System costs of European Electricity Transmission System Operators – A Benchmark

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Abstract: Ongoing discussions on the efficiency of the European internal electricity market tend to focus on particular aspects of the power system operation, such as the evolution of redispatch costs over the last years. Given the structural heterogeneity of European electricity systems, it seems intuitive not only to look at economic aspects but also to fundamental features of those systems. Additionally, although important steps towards data transparency have been taken, harmonization across countries has yet to be fully achieved. In this paper, we analyse and compare costs for relevant activities of electricity transmission system operators (TSOs) in six European countries. The study is based on available public information on congestion management, balancing, and other ancillary services. Our benchmark provide insight into the costs incurred by TSOs, including additional dimensions concerning power system characteristics. We highlight the role of heterogeneous structural differences across countries for the system costs, along with the approaches for addressing the ambitious decarbonisation targets. The framework outlined in this paper contributes to a more balanced discussion on the efficiency of electricity transmission operators.

Keywords: System costs; Electricity transmission system operator; Redispatch costs; Integration vRES; Benchmark

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1. Introduction

With the implementation of several network codes and guidelines, the European Commission drives the full integration of the internal electricity market. The European target model for power markets provides a clear outlook of the power system in the future, integrating cleaner resources efficiently to achieve decarbonisation targets in all sectors. In this context, increasing efficiency in the operation of the electrical systems is particularly important for maximizing the net economic and environmental value of electricity. Nevertheless, the perceived unused potential for improvement in market integration has fostered an ongoing debate among different market actors [1, 2]. Concerns about the efficient use of interconnectors and the volume of loop flows affecting several countries in Central Europe are some of the critical issues to be addressed by the transmission system operators (TSOs). As a result, the adaptation of the current market design has been brought up as one of the options for reducing system inefficiencies. Accordingly, the requirement to review the configuration of the bidding zones was integrated into the European legislation (EU Regulations 2015/1222 and 2019/927). Some academics even propose more fundamental changes in the market design, such as the introduction of locational pricing signals [3,4,5]. Against this background, the increasing congestion management costs in Germany have been the subject of many discussions, from economical, technical, and political perspectives [6,7,8]. However, when trying to assess the efficiency regarding the costs incurred in relevant system services, it seems intuitive not only to look at the economic aspect but also at fundamental features of the systems. The rationale appears straightforward: specific characteristics of the electricity system determine its complexity widely and, therefore, the monetary efforts required to provide reliable system operation could be expected to be correlated to said complexity. For instance, the challenges faced by systems with a high penetration level of renewable energy sources (RES) may differ from a system where this is not the case. The operational efforts may even be exacerbated by a large share of weather-dependent RES, such as wind and photovoltaic generation units.

Regulatory authorities publish regularly detailed data concerning the electricity generation mix and installed capacity. Similarly, official data sources provide valuable information about the system costs arising from the core activities of the TSOs. However, this information is mostly neither harmonized nor centrally published, which hampers an objective comparison between electricity systems with different features and challenges. Since transparency is a critical element of the internal European electricity market, we explore in this paper available public information concerning relevant system costs, such as congestion management, balancing, and other ancillary services. An additional dimension is then considered for capturing specific features of the electricity systems for which the following fundamental indicators are assessed: the electricity generated, the penetration of weather-dependent RES in the system, and the CO_2 emissions level. Thus, by including fundamental system features to a discussion based solely on system costs, we provide an assessment framework for a more balanced discussion about the efficiency of European TSOs.

The paper is organized as follows. Section 2 gives an overview of available literature dealing with TSOs performance in a broader sense. Section 3 presents the information gathered and the building of indicators for benchmarking. A discussion on the results is presented in Section 4, and Section 5 provides the conclusions and future work.

2. Findings on Transmission System Operators efficiency

An objective efficiency assessment of any system requires the availability of reliable and robust data. If efficiency levels from different systems are to be inferred from such an assessment, data comparability becomes an essential element to consider. In the following, we briefly describe the most relevant literature and data sources available for assessing TSOs efficiency.

2.1. The ENTSO-E Transparency Platform

Concerning data on the European electricity systems, the European Network of Transmission System Operators for Electricity (ENTSO-E) created a freely available online platform to provide basic information from all 28 European TSOs [9]. This platform may be considered as the central primary source of information about power systems in Europe. However, users may encounter several issues when searching for specific data. Indeed, anecdotal evidence shows that data complete-ness varies strongly across countries. There is limited or no data for some categories, and significant discrepancies can be found when comparing data with other official sources, such as national reports. Justified reasons for the lack of completeness may undoubtedly exist, and those are not to be easily ignored. Nevertheless, comparability among observations delivered by the system operators should contribute to increasing transparency. Hirth et al. [10] found similar results, highlighting the shortcomings in the documentation, which hampers data quality significantly.

2.2. Literature addressing TSOs performance

The Transmission Cost Benchmarking project, an initiative by the Council of European Energy Regulators (CEER), published results of a Pan European cost-efficiency benchmark for electricity TSO [11]. The study collected and validated data from several TSOs for building efficiency indicators, which comprised transportation work, capacity provision, and customer service. Despite the efforts for providing reliable data and models, the submitted information was classified as confidential and details for individual operators were not disclosed. Even though data confidentiality is compliant with current regulations, the results do not provide the whole picture since vital information about the respective systems, such as generation portfolio and system dynamics, cannot be inferred. The CEER Benchmarking reports [12,13] are another source of information. They provide relevant figures for a broad range of transmission operators, which allows for a straightforward comparison. Nevertheless, the focus remains on the quality of supply. Couto and Camanho [14] evaluated the performance of European power systems. Similar to the CEER study, the authors use a Data Envelopment Analysis (DEA) for exploring TSOs performance concerning the quality of service, network costs, and environmental impact. The Agency for the Cooperation of Energy Regulators (ACER) in cooperation with CEER publish annual reports on the monitoring of the internal electricity market. The focus lies on key developments of the electricity wholesale markets, such as price convergence, the evolution of available cross-zonal capacities made available to the market, and its efficient use [e.g. 1]. In [15] ENTO-E provides an analysis of the current bidding zone configuration focusing on grid congestions, flows schedules outside the market, and costs for these congestions. Similar to the other sources, limited attention is given to the system characteristics.

2.3. Other sources

National reports by regulatory authorities and the TSOs themselves provide relevant information concerning system costs. Still, the level of detail varies broadly across countries, and it becomes evident that a harmonized publication of relevant TSOs information has yet to be fully achieved.

Given the available literature and data sources, the authors see the need for alternative approaches for evaluating TSO performance, using publicly available sources, and taking into ac-count relevant system characteristics. Thus, we introduce in this paper an assessment framework for presenting an overview of the efficiency of European TSOs taking into account system complexity.

3. Methodology

An efficiency assessment based on system costs alone may not provide the whole picture since transmission operators face different challenges deeply related to the system they manage. Nevertheless, the brief overview of the literature available presented in Section 2 shows that the comparison efforts neglect to take into account additional parameters. For this reason, the present study builds on those findings and expands the efficiency assessment by weighting in fundamental electricity system indicators. In this Section, we introduce the relevant system costs and electricity system characteristics upon which this analysis is based on.

3.1. System Costs

In order to allow an objective comparison, this paper focuses on comparable costs directly related to the system operators. One of the core activities of European TSOs being the secure and reliable operation of the electricity system, the categories addressed are congestion management, balancing, and complementary ancillary services. In the following, we describe briefly each cost category along with the rationale behind its inclusion. A detailed financial analysis for assessing the overall competitiveness of the TSOs is out of the scope of this study.

a) Congestion management: Grid congestions occur when there is a mismatch between transmission requests and available transmission capacity. In such situations, the system operator has to take action to avoid or relieve congestions in order to ensure the security and reliability of the transmission system. The congestion management process can be defined as “any systematic approach used in scheduling a matching generation and loads in order to manage congestion.” [16]. It seems intuitive to include this cost category since increasing congestion management costs in several countries is the focus of many discussions.

b) Balancing: The procurement and use of balancing services are one of the primary responsibilities of a system operator. Balancing is defined as “all actions and processes, on all timelines, through which TSOs ensure, in a continuous way, the maintenance of system frequency within a predefined stability range…” [17]. Balancing costs are included as they provide insights into the economic efficiency of the system operation.

c) Other ancillary services: Additional services are required to maintain the electricity supply reliability, such as reactive power, black start capability, and grid losses. It is to note, that the scheme for recovering costs varies across countries. For instance, the TSOs in Germany, France and Austria use a market-based procurement to cover their grid losses. In Great Britain and Spain, the suppliers are obliged to cover their grid losses and they pass the costs directly to the consumers. Lastly, in Italy the TSO only procures the difference between actual and the so-called standard losses, which are procured by the balance responsible party [18].

An in-deep discussion on the congestion management and balancing schemes used by the different TSOs is out of the scope of this analysis. For a more comprehensive discussion on these processes, the reader is referred to [19,20,21].

3.2. Specific system costs

We introduce the concept of specific system costs, which we define as follows:

$$Specific\ System\ Costs = \frac{SC_i}{E_i}, \qquad (1)$$

Where SC are the costs defined in Section 3.1 for system *i* and E is the amount of electricity generated in the same system. In this way, the incurred systems costs can be assessed related to the size of the system.

3.3. System indicators

An electric system can be defined from different perspectives. For instance, a technical (load curve, infrastructure), market (price volatility, market design, and organization) or a regulatory perspective (composition of the electricity bill, network tariff design) may be used for describing a specific system. Given that the focus of this assessment lies in the operational challenges directly related to TSOs activities, the features considered are the electricity generated, the penetration of weather-dependent RES in the system, and the CO2 emissions level.

a) Electricity generation: This indicator reflects the amount of electricity being fed into the grid and managed by the system operator.

b) Penetration of weather-dependent RES (wind and solar): The growing deployment of RES and its integration in the system poses challenges to the system operation due to the higher volatility and uncertainty associated. Therefore, the degree to which the installed capacity of weather-dependent generation units, namely wind and solar, are integrated into the system reflects the associated system complexity. Even though run-of-river hydropower relies on water availability, which depends on multiple climatic drivers, this resource is not included in this parameter due to its inherent flexibility. Additionally, no significant development in this area is expected in many countries since the development potential for increasing hydropower capacity can be considered as exhausted or not economically feasible [22,23].

c) CO_2 intensity: For our analysis, we define CO_2 intensity as the CO_2 emissions per generated unit of electricity. In view of the ambitious European decarbonisation targets, emissions attributed to electricity generation will have to be near zero by 2050 [24,25]. Meeting climate goals remain a challenge, in particular for those countries with an extensive use of fossil fuels for electricity generation, increasing the relevance of low-carbon technologies. Even though the role of nuclear power and carbon capture technologies remain unclear and it may differ across countries, the extant literature predicts the crucial role of weather-dependent RES.

It can be argued that other system features may have an impact on the system complexity as well, such as the geographical nature of the electricity system (i.e., topography, land use, climate) and population density, among others. Nevertheless, we feel that the three system features considered giving a robust indication of the system complexity.

4. Results and discussion

The costs for the categories and the system characteristics introduced in Section 3 were collected from publicly available sources. Detailed data on electricity generation and installed capacity is provided by ENTSO-E for all members TSOs' countries and for the years 2015-2018 [26-29]. As pointed out earlier, system costs data availability is rather reduced due to the lack of a central and harmonized publication of relevant TSOs information. Nevertheless, data on the relevant cost categories for six countries were available for this study: Austria [30-35], Germany [36], Spain [37-40], France [41-44], Great Britain [45], and Italy [46,47]. These six countries accounted for around two-thirds of the total EU electricity generation in 2018 [26].

Using Equation 1, the evolution of the specific system costs from 2015 to 2018 is shown in Figure 1. A detailed assessment of the reasons behind the development of the cost in each country would require a lengthy departure from the scope set out in this paper. Nevertheless, it is to note, that while France has a low interannual variability, Germany, the United Kingdom, Italy, and Austria show a higher variability across the years considered. Moreover, a strong downward trend can be observed in Spain.

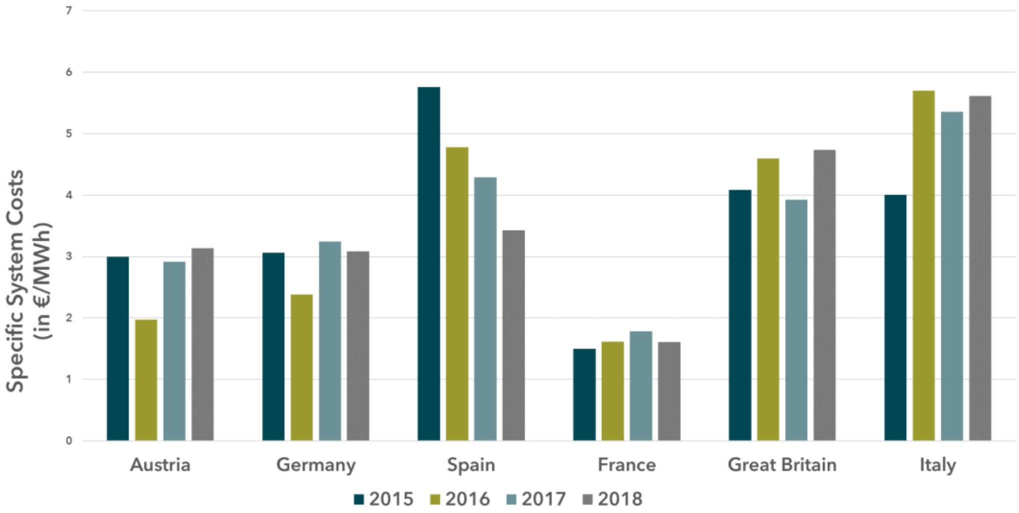

Figure 1. Specific system costs for several countries. Own estimation

By drawing upon the system characteristics introduced in Section 3, we provide relevant additional information for a more objective comparison. Figure 2 depicts the generation mix in several European countries in 2018, showing its heterogeneity [26]. While countries like Austria account for substantial hydropower contributions, other countries have restricted access to this resource. On the other hand, countries like Germany, Spain, and the United Kingdom show a significant share of electricity generation from wind and solar units. Moreover, France relies heavily on the contribution of conventional energy sources, such as nuclear power, coal, and gas.

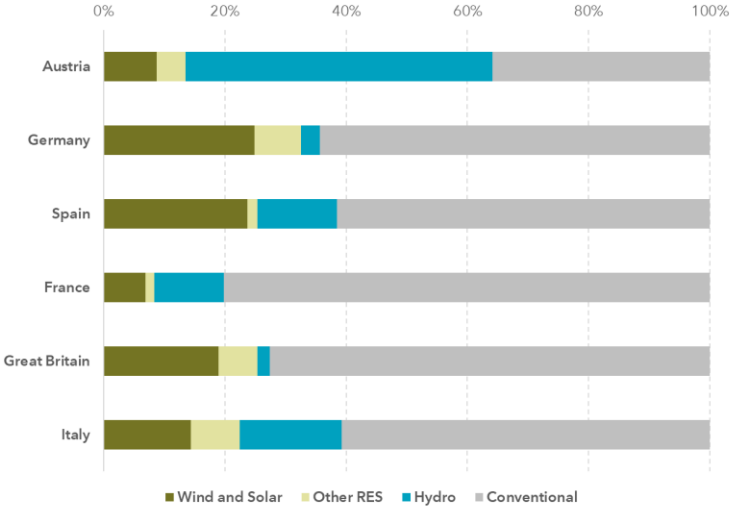

Figure 2 Electricity generation mix for the year 2018.

The share of wind and solar installed capacity for the same European countries and year is shown in Figure 3 [26]. The ranges of penetration vary from below 20% in Austria and France to almost half of the total installed capacity in Germany. The United Kingdom and Spain show a large share of weather-dependent resources, which is dominated by wind capacity. A balanced share between solar and wind is found in Germany, whereas solar capacity has a larger share in Italy.

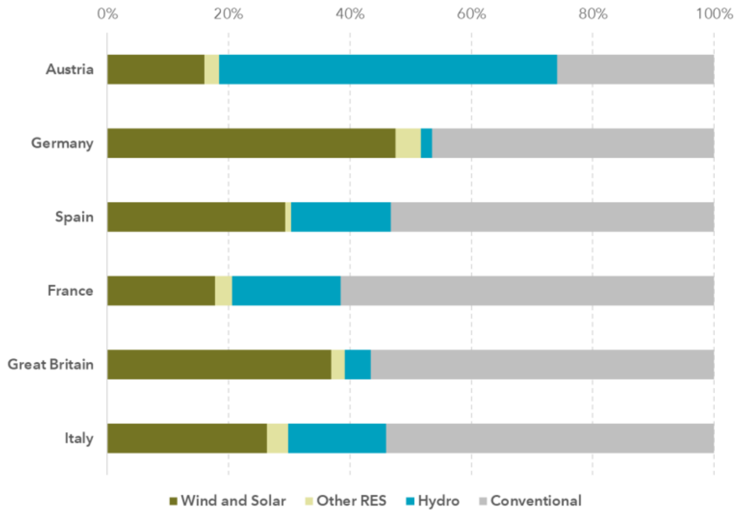

Figure 3 Installed capacity for the year 2018.

Using data from [48], Figure 4 shows the evolution of the CO_2 intensity in the countries of interest over the last four years. Similar values are observed in France and Austria, in the former country due mostly to low-carbon nuclear electricity generation and to the share of hydropower in the latter. Spain, Italy, and Great Britain have values around two times higher, which reflect a higher share of fossil-fueled power generation in those countries. While Germany has the highest value of the six countries in our analysis, a strong downward trend can be observed. For achieving decarbonisation targets, each country has implemented actions to curb greenhouse emissions – An in-depth assessment of the progress of European countries in this matter is found in [49]. Of particular relevance for the electricity sector is the phase out of coal, which poses different challenges across the countries analysed. For instance, the share of coal in the electricity mix of Germany yields around one third of the total generation as of 2018, a significant difference when compared to France (1%) and Austria (3%) or even Great Britain (6%), Italy (10%), and Spain (13%).

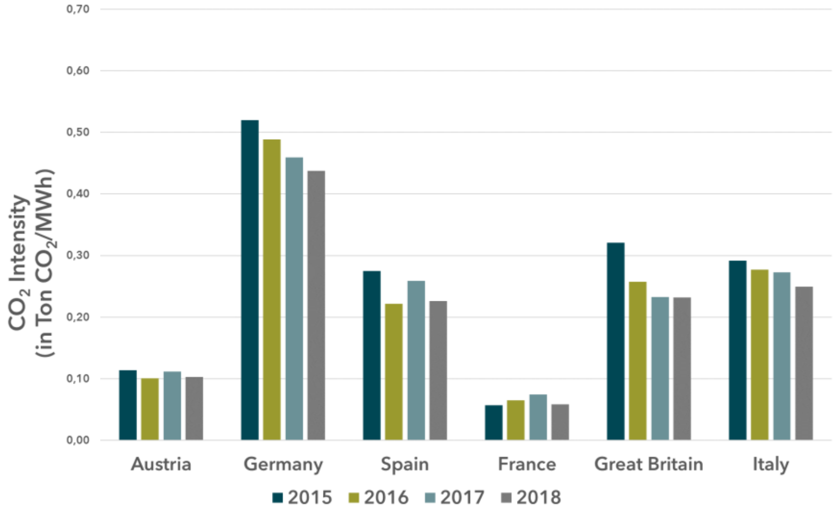

Figure 4. Evolution of CO_2 intensity

Given the data presented above, we now use both dimensions (costs and system features) for building a benchmarking chart with the system costs on the x-axis and the relevant system characteristic in the y-axis. The metrics are then plotted in such a way that the upper left quadrant represents a higher efficiency than the lower right quadrant. The advantages of using this benchmarking approach are twofold: It allows us to identify the outliers and role models, and on the other hand, to explain the cost differences across countries to some extent. For instance, Figure 5 shows the share of RES in the total amount of electricity generated against specific costs. In this case, it can be argued that the target system would have a high penetration of RES paired with low specific system costs (upper left quadrant). In this case, the diagram shows several countries with low specific system costs paired with a low share of RES. Austria could then be considered an outlier, which can be partly explained by the large share of hydropower in the system.

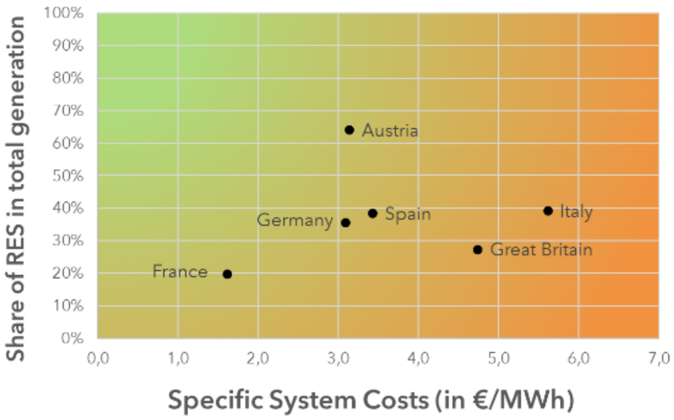

Figure 5 Specific system costs and share of RES in total generation

It seems evident that the hydro component in the generation mix plays a significant factor in the system costs. As mentioned in section 3, the expansion potential for hydropower is perceived as low in several countries. Lack of locations economically feasible for new developments and high environmental requirements hamper new developments. As a result, improving the efficiency of existing hydropower plants is regarded as the only option for increasing hydropower share in the electricity mix [22]. Consequently, we look into the integration degree of wind and solar resources and the corresponding benchmark is shown in Figure 6. From the low share in Austria and France could be inferred that wind and solar are regarded as complementary to other available resources (i.e., hydro and nuclear). Germany has the highest share, which accounts for almost half of its total installed capacity. Thus, it seems that Germany integrate volatile generation at lower specific system costs when compared to the other countries in our analysis.

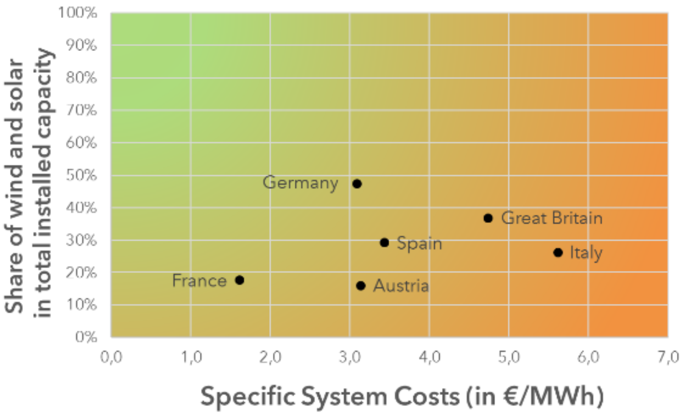

Figure 6 Specific system costs and share of wind and solar in total installed capacity

Finally, the CO_2 intensity against specific system costs is shown in Figure 7. Again, the nuclear and hydropower contributions are reflected in the low carbon intensity of France and Austria. As already observed above, the large share of coal in the electricity mix of Germany is reflected clearly in the benchmark. Hence, it is not surprising that as part of its transition towards a carbon-free economy, Germany will shut out all of its coal-fired power plants by 2038 at the latest (Act to Reduce and End Coal-Fired Power Generation).

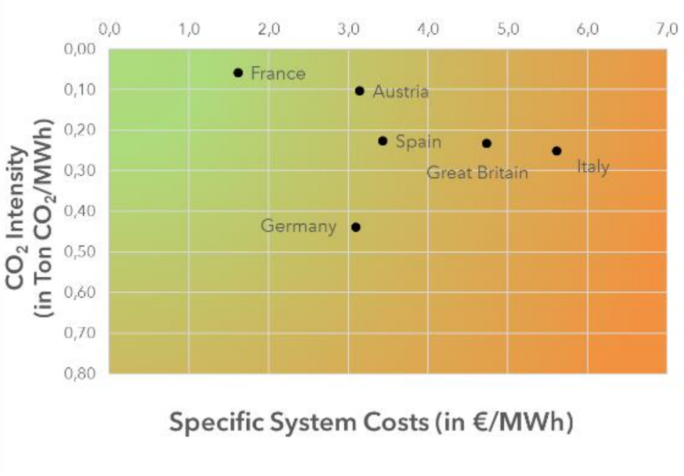

Figure 7 Specific system costs and CO_2 intensity

In summary, the data presented in this study suggest that the specific costs correlate directly with the share of wind and solar penetration in the system. However, when a system has a large share of nuclear or hydro resources available, the relationship mentioned above is weaker, making that system an outlier in our benchmark. Given that many countries have no potential to increase their hydropower capacity significantly and nuclear power is socially and politically accepted in only some European countries, the deployment of wind and solar will continue to be a crucial element to achieve decarbonisation targets. The increasing operational challenges faced by systems with high shares of wind and solar generation have been discussed at length in the literature [50-53]. Against this background, the German system provides some interesting features: Despite the integration of the highest share of wind and solar capacity, the specific system costs derived are comparable to those of countries with significantly lower shares of those resources, and therefore, less volatility.

Moreover, the lumpiness of transmission grid development has not hampered the integration of wind and solar capacity. In fact, the installed wind and solar capacity accounted for almost the same amount of conventional capacity. One reason to explain the efficiency savings may be found in the high system flexibility and coordination across processes [54]. The coordinated processes may be suitable for other electricity systems that have similar characteristics and market designs since they will probably face increasing internal grid congestions due to an increasing share of wind and solar in their system.

5. Conclusions

This paper provides insight into the costs incurred by TSOs for some of their core activities in six countries, including additional dimensions concerning fundamental system characteristics. The authors believe that such inclusion is essential for allowing a more balanced discussion on the efficiency of TSOs. Further, the results identify systems with a large share of wind and solar resources paired with specific system costs comparable to those of systems with a lower share. A more in-depth analysis of the reasons behind this development could be the subject of future research. Considering the operational challenges posed to the system with high penetration of weather-dependent RES will most probably be faced by a large number of systems in the near future. Thus, closer collaboration and sharing of best practices may prove to be a crucial element for reaching the ambitious European decarbonisation targets in an efficient manner. It is recognized that more sophisticated methodologies may provide additional conclusions. For instance, relevant environmental factors could be included for taking into account heterogeneous operating conditions. Finally, a higher harmonization in the publication of relevant TSOs information will undoubtedly contribute to more transparency in the assessment of electricity systems.

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Supplementary Information

Detailed sources of system costs, all values in millions of Euros

S.1. System Costs – Austria

Concept	2018	2017	2016	2015	Source
Congestion Management	116,59	90,30	28,81	23,20	[30]
Balancing	69,70	95,80	88,50	145,30	[31 - 34]
Grid Losses	24,98	18,73	22,26	24,97	Own calculations, as this value is not specifically reported. Using procurement cost for grid loses at the distribution and transportation level [31] and the amount of the losses at the transportation level [18], a conservative value for this category was estimated
Total	211,27	204,83	139,56	193,47	

S.2. System Costs – Germany

Concept	2018	2017	2016	2015	Source
Congestion Management	1.438,40	1.510,70	893,00	1.141,20	[36]
Balancing	151,30	172,40	223,60	343,70	[36]
Grid Losses	273,20	280,40	304,80	277,40	[36]
Other	18,40	19,60	43,60	37,70	[36]
Total	1.881,30	1.983,10	1.465,00	1.800,00	

S.3. System Costs – Spain

Concept	2018	2017	2016	2015	Source
Congestion Management	390	391	546	736	[39] and [40]
Balancing	197	187	217	274	[39] and [40]
Grid Losses	N/A	N/A	N/A	N/A	
interruptibility services	316	525	503	508	[37] and [38]
Other	8	23	-13	24	[39] and [40]
Total	911,00	1.126,00	1.253,00	1.542,00	

S.4. System Costs – France

Concept	2018	2017	2016	2015	Source
Grid losses	444,921	503,683	n.a.	465,738	[41] - [44]
Costs other than grid losses	439,08	439,32	n.a.	354,26	[41] - [44]
Total	884,00	943,00	859,00	820,00	[41] - [44]

S.5. System Costs – Great Britain

Concept	2018	2017	2016	2015	Source
SBR and DSBR (Balancing Reserves)	0	0	118	27	[45]
Black start	49	58	134	0	[45]
System	680	512	413	428	[45]
Energy (excluding SBR abd DSRB)	461	509	543	514	[45]
Total in millions of £	1190	1079	1208	969	[45]
Currency convertion- Average Closing Price	0,88	0,88	0,82	0,73	
Total in millions of Euros	1352,3	1226,1	1473,2	1327,4	

S.6. System Costs – Italy

Concept	2018	2017	2016	2015	Source
Dispatching services Market (DSM)	1573	1528	1561	1081	[46] and [47]
Total	1573	1528	1561	1081	

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