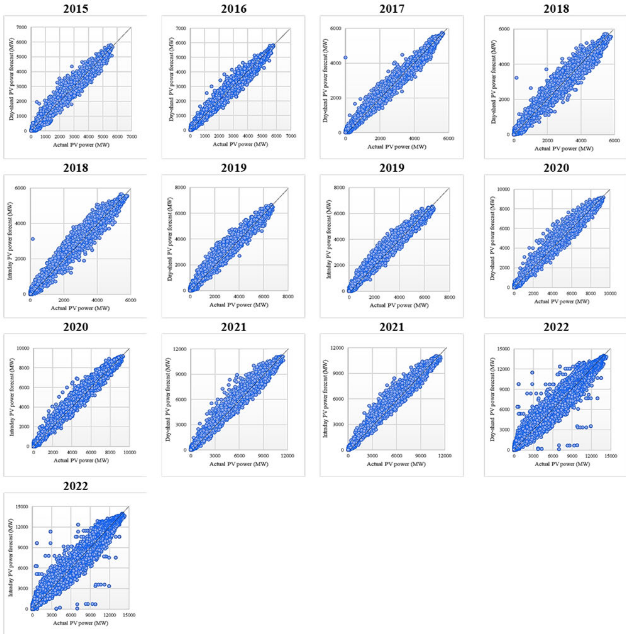

FIGURE 12. The joint distributions of the real and forecasted PV power data in the case of Spain in the examined years.

of the subsequent scheduling periods. The proportions of the annual downward and upward regulation requirements to the energy production show the following (Table 12.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 15.2% and 7.0%. The deployment of ID scheduling was able to achieve slight improvements.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 20.5% and 7.4%. The use of ID scheduling was able to produce some slight improvements here too.

j: GREECE (GR)

In the case of Greece, it was only in 2017 when the data provision was not adequate. This is the reason why this country was not classified as one of the 'countries with significantly inadequate or incomplete data provision'. In that year the actual power data were identical to the DA energy generation forecast figures on several occasions. Due to this, it was only for that year that the quantities of the downward and upward regulation requirements were not determined from the differences of the real energy generation and the forecasts.

Similarly to Spain and Germany, the Greek results also suggest that this country has a relatively accurate DA and ID forecasting solution related to PV technology. It can be seen that, in the case of the DA forecasts, a significant portion of the dots is quite near the diagonal, which indicates relatively accurate forecasting (Figure 14). Scheduling is made significantly easier by the fact that Greece is one of the sunniest countries in Europe [75]. Nevertheless, the 2021 data also indicate that, even in a country that deploys a

TABLE 12. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of France.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	7.0	11.8	8.4	10.2	8.5	7.7	15.2	7.1
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	8.5	10.6	7.1	7.4	9.1	9.1	20.5	10.9
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	5.5	8.0	7.1	14.7	7.1
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	6.0	8.5	8.6	20.3	10.3
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	4.7	0.5	0.7	0.5	0.0
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	1.3	0.6	0.5	0.2	0.6

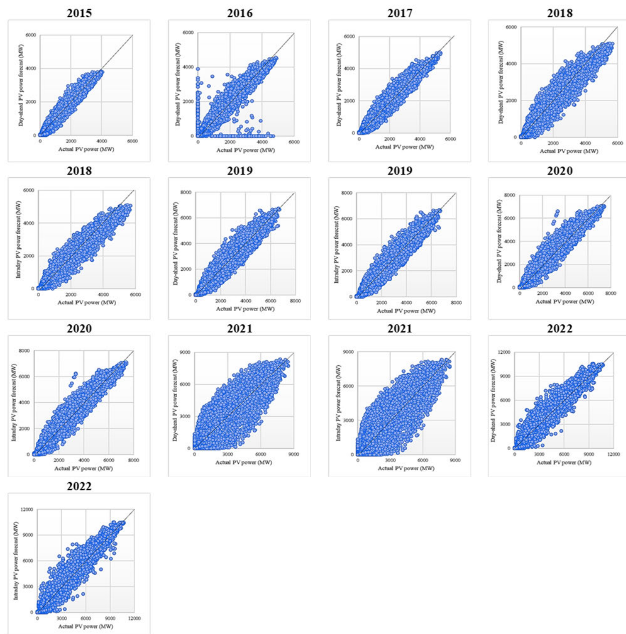

FIGURE 13. The joint distributions of the real and forecasted PV power data in the case of France in the examined years.

relatively precise DA and ID forecasting solution, there may be events when either overscheduling of a greater magnitude occurs (e.g. in the periods of early morning or late afternoon), or those preparing the prognoses do not have adequate information on the unfavorable, unexpectedly variable cloudy weather of the following scheduling periods, causing some greater errors. The proportions of the annual downward and upward regulation requirements to the energy production also confirm the above (Table 13.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 6.7% and 3.3%, which demonstrated some minor improvement by the deployment of ID forecasting.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 10.3% and 3.9%. The deployment of ID scheduling did not lead to any improvement compared to DA scheduling. On the contrary, it even decreased the forecasting accuracy to a slight degree.

TABLE 13. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Greece.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	6.7	5.3	data error	4.0	5.6	3.3	5.0	5.6
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	6.8	3.9	data error	6.3	4.0	5.2	10.3	7.3
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	N/A	N/A	2.0	5.5
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	N/A	N/A	12.9	7.0
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	N/A	N/A	3.0	0.1
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	N/A	N/A	-2.7	0.3

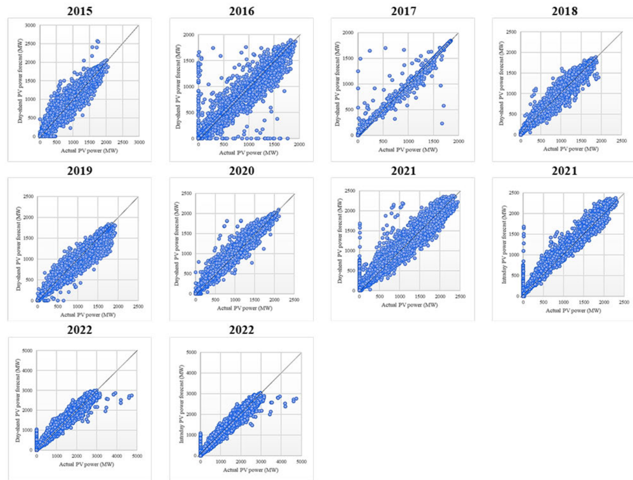

FIGURE 14. The joint distributions of the real and forecasted PV power data in the case of Greece in the examined years.

k: HUNGARY (HU)

In the case of Hungary, the obtained results indicate that underscheduling characterized the DA as well as the ID forecasts made for PV power generation. However, it is to be seen that most of the dots are located near the diagonal, which suggests that the forecasts were accurate for the most part (Figure 15). The inaccuracies that occurred could be attributable, e.g. to the fact that, compared to Germany and Spain, the PV power plants are spread over a smaller geographical area, thus an unexpected weather event may have a more significant effect on the accuracy of forecasting. The proportions of the annual downward and upward regulation requirements to the energy production show the following (Table 14.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 7.3% and 5.6%. Applying ID forecasting did not result in any improvement in terms of accuracy.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 6.7% and 3.6%. The use of ID scheduling was able to achieve some slight improvement in this case.

TABLE 14. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Hungary.

Denomination	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	7.1	7.3	5.6
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	6.7	3.7	3.6
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	7.1	7.1	5.7
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	6.2	3.3	3.1
The improvement of the annual downward regulation requirement when using ID forecasting (%)	0.0	0.1	-0.1
The improvement of the annual upward regulation requirement when using ID forecasting (%)	0.5	0.5	0.5

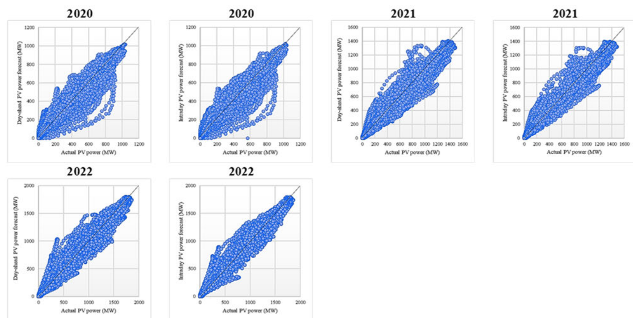

FIGURE 15. The joint distributions of the real and forecasted PV power data in the case of Hungary in the examined years.

l: ITALY (IT)

The results displayed in Figure 16 show that in the case of Italy underscheduling was characteristic for the DA forecasting related to PV technology. The proportions of the annual downward and upward regulation requirements to the energy production can be described as follows (Table 15):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 7.8% and 5.0%.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 3.3% and 2.5%.

TABLE 15. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Italy.

Denomination	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	7.8	5.0	7.0	7.3
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	3.3	2.5	2.9	2.5

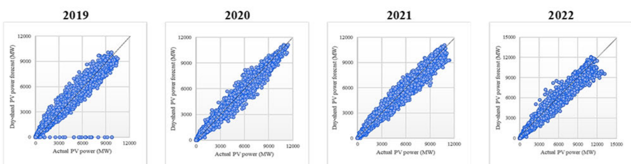

FIGURE 16. The joint distributions of the real and forecasted PV power data in the case of Italy in the examined years.

m: LITHUANIA (LT)

In the case of Lithuania, similarly Bulgaria, the results indicated that both under- and overscheduling characterized the DA and ID forecasts made for the PV power plants (Figure 17). Also in this case, the explanation of the phenomenon may be that those preparing the prognoses did not have adequate information on the unfavorable, unexpectedly variable cloudy weather of the following scheduling periods. The use of ID scheduling resulted in a slight improvement compared to DA scheduling in some cases, while in others it decreased the forecasting accuracy. It is necessary to note here that DA forecasts of appropriate quality are available from 2017 onwards. The earlier forecasts seem to be related to PV systems of different capacities, which resulted mostly in overscheduling in 2015, and mostly underscheduling in 2016. This is illustrated by the following examples:

- sunny period: 03.10.2015 11:00 – 12:00 (CET), real PV power: 18 MW, DA forecasted power 32 MW;
- sunny period: 14.06.2016 11:00 - 14.06.2016 12:00 (CET), real PV power: 32 MW, DA forecasted power 7 MW.

Because of these scheduling characteristics, the proportions of the downward and upward regulation requirements to the energy generation were only determined for the years 2017 – 2021 (Table 16):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 26.0% and 10.3%, The deployment of ID scheduling was able to achieve improvements in 2021 and 2022.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 24.8% and 8.7%.

TABLE 16. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Lithuania.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	data error	data error	13.9	13.0	16.6	10.3	25.8	26.0
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	data error	data error	15.7	11.2	8.7	24.8	14.3	13.6
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	17.4	16.4	10.4	13.0	13.6
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	17.3	8.5	24.6	27.9	14.2
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	-4.5	0.1	-0.1	12.8	12.4
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	-6.1	0.2	0.1	-13.6	-0.6

n: POLAND (PL)

Similarly to the state of scheduling in Lithuania and Bulgaria, the Polish results also signify that the DA and DI forecasts made for PV power generation were characterized by both under- and overscheduling (Figure 18). The explanation of the phenomenon may again be that those making the prognoses did not have adequate information on the unfavorable, unexpectedly variable cloudy weather of the following scheduling periods. The proportions of the annual downward and upward regulation requirements to the energy production developed as follows (Table 17.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 12.7% and 4.3%, which showed minor improvements by the deployment of ID forecasting.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 19.4% and 7.4%. The deployment of ID scheduling did not lead to any improvement compared to DA scheduling, on the contrary, it even decreased the forecasting accuracy to a slight degree.

o: PORTUGAL (PT)

In the case of Portugal, it can be stated that both under- and overscheduling characterized the DA forecasts made for the PV power plants (Figure 19). Also in this case, the explanation of the phenomenon may be that those preparing the prognoses did not have adequate information on the unfavorable, unexpectedly variable cloudy weather of the following

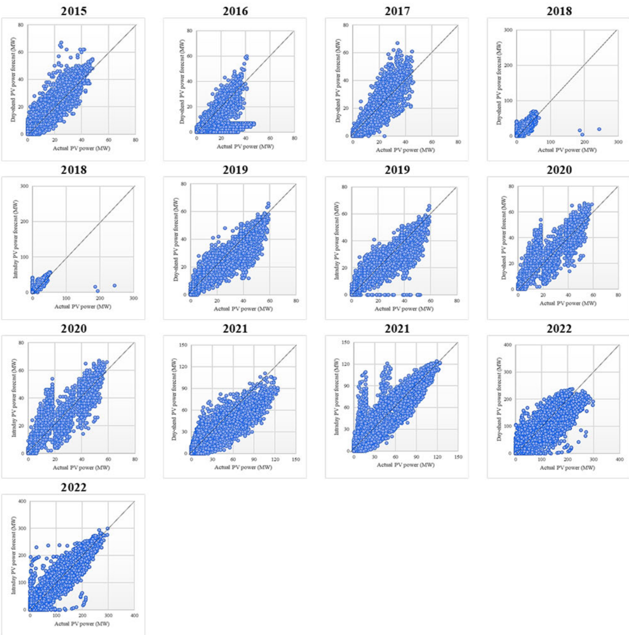

FIGURE 17. The joint distributions of the real and forecasted PV power data in the case of Lithuania in the examined years.

TABLE 17. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Poland.

Denomination	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	10.0	4.3	12.7
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	8.4	19.4	7.4
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	9.7	3.9	11.1
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	8.6	20.2	7.7
The improvement of the annual downward regulation requirement when using ID forecasting (%)	0.3	0.4	1.6
The improvement of the annual upward regulation requirement when using ID forecasting (%)	-0.2	-0.7	-0.3

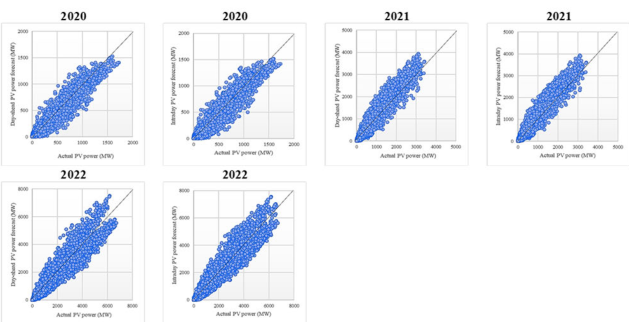

FIGURE 18. The joint distributions of the real and forecasted PV power data in the case of Poland in the examined years.

scheduling periods. The proportions of the annual downward and upward regulation requirements to the energy production were as follows (Table 18.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 15.3% and 2.1%. By the deployment of ID scheduling some slight improvement could be reached.

TABLE 18. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Portugal.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	15.3	4.9	2.1	5.9	10.6	13.8	11.6	8.1
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	10.5	10.2	11.6	17.3	8.9	10.8	9.3	9.2
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	5.0	10.5	9.9	11.5	7.8
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	16.6	6.7	9.3	10.2	8.6
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	0.9	0.1	3.9	0.0	0.3
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	0.7	2.2	1.6	-0.9	0.6

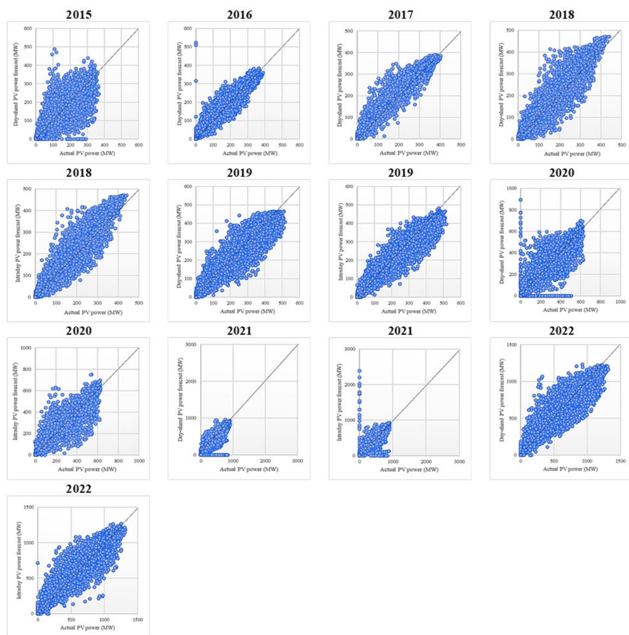

FIGURE 19. The joint distributions of the real and forecasted PV power data in the case of Portugal in the examined years.

- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 17.3% and 8.9%. The application of ID scheduling could enhance the accuracy compared to DA scheduling in the vast majority of the cases.

p: ROMANIA (RO)

In the case of Romania, it can be seen that both under- and overscheduling characterized both the DA and ID forecasts made for the PV power plants (Figure 20). The results indicate that underscheduling was more typical between 2015 and 2017, while the period 2018 – 2021 was dominated by overscheduling. This may have been caused by using a new forecasting algorithm different from that used in previous years, or by a systematic operational error, or the preparation of the schedules might have been guided by considerations preferring overscheduling. The phenomena mentioned above are illustrated by the following examples:

- sunny period: 30.07.2017 12:00 – 13:00 (CET), real PV power: 783 MW, DA forecasted power 461 MW;
- sunny period: 10.08.2018 12:00 – 13:00 (CET), real PV power: 748 MW, DA forecasted power 1008 MW.

Of course, it cannot be completely ruled out either that, simply, those preparing the prognoses did not have adequate information on the unfavorable, unexpectedly changeable cloudy weather of the following scheduling periods in the majority of the cases.

Regarding the ID data, it seems that the actual data and the forecasted values were related to PV systems of different capacities in 2020. This is illustrated below:

- sunny period: 02.08.2020 12:00 – 3:00 (CET), real PV power: 777 MW, ID forecasted power 386 MW.
- sunny period: 23.11.2020 10:00 – 11:00 (CET), real PV power: 400 MW, ID forecasted power 206 MW.

This was the reason why the proportions of the annual ID downward and upward regulation requirements to the energy production were only determined for 2021 (Table 19):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 31.6% and 1.6%. The ID scheduling showed inaccuracies of a lesser degree compared to the DA scheduling.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 21.3% and 2.7%. The use of ID scheduling could enhance the accuracy compared to DA scheduling only to a slight degree in this case.

q: SLOVENIA (SI)

In the case of Slovenia, it can be concluded that both under- and overscheduling characterized the DA and ID forecasts made for the PV power plants (Figure 21). It was only in 2015 when the data provision was not adequate. This is the reason why this country was not classified as one of the 'countries with significantly inadequate or incomplete data provision'. The data showed that the provision of DA forecast data started a few hours later than those of actual power on several occasions in 2015. This caused considerable deviations in scheduling. Due to this, it was only for 2015 that the quantities of the downward and upward regulation requirements were not determined from the differences of the real energy generation and the forecasts.

In 2016 – 2017, underscheduling was typical, while in the subsequent years it seems that a forecasting algorithm different from that used earlier was deployed, as the forecasting accuracy improved continuously. The proportions of the annual downward and upward regulation requirements to the energy production were as follows (Table 20.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 36.6% and 6.0%. By the deployment of ID scheduling some slight improvement could be reached.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 17.8% and 1.3%. The application of ID scheduling could enhance the accuracy compared to DA scheduling to some degree in the vast majority of the cases.

TABLE 19. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Romania.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	27.1	22.9	31.6	14.9	1.9	2.0	2.2	1.6
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	4.8	9.0	2.7	17.9	16.5	15.7	21.3	20.8
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	N/A	data error	3.6	2.9
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	N/A	data error	20.8	20.6
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	N/A	data error	-1.3	-1.3
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	N/A	data error	0.5	0.2

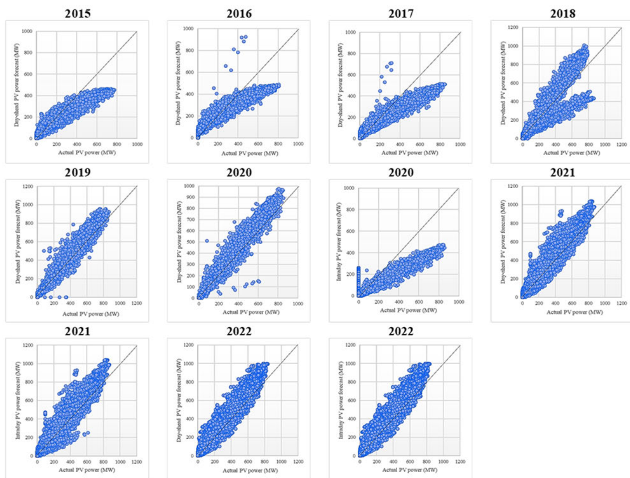

FIGURE 20. The joint distributions of the real and forecasted PV power data in the case of Romania in the examined years.

TABLE 20. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Slovenia.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	data error	36.6	31.6	21.0	11.4	3.6	6.0	6.6
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	data error	4.2	11.3	12.6	17.8	1.3	3.4	4.1
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	17.7	11.3	3.5	6.0	5.5
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	14.7	17.7	1.0	3.3	1.9
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	3.3	0.1	0.1	0.0	1.1
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	-2.1	0.0	0.2	0.1	2.2

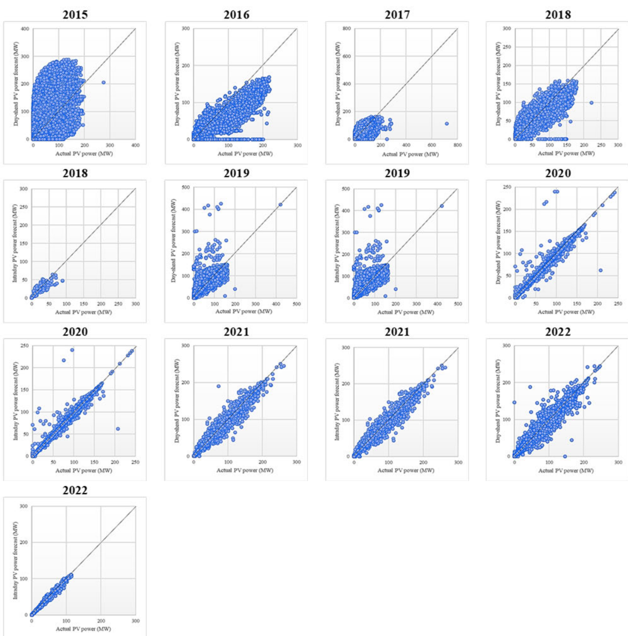

FIGURE 21. The joint distributions of the real and forecasted PV power data in the case of Slovenia in the examined years.

r: THE SLOVAK REPUBLIC (SK)

In the case of Slovakia, it can be seen that both under- and overscheduling characterized the DA and ID forecasts made for the PV power plants (Figure 22). The most probable cause of the phenomenon in this case may be that those preparing the prognoses did not have adequate information on the unfavorable, unexpectedly variable cloudy weather of the following scheduling periods. After 2020 it seems that an improved algorithm was introduced, as the accuracy of the forecasting improved somewhat compared to the previous years. The proportions of the annual downward and upward regulation requirements to the energy production were as follows (Table 21.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 26.4% and 12.5%. It was only in 2019 that some slight improvement could be achieved by the use of ID forecasting compared to DA forecasting. In the subsequent years, the DA and ID schedules were practically identical.
- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 31.1% and 13.2%. The use of ID scheduling resulted in some negligible improvement compared to DA forecasting only in 2019, after which the DA and ID schedules were practically identical.

TABLE 21. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of Slovakia.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	23.7	26.4	24.3	21.1	22.6	12.5	13.1	14.1
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	24.7	26.8	28.2	31.1	29.1	18.0	16.6	13.2
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	21.5	12.5	13.1	14.1
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	28.3	18.0	16.6	13.2
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	1.1	-0.03	0.0	0.0
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	0.8	-0.02	0.0	0.0

s: THE UNITED KINGDOM (UK)

In the case of the UK, both under- and overscheduling characterized both the DA and ID forecasts made for the PV power plants (Figure 23). Also in this case, the most probable cause of the situation may have been that those preparing the prognoses did not have adequate information on the unfavorable, unexpectedly variable cloudy weather of the following scheduling periods. The proportions of the annual downward and upward regulation requirements to the energy production were as follows (Table 22.):

- The proportion of the yearly downward regulation requirement to the energy generation in the case of the DA forecasts varied between 13.1% and 4.8%. By the deployment of ID scheduling some slight improvement could be reached.

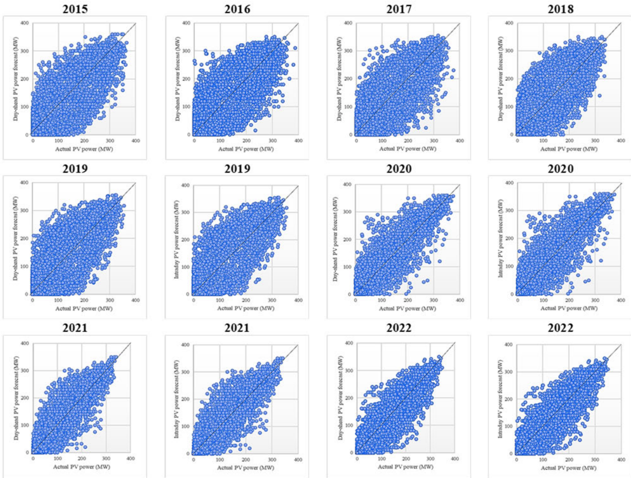

FIGURE 22. The joint distributions of the real and forecasted PV power data in the case of Slovakia in the examined years.

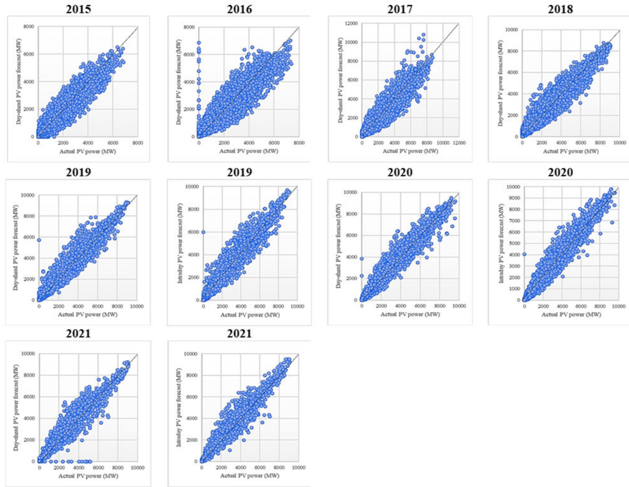

FIGURE 23. The joint distributions of the real and forecasted PV power data in the case of the UK in the examined years.

TABLE 22. The proportions of the annual PV-based downward and upward regulation requirements to the energy production in the case of the UK.

Denomination	2015	2016	2017	2018	2019	2020	2021	2022
The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)	13.1	12.9	12.2	8.4	4.8	5.3	5.1	13.1
The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)	8.0	10.9	10.6	11.4	8.6	7.4	10.3	8.0
The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	3.8	4.1	4.7	N/A
The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)	N/A	N/A	N/A	N/A	10.0	9.2	10.6	N/A
The improvement of the annual downward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	1.1	1.2	0.4	N/A
The improvement of the annual upward regulation requirement when using ID forecasting (%)	N/A	N/A	N/A	N/A	-1.3	-1.8	-0.4	N/A

- The proportion of the yearly upward regulation requirement to the energy generation in the case of the DA forecasts ranged between 11.4% and 7.4%. The deployment of ID scheduling resulted in less precision compared to the DA forecasts, albeit to an insignificant degree.

B. THE SUMMARIZED EVALUATION OF THE COUNTRIES SUITABLE FOR THE COMPARATIVE ANALYSIS OF THE SCHEDULING CHARACTERISTICS OF THEIR PV POWER PLANTS, BASED ON THE FIGURES OF THEIR ANNUAL DOWNWARD AND UPWARD REGULATION REQUIREMENTS

The examined countries showed great variation regarding the accuracy of the scheduling of their PV power plants. Tables 23 – 26 summarize what degree of precision was achieved in the particular countries, based on the information on their annual downward and upward regulation requirements. The color coding in Tables 23 – 26 is meant to help readers see and interpret the data regarding the studied countries:

- The closer the shade of the cell of a given figure to green is, the more accurate the forecast is. Dark green indicates a difference of 0%.
- The closer the shade of the cell of a given figure to red is, the more inaccurate the forecast is. Red means a deviation of 50%.
- The farther the color of a value from green is and the more it fades into yellow, orange and then red, the greater the magnitude of the downward or upward regulation needs was in the case of the DA and ID energy production forecasts.

Also regarding the figures of the individual years, based on the annual DA downward and upward regulation requirement values, it can be stated that Germany and Spain were able to produce more accurate forecasts than the other studied countries. This may be due to the geographical locations of the two nations, the sizes of their territories, the capacities and distributions of their PV power plants, as well as the accumulated experience of more than ten years in Germany's development activities in the field of PV system energy generation forecasting [71] and Spain's activities in the same field since 2013 [74]. Some countries with smaller areas and cloudier climatic conditions were still able to prepare relatively precise forecasts, albeit less accurate than those of Germany and Spain. These nations included Belgium, the Czech Republic, Greece, Hungary and Italy. Less accurate scheduling was carried out by Bulgaria, Estonia, Lithuania, Romania and Slovakia. The less precise forecasting in these countries may have been caused by the use of less time-tested forecasting algorithms, operational errors at the system level, scheduling with a preference for over- or underscheduling, or the occurrence of cloudier weather conditions.

TABLE 23. **The summarized evaluation of the countries suitable for the comparative analysis of the scheduling characteristics of their PV power plants, based on the figures of their annual DA downward regulation requirements (Dark green: 0% difference; red: 50% difference. The farther the color of a value from green, fading into yellow, orange, and red, the greater the regulatory need).**

	The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting (%)									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BE	8.9	8.3	8.7	9	8.9	7.4	7.6	7	8.3	7.7
BG	N/A	N/A	10.2	11.8	8.8	6.5	7.8	17.8	11.7	8.8
CH	N/A	N/A	9.4	8.5	4.6	4.6	5.3	data error	data error	data error
CZ	N/A	N/A	10.4	8.3	7.9	5.1	4.5	4.2	5.8	3.6
DE	N/A	N/A	3.9	3.3	4.2	3.4	3.9	3.3	3.5	3.2
DK	N/A	N/A	10	8.9	6.8	6	5.3	11.5	11.5	15.2
EE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	46.8	45.6	32.3
ES	N/A	N/A	4.8	3.6	3.4	4.3	4	3	3.8	4.4
FR	N/A	N/A	7	11.8	8.4	10.2	8.5	7.7	15.2	7.1
GR	N/A	N/A	6.7	5.3	data error	4	5.6	3.3	5	5.6
HU	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7.1	7.3	5.6
IT	N/A	N/A	N/A	N/A	N/A	N/A	7.8	5	7	7.3
LT	N/A	N/A	data error	data error	13.9	13	16.6	10.3	25.8	26
PL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10	4.3	12.7
PT	N/A	N/A	15.3	4.9	2.1	5.9	10.6	13.8	11.6	8.1
RO	N/A	N/A	27.1	22.9	31.6	14.9	1.9	2	2.2	1.6
SI	N/A	N/A	data error	36.6	31.6	21	11.4	3.6	6	6.6
SK	N/A	N/A	23.7	26.4	24.3	21.1	22.6	12.5	13.1	14.1
UK	N/A	N/A	13.1	12.9	12.2	8.4	4.8	5.3	5.1	N/A

TABLE 24. **The summarized evaluation of the countries suitable for the comparative analysis of the scheduling characteristics of their PV power plants, based on the figures of their annual DA upward regulation requirements (Dark green: 0% difference; red: 50% difference. The farther the color of a value from green, fading into yellow, orange, and red, the greater the regulatory need).**

	The proportion of the annual upward regulation requirement to the annual energy generation in the case of DA forecasting (%)									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BE	14.4	12.3	8.1	8.2	8.2	8.6	8	6.6	7.7	6.2
BG	N/A	N/A	14.6	12.5	15.7	22.5	20.9	6.5	9.4	18.5
CH	N/A	N/A	37.5	20	16.6	42.7	12	data error	data error	data error
CZ	N/A	N/A	7.8	9.7	9	5.8	6.1	6.4	4.4	5.2
DE	N/A	N/A	6.1	5.1	3.8	3.6	3.1	3.4	3.6	3.2
DK	N/A	N/A	6.4	7.2	7.1	8	10.8	5.7	6.8	8.1
EE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	17.6	1.8	1.1
ES	N/A	N/A	4.4	4.1	3.5	5.9	5.2	5.3	4.3	5.6
FR	N/A	N/A	8.5	10.6	7.1	7.4	9.1	9.1	20.5	10.9
GR	N/A	N/A	6.8	3.9	data error	6.3	4	5.2	10.3	7.3
HU	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.7	3.7	3.6
IT	N/A	N/A	N/A	N/A	N/A	N/A	3.3	2.5	2.9	2.5
LT	N/A	N/A	data error	data error	15.7	11.2	8.7	24.8	14.3	13.6
PL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.4	19.4	7.4
PT	N/A	N/A	10.5	10.2	11.6	17.3	8.9	10.8	9.3	9.2
RO	N/A	N/A	4.8	9	2.7	17.9	16.5	15.7	21.3	20.8
SI	N/A	N/A	data error	4.2	11.3	12.6	17.8	1.3	3.4	4.1
SK	N/A	N/A	24.7	26.8	28.2	31.1	29.1	18	16.6	13.2
UK	N/A	N/A	8	10.9	10.6	11.4	8.6	7.4	10.3	N/A

Similar conclusions can be made about the ID downward and upward regulation requirement figures as in the case of the DA schedules. In this case, the analysis of not 19 but 14 countries was possible. The deployment of ID forecasting generally had a favorable impact on scheduling accuracy. The application of ID scheduling could enhance the accuracy compared to DA scheduling in the vast majority of the cases.

Solar energy generated from PV systems is one of the most promising and fastest growing type of renewable energy. However, unlike the power generated from traditional sources, the power generated from PV systems is highly variable, as it depends on the solar irradiance and other meteorological conditions. To successfully integrate solar power in the electricity grid, there is a need for the accurate forecasting of the solar power output for different forecasting horizons.

Nowadays numerous studies that present PV power generation forecasting algorithms, systems or services are already available. However, their published results have not offered adequate insight into prognoses at the level of the nations in terms of accuracy so far. It was this lack of information that determined the innovative direction of the present study. The novel, practical contribution of the research presented in this paper is that it determines those characteristics related to the day-ahead and intraday PV forecasting accuracies of the ENTSO-E countries that are relevant from a practical perspective to the TSOs, the main actors of the energy market as well as the decision makers.

The results of the research highlight that it is of decisive importance to understand the country-specific characteristics of PV power forecasting methods used in each country. This is particularly important because the methods used in

TABLE 25. The summarized evaluation of the countries suitable for the comparative analysis of the scheduling characteristics of their PV power plants, based on the figures of their annual ID downward regulation requirements (Dark green: 0% difference; red: 50% difference. The farther the color of a value from green, fading into yellow, orange, and red, the greater the regulatory need).

	The proportion of the annual downward regulation requirement to the annual energy generation in the case of ID forecasting (%)									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BE	6.9	5.8	6.5	5.6	6.1	4.7	5.1	5.1	6.1	4.5
CZ	N/A	N/A	N/A	N/A	N/A	N/A	4.6	3.6	8.9	3.7
DE	N/A	N/A	data error	data error	data error	5.6	3.3	2.7	2.8	2.4
ES	N/A	N/A	N/A	N/A	N/A	3.9	3.5	2.3	3.1	4
FR	N/A	N/A	N/A	N/A	N/A	5.5	8	7.1	14.7	7.1
GR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	5.5
HU	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7.1	7.1	5.7
LT	N/A	N/A	N/A	N/A	N/A	17.4	16.4	10.4	13	13.6
PL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.7	3.9	11.1
PT	N/A	N/A	N/A	N/A	N/A	5	10.5	9.9	11.5	7.8
RO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	data error	3.6	2.9
SI	N/A	N/A	N/A	N/A	N/A	17.7	11.3	3.5	6	5.5
SK	N/A	N/A	N/A	N/A	N/A	N/A	21.5	12.5	13.1	14.1
UK	N/A	N/A	N/A	N/A	N/A	N/A	3.8	4.1	4.7	N/A

TABLE 26. The summarized evaluation of the countries suitable for the comparative analysis of the scheduling characteristics of their PV power plants, based on the figures of their annual ID upward regulation requirements (Dark green: 0% difference; red: 50% difference. The farther the color of a value from green, fading into yellow, orange, and red, the greater the regulatory need).

	The proportion of the annual upward regulation requirement to the annual energy generation in the case of ID forecasting (%)									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BE	12.3	11.2	6.1	5.6	6.3	5.6	5.8	5	5.2	4
CZ	N/A	N/A	N/A	N/A	N/A	N/A	6.1	5.8	5.5	8
DE	N/A	N/A	data error	data error	data error	2.6	2.7	2.9	2.9	2.9
ES	N/A	N/A	N/A	N/A	N/A	5	4.7	5.2	4.3	5.4
FR	N/A	N/A	N/A	N/A	N/A	6	8.5	8.6	20.3	10.3
GR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12.9	7
HU	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.2	3.3	3.1
LT	N/A	N/A	N/A	N/A	N/A	17.3	8.5	24.6	27.9	14.2
PL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.6	20.2	7.7
PT	N/A	N/A	N/A	N/A	N/A	16.6	6.7	9.3	10.2	8.6
RO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	data error	20.8	20.6
SI	N/A	N/A	N/A	N/A	N/A	14.7	17.7	1	3.3	1.9
SK	N/A	N/A	N/A	N/A	N/A	N/A	28.3	18	16.6	13.2
UK	N/A	N/A	N/A	N/A	N/A	N/A	10	9.2	10.6	N/A

different countries are not uniform and have different levels of development, resulting in significant differences in accuracy. It would be advisable to develop a uniform European day-ahead and intraday PV power forecasting system based on the best practical solutions. This would allow for more efficient PV integration compared to different approaches. This would also facilitate the more efficient planning and forecasting of PV power generation in Europe. Based on the data collected and analyzed in a unified system, it would be possible to better time PV generation, make optimal use of capacities and ensure grid stability. This would increase the efficiency and reliability of energy production from variable renewable energy sources, contributing to achieving the goals of sustainable energy production.

The research has proven that it is not possible to prepare 100% accurate schedules for the energy generation of solar power plants because of the various natural effects, which leads to unpredictable expenses. The study has shown the accuracy of the daily and the intraday scheduling of energy generation in the PV systems of the ENTSO-E countries. Nowadays, this information is important to the main actors of the energy market and the decision makers because it allows them to learn about the limitations of the accuracy of the forecasting methods of all ENTSO-E member states. Moreover, this knowledge is of help to investors investing in PV power plants with the economic aspects of their investments, and it may also contribute to the market-related development of the management systems of energy storage solutions related to PV technology. It is important to point out that this kind of information is extremely important for the deployment of VRES. Therefore, it is essential to further expand the related body of knowledge, which is the aim of future research.

IV. CONCLUSION

Solar photovoltaic plants are widely integrated into most countries' electric power systems worldwide. Due to the ever-growing utilization of solar photovoltaic plants, either via grid-connection or stand-alone networks, dramatic changes can be anticipated in both power system planning and operation. Solar photovoltaic integration requires the capability of handling the uncertainty and fluctuations of power output. Consequently, solar photovoltaic power forecasting is a crucial aspect to ensure the optimal planning and modelling of solar photovoltaic plants. Accurate forecasting provides grid operators and power system designers with significant information to help with the design of optimal solar photovoltaic plants as well as with the management of power demand and supply.

The examined countries displayed a varied picture concerning the accuracy of the scheduling of their PV power plants. Regarding also the figures of the individual years, it can be stated that Germany and Spain were able to produce more accurate forecasts than any of the other studied countries. The proportion of the annual downward regulation requirement to the annual energy generation in the case of DA and ID forecasting in these two countries varied between 5.6% and 2.3%. Furthermore, the proportion of the yearly upward regulation requirement to the energy generation, in the case of the DA and ID forecasts, ranged between 6.1% and 2.6%.

Contrary to that, there were less precise scheduling practices too. It even occurred that the proportion of the annual downward regulation requirement to the annual energy generation in the case of DA forecasting reached 46.8%. In the case of ID scheduling, it was 21.5% at most. There was also an instance when the proportion of the annual upward regulation requirement to the annual energy generation reached 42.7% in the case of DA forecasting. When deploying ID scheduling, it was 28.3% maximum.

The goal of the future investigations is to determine the information presented in this study in the context of wind energy too.

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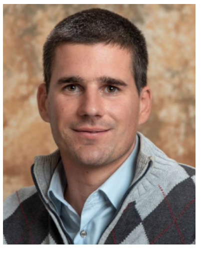

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