Study on the quality of electricity market data of transmission system operators, electricity supply disruptions, and their impact on the European electricity markets

Final report

VVA, Copenhagen Economics, Neon, Deloitte
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Contact: Balazs JOZSA

E-mail: balazs.jozsa@ec.europa.eu

European Commission
B-1049 Brussels

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0. LIST OF ABBREVIATIONS

Abbreviation	Full name
ACER	Agency for the Cooperation of Energy Regulators
CEER	Council of European Energy Regulators
DSO	Distribution System Operator
ECP	Energy Communication Platform
EEX	European Energy Exchange
ENTSO-E	European Network of Transmission System Operators for Electricity
MoP	Manual of Procedure
NTC	Net transfer capacity
NRA	National Regulatory Operator
Q&A	Questions & Answers
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
ToR	Terms of Reference
TP	Transparency Platform
TSO	Transmission System Operator
UMM	Urgent Market Messages
VoLL	Value of lost load

1. EXECUTIVE SUMMARY

1.1 Objective and scope

The “Study on the quality of electricity market data of transmission system operators, electricity supply disruptions, and their impact on the European electricity markets” was carried out by VVA (lead), Copenhagen Economics, Neon and Deloitte for the European Commission (DG ENER) under the framework contract ENER/A4/516/2014. The study aimed to assess the completeness and quality of electricity market data reported by transmission system operators, identify and fill the data gaps related to electricity generation outages and supply disruptions as well as assess their impacts on consumers and on the market. The study covered the 28 Member States and the period 2010–2016.

1.2 Methodology

The study consisted of two work packages, both covering the 28 EU member states and involving data-intensive analyses, but independent from each other otherwise.

Work package 1 (Outputs 1 and 2) aimed to evaluate the quality of the data provided by European TSOs through the ENTSO-E Transparency Platform[1] (TP) as well as the legal conditions upon which it can be used. Understanding to which degree market participants have access to this data is vital for facilitating efficient production, consumption and trading decisions as well as deeper market integration and the integration of variable renewable energy sources.

For the technical evaluation (Output 1), an extensive statistical assessment was conducted, an online user survey was implemented, and experts were interviewed. The work package covers the period 2015–2016. For the legal evaluation (Output 2), a legal opinion was commissioned from a specialized lawyer.

Based on these steps, we provided a detailed analysis of the completeness, accuracy, timeliness and technical accessibility (user friendliness) as well as legal accessibility of the data published in the ENTSO-E Transparency Platform, thus assessing the extent to which TSOs are fulfilling Commission Regulation (EU) 543/2013.

Work Package 2 (Outputs 3 to 6) aimed to provide information on the electricity outages and significant electricity supply disruption events in the 2010–2016 period, with an analysis of their causes and their impact on the electricity market. We also assessed to what extent voluntary demand curtailments are used to face supply disruption events, and which supply margins they offer. Finally, we estimated the value of lost load resulting from the significant supply disruption events, representing the cost for society of these disruptions.

This work package was articulated between desk-based research on the ENTSO-E platform and publications from national regulators, electricity providers, TSOs and DSOs on the one hand, and stakeholder consultation via web-based surveys or in-depth interviews to complete the information.

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[1] https://transparency.entsoe.eu/

The identification of the main features and causes of electricity outages and supply disruption events as well as the use of voluntary demand curtailments and the value of lost load are essential to reduce the impact of such events and strengthen security of supply.

1.3 Findings of the study and conclusions

1.3.1 Work Package 1

1.3.1.1 Analysis of ENTSO-E datasets (Output 1)

Output 1 aimed to evaluate the quality of data published through the ENTSO-E Transparency Platform (TP) as well as the user friendliness of the platform itself. In the following, the core findings and conclusions are presented.

Completeness

Assessing completeness means verifying whether all data items specified in Regulation 543/2013 are available on the TP for all geographic entities that apply and for all time steps since January 5, 2015, when the Regulation came into force. We identified two types of issues regarding completeness:

- Missing data: data that should be published are not (data gaps)
- Information about missing data: users are not informed about data gaps

Additionally, some users requested broader coverage and identified data they would be interested in that go beyond what is prescribed in Regulation 543/2013.

Our assessment confirmed that **many of the data items are incomplete**. For example, only one third of all countries have reported a complete time series of "Actual Total Load" and there is only a single case of a complete time series for "Day-ahead Prices". This is problematic as even just 1% of missing data can render the entire time series useless for many analyses. While most gaps in the data concern a few hours or days, some are stretching for an entire year.

Moreover, the information of users about missing data is very limited. **There is no overview of data completeness**, a fact that complicates the use of TP data.

Accuracy

The accuracy analysis identifies whether data are "correct"; as a metric, we compared values on the TP to values reported elsewhere. We found four major issues related to accuracy of the TP:

- Inconsistencies with other ENTSO-E data,
- Inconsistencies with other data sources,
- Information about inaccuracy: users are not informed about incorrect data and
- Inaccurate data definitions.

While inconsistencies between TP data and another source does by itself not imply that the TP data is incorrect (the inconsistency might stem from deviating data definitions, or the other source might be wrong), **we find the level of inconsistency considerable**. Comparing "Actual total load" and "Aggregated wind generation per type" with data from Eurostat and ENTSO-E's own Power Statistics, we find deviations for both data items for all countries, with differences ranging from minus 25% to plus 95%. The extent and the pattern of the deviations vary widely between countries and over time.

As in the case of completeness, **users are not informed about inaccuracies**, nor can they inform other users if they identify problematic data. Finally, unclear data definitions lead to inaccurate data due to inconsistent interpretation by Data Providers (e.g., is a 100 MW reporting threshold applied to individual machines such as a wind turbine or entire power plants such as a wind farm).

Timeliness

Assessing timeliness means confirming that data are published on the TP within reasonable timeframes, ideally those specified in Regulation 543/2013. We relied on user input for the timeliness assessment, in particular from market participants. We summarize the main issues with timeliness as follows:

- Outage data and UMMs
- Overwriting forecasts
- Delays in data availability

Timeliness is of particular importance for data used by market participants to inform their trading decisions such as outages of generation and consumption units as well as transmission grid elements, altogether referred to as "Urgent Market Messages" (UMMs). Outage data is one of the areas of particular concern: **Users report that the UMM data published on the TP is burdensome to work with, as there are often duplicates or inconsistencies with other sources that also publish UMMs. Furthermore, users were missing an overview of all outages for a single asset.**

Another issue is that data are overwritten by updates even though the historical values may also be relevant for analysis. **Users complained of useful historical data being overwritten by updates** without any indication of whether there was an update, when it was made and where historical data would be available. Finally, users reported **numerous examples of deadlines that were not adhered to**.

User friendliness

We assessed user friendliness by means of an online survey and expert interviews as well as our own experience with the TP. Issues regarding user friendliness can be categorized into six broad categories:

- Website and GUI, including ease of finding data, data presentation and ease of accessing data for downloads;
- Automatic downloads, including useful documentation and reliable access;
- Data files;
- Displaying data availability, including why data is unavailable;
- Data documentation and

- User support.

Regarding the website, the main issues are **slow response times and impractical navigation** that do not allow users to find relevant data and restrict download to one country at a time. A quickly accessible overview on data availability, showing which data items are expected for which countries would be valuable for users. **Users are overall satisfied with the more advanced download options FTP and Restful API, but many are not aware these options exist or how to use them** because of lacking information on the website. Availability and quality of data definitions is another issue.

The TP does not publish contact details or even the identity of Data Providers or Primary Data Owners. All requests for user support are channelled through the TP service desk, which usually does not publish its replies, so future users are not warned about quality issues. Some users report waiting sometimes very long to get an answer to their requests.

Suggestions for improvements

The individual issues outlined in the sections on completeness, accuracy and timeliness should be improved upon. The objective should be to increase completeness of time series data such as load, prices and generation to 100%. Inconsistencies with other data sources should be resolved or explained. The provision of event-driven data, i.e. outage data (7.1.A&B, 10.1A&B, 15.1.A–D) should be improved due to its importance for market actors: the messages should be displayed in a sensible order, duplicates are to be avoided and older versions of UMMs should be retained and not overwritten.

Furthermore, we developed the following suggestions for improvements that do not pertain to individual data items, but rather to cross-cutting issues related to usability, incentives and governance:

- Improve information and navigation
- Introduce a crowd-sourced public data quality log
- Introduce automatic quality reporting
- Publish machine-readable metadata
- Adjust governance, ownership and incentives.

1.3.1.2 Terms on data management and access (Output 2)

Output 2 concerned legal aspects of using the Transparency Platform (TP), in particular the applicability of intellectual property rights and implications of the terms of use of the TP. Specifically, it addressed the four questions below. In the following, the core findings and conclusions are presented.

Is the TP protected under copyright or the *sui generis* database right? The TP is likely to be not protected by copyright, but under the *sui generis* database right established by Art. 7 of the Database Directive 96/9/EC. Therefore, it is protected as intellectual property.

What kind of use is currently legally permitted? To answer this question, for each type of use one needs to address three sub-questions:

- Is the respective act of reusing the data covered by the exclusive rights of the right-holder (or is the use outside the scope of the protection)? When downloading data from the website of a Data Provider the person who downloads is creating a new copy of the data. This reproduction affects the rights of the owner of the sui generis right if the database is copied as a whole or a qualitatively or quantitatively substantial part of the database is copied.
- Are any statutory exceptions to the sui generis right applicable (e.g. some kinds of private use, scientific research)? Some Member States permit by means of law downloading substantial parts for private or scientific use for non-commercial purposes. However, most use of TP is likely to be for commercial purposes; for these types of use, this exception does not apply.
- Is the respective act of reusing the data allowed under the licence provided by the maker of the database? The "General Terms and Conditions for the Use of the ENTSO-E Transparency Platform" is governing the use of data published on ENTSO-E's website. This is not a classical licence agreement but it stipulates which uses shall be allowed. It does not include any explicit statement to grant the right to use the database.

As a consequence, most use of the TP going beyond the mere download can be seen as constituting a copyright infringement. In other words, most users cannot use TP data in a legally safe manner.

Who is the rightholder? It seems likely that both ENTSO-E and Primary Data Owners and possibly intermediaries that have transferred the data hold *sui generis* rights on the TP database. This is because it seems to be the case that they have made a qualitatively and/or quantitatively substantial investment in either the obtaining, verification or presentation of the contents.

How can legally reliable reuse of TP data be granted in the future? The best way forward seems to be to grant an open licence of the TP database. This requires, however, consent of all rightholders.

1.3.2 Work Package 2

Security of electricity supply is a key concern for European Member States. A reliable power supply has indeed become one of the main foundations of modern economies. While overall, security of supply is thought to be high in the EU, concerns have been raised that it is now becoming challenged. This is due to a combination of the substantial – and increasing – deployment of intermittent renewable energy sources, and consequent closure of controllable capacity (also driven by an insufficient pricing of flexibility). These concerns have spurred a number of countries to improve the resiliency of the electricity system by e.g. improving the market design, pursuing subsidies for having adequate capacity available such as capacity payments and strategic reserves, and strengthening reserves for operational balancing (e.g. manual reserves).

The reason for ensuring a well-functioning power supply is that power is a valuable resource to society. Every time a MWh is not supplied to a consumer that is willing to pay the price, this constitutes a loss to society. Such losses are typically measured by the so called 'value of lost load' (VoLL), which measures the perceived value to consumers of preventing an electricity disruption.

In this study, we distinguish consistently between outages (focus in output 3) and disruptions (focus in output 4). We define *an outage* as an event where a power generation unit is out of service; this can be planned, for example for the maintenance of units, or forced for example as a consequence of technical malfunctions in the unit. An outage can lead to a loss of power for consumers but this will typically not be the case. We define *a disruption* as a situation where consumers cannot consume the amount of electricity they would otherwise have liked. A disruption is therefore associated with a loss of power to one or more consumers, e.g. through a brownout or local grid malfunctions.

While the concern for security of supply is quite widespread across Member States, there is currently a lack of knowledge about the extent of disruptions across the EU and the overall loss to society from such disruptions. In addition, there seems to be no clear understanding of the causes of the disruptions, and in particular to what extent they were caused by not structurally having enough generation capacity available (called *adequacy* in the literature), or by problems related to grid infrastructure such as congestion and physical failure through e.g. damaged cables (called *reliability* in the literature).[2]

In this study we are providing a more comprehensive picture of these issues. In particular we have been looking into the following questions:

1. To what extent is European power generation capacity unavailable to the market, and is it due to planned maintenance or unplanned failures? What is the overall amount of 'non-generated energy' in the EU?

2. What is the extent and causes of power disruptions[3] in the EU?

3. To what extent has the demand side played a role in mitigating stressful situations in the system?

4. What is the value lost to society from power disruptions?

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[2] The concept of reliability typically also includes the short term operational response by TSOs such as the use of Frequency Containment Reserves etc.

[3] Defined as power not reaching consumers, which they would otherwise have paid to consume.

Our main take-away from the analysis is the following:
We estimate that **an average consumer in the EU faces one to two disruptions per year, each taking on average roughly 1-2 hours.** In total, we come to the estimate that **each year, approximately 600 to 850 GWh of electricity are not supplied to consumers that would otherwise have paid to consume it**.[4] This amount of electricity corresponds roughly to the electricity consumption of Spain or Italy in one day. The main reasons for this are unplanned malfunctions in the grid – with the vast majority of malfunctions happening in the distribution grid. It is worth mentioning that there has to our knowledge been no major disruption in the transmission system in the period 2010-2016 leading to brownouts or blackouts. Transmission system disruptions can potentially have massive scale, and even a few of these evens would increase non-supplied electricity significantly. This can be exemplified by an event in Italy in 2003 where one massive event led to 56 million people being out of power for between 3-12 hours. This event alone led to about 180 GWh of power not being supplied to consumers.[5]

The lost value to consumers from this non-supplied electricity is roughly estimated to be about 10 to 25 billion EUR per year. This means, that if consumers could have consumed the power that was not supplied, it would have brought benefits of 10-25 billion EUR. It should be noted that the estimation of the value of lost load is extremely uncertain, and estimates in the literature vary substantially.

1.3.2.1 Outages in power generation (Output 3)

Power generation assets, such as thermal power plants, provide a certain generation capacity to the power market. However, situations are likely to arise where the capacity is not available e.g. in situations of technical malfunction or simply when the plant needs scheduled maintenance. Such periods of unavailability can be problematic for the power system, in particular when it is combined with other stressful events. The possibility of having an unplanned failure is a key reason for TSOs to regulate in the market e.g. by contracting reserve capacity. However, also scheduled downtime due to e.g. maintenance can be problematic to the system. While it does not in itself pose a direct problem, it reduces the overall capacity available in the system, and thereby increases the vulnerability of the system consequently increasing the likelihood of a trip in a different generator or interconnectors becoming a severe event. Most TSOs also regulate this by e.g. ordering in which time periods specific power plants are allowed to go out for maintenance.

In 2016, approximately 886 GW of power generating capacity was available in the EU. However, due to outages this full capacity was not available for generation all the time. In fact, **more than 14,700 outages have been reported in Europe each year (2015-2016 average)**, which corresponds to 17 outages each year per installed GW of generation.[6]

When taking into account the length of the individual outages, we estimate that **the total non-generated electricity due to outages in the EU in 2016 was about 13 TWh.**

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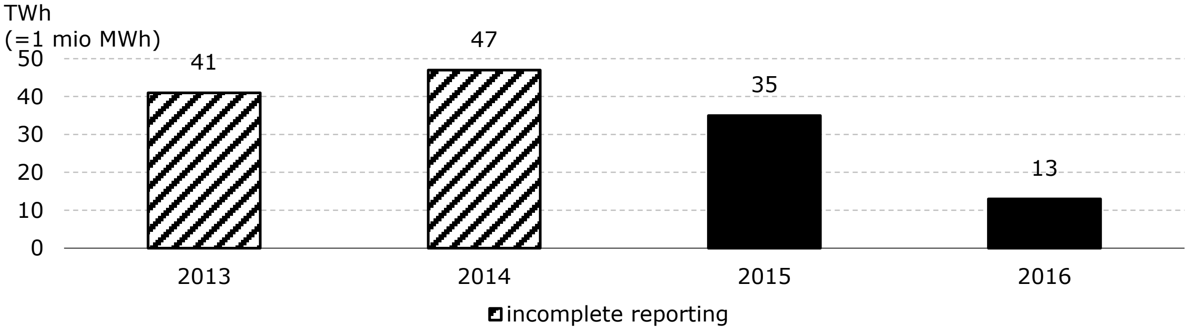
[4] It is a rough approximation and based on several simplifying assumptions.

[5] IEEE (2007) Blackout experiences and lessons, best practices for system dynamic performance, and the role of new technologies

[6] These numbers include only outages above 100 MW, Commission Regulation No. 543/2013. This excludes most renewable energy generation except for large onshore and offshore wind turbines.

This means electricity that could have been generated if the power plants had not been out for whatever the reason. This corresponds to the 886 GW of power generating capacity in Europe being completely out for around 15 hours in the whole year of 2016, or to 0.17% of Europe's capacity being out constantly. This number is **significantly lower than just a few years back,** having been reduced to 13 TWh from about 41 TWh in 2013, 47 TWh in 2014 and 35 TWh in 2015 (see figure). The decline is actually likely to be even higher than this, as data availability for 2013 and 2014 was significantly lower than for 2015 and 2016.[7]

Figure 1 : Total non-generated electricity per year in Europe



Note: Croatia, Cyprus and Slovenia did not report outages in any of the years. 2015 is the first full year where the reporting of outages to ENTSO-E is mandatory; the data for 2013 and 2014 is therefore incomplete in the sense that it only shows the outages that were reported voluntarily. The real total non-generated electricity in those years might be much higher, meaning that the decline over time to 2016 is much more significant than it seems in this figure.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

Forced/unplanned outages constitute the majority of the non-generated electricity and they occur significantly more frequently. About **60%** of all outages are forced events. The duration of the outage is significantly shorter when it is forced than when it is planned (about 9 hours on average compared to 34 hours for planned downtime). Moreover, **forced outages typically happen for larger assets than planned outages.** Indeed, the average affected capacity for a forced outage is about 410 MW compared to about 260 MW for planned outages (see figure). This suggests that larger generation assets are more susceptible to forced outages than smaller ones.

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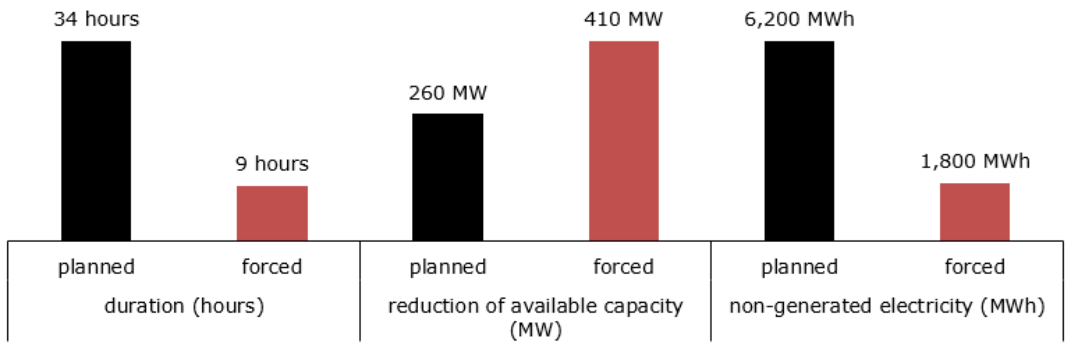
[7] Planned outages are typically periods where power plants are out for maintenance. These outages could potentially be reduced in duration and frequency, but cannot be prevented, as maintenance is necessary for stability in operation and required by law.

Figure 2 : Characteristics of an average outage in Europe, planned vs forced, 2010-2016



Note: Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

Fossil-fuel assets have by far the longest duration for planned outages of about 20-40 hours on average, compared to less than 1 hour for wind turbines, 5 hours for nuclear plants and about 7 hours for hydro plants. The comparably high figure for fossil fuel assets is to a large extent driven by single power plants – mainly coal fired plants – that were taken down for several months. Generally, when looking across technologies, it is however worth noting that the majority of reported planned outages is quite short: 61% of all reported planned outages last shorter than an hour, and 41% are even shorter than 15 minutes, see also Figure 31.

Fossil-fuel based generation assets seem on the other hand to bounce back from a forced outage as quickly as an average generation type taking about 2.8 hours, similar to hydro and nuclear. That is faster than biomass (8.4 hours) but slower than off- and onshore wind assets using 1.8 and 1.3 hours respectively.

Offshore wind turbines are most prone to outages, with 331 outages per installed GW – of which most are planned. It is important to note that these are relative numbers (per installed GW); as fossil-fuel based generation units still dominate the total fleet of generation units, these units will have more outages in absolute terms. Only very few outages are reported for onshore wind, and none for solar energy, which is due to the fact that the units are below the threshold of reporting obligation of 100 MW.[8]

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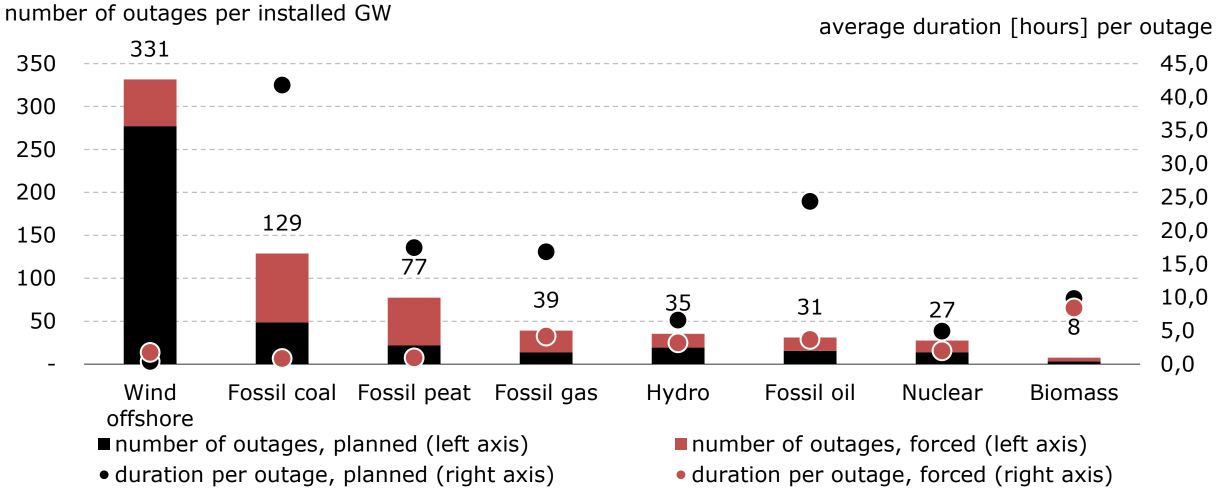
[8] Following Commission Regulation No. 543/2013. This threshold is shortly discussed in footnote 37 in the chapter on output 3.

Figure 3 : Number and duration of planned and forced outages for different generation types, 2010-2016

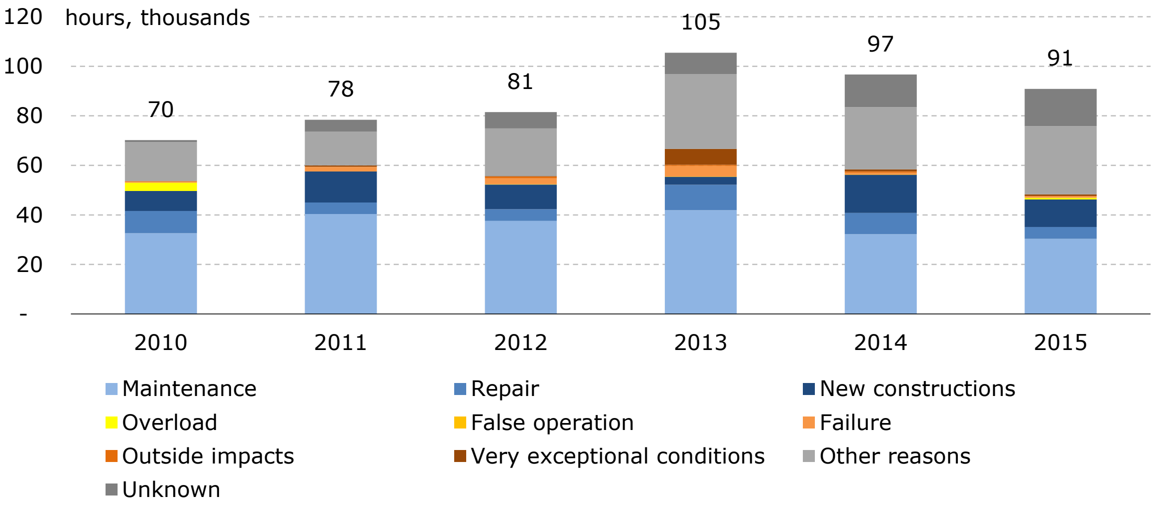


Note: Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

Just as an outage at a generation unit, an unavailable interconnector will limit the power generation capacity available to a country or region**. Interconnectors have been unavailable for roughly 87,000 hours every year (2010-2015 average),** which means that 10 'average' interconnectors are unavailable in Europe at all times on average. **The main reasons for the unavailability are especially maintenance, repair and new constructions,** while forced outages (due to overload, false operation, failure, outside impacts or very exceptional conditions) happen very rarely, see Figure 4. Outages due to works at the infrastructure (e.g. at overhead lines or underground cables) tend to take longer; the longest durations are due to new constructions, where an outage takes almost 10 days on average. Forced outages can on average be fixed much quicker, after 3 hours to 3 days. The somewhat increasing trend in the number of outages should be seen in light of the increasing number of interconnectors.

Figure 4: Total duration of interconnector outages, 2010-2015



Note: Incomplete data for 2016, therefore shown until 2015.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

1.3.2.2 Disruptions of power supply to consumers (Output 4)

Power supply is very reliable in the EU. For an average EU country**, power consumers will on average have access to power in 99.948% of the time** (measured in 2014). An average EU power consumer will face about **1-2 significant disruption events** each year.[9] Since 2010 this number has fallen from 1.7 to 1.4 in 2014. The number of disruptions and the duration vary across individual Member States with **Luxembourg, Denmark, Germany and the Netherlands at the high end of reliability** with around 20 minutes to half an hour of disruptions per customer per year, **and Romania, Latvia and Croatia in the low end** with about 550-850 minutes of disruptions per customer per year, see figure.

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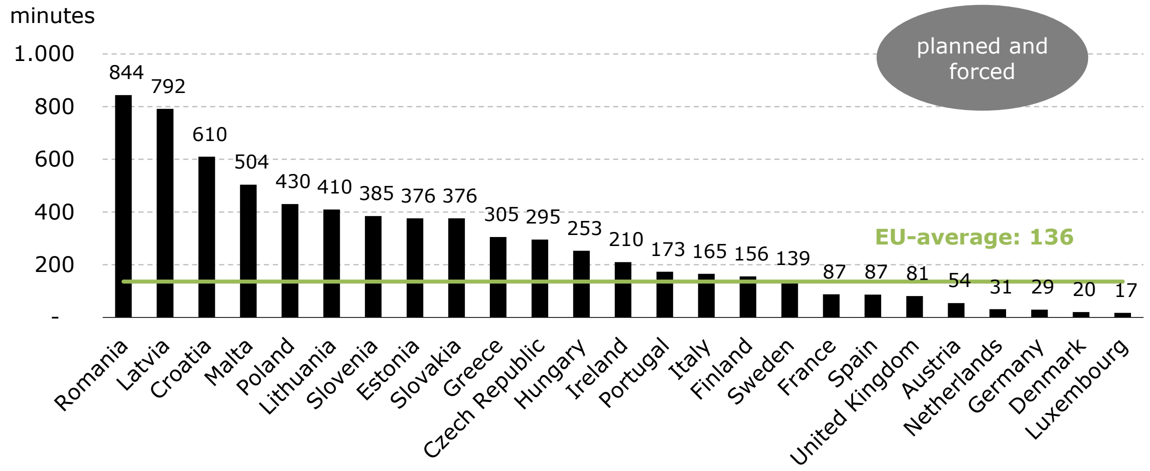
[9] "Longer than 3 minutes" is the most commonly used threshold across the EU, with 24 of the 28 Member States using it. The four Member States reporting disruptions in a different way are Denmark and the Netherlands, which report all disruptions of at least 1 minute and 5 seconds respectively, as well as Cyprus and Malta, which do not have a classification.

Figure 5 : Average minutes lost per year and customer due to significant disruptions (planned and forced), 2010-2014



Note: The graph shows a weighted indicator. The weighting is described in Table 4, and allows for an overall interpretation of the indicator as "per customer". No data available for Belgium, Bulgaria, Cyprus. The average is a simple average across countries and is calculated based on the EU28-countries with available data.

Source: Copenhagen Economics based on CEER data.

When a power disruption happens, it is either due to a malfunction in the grid infrastructure at distribution level or transmission level, or due to a lack of generated power. While the **vast majority of the disruptions occur due to problems in the grid** such as weather-related breakdown of lines or transformer station malfunctions, a few incidents have been reported where lack of power generation to meet supply has led to disruptions.

We have identified about 175 instances between 2010-2016 where a lack of power led to a supply disruption. The bulk of those incidents happened in the UK (100 instances since 2010) and Malta (69 instances since 2010) in the early years of that 7-year-period. Both countries show a strong downward trend: in the recent years of 2015-16, only nine out of 12,927 outages in the UK (0.07%) and five out of 192 outages in Malta (2.6%) led to disruptions. Ireland, Poland, and Romania report single cases as well, see Table 5 for details. Ireland for example has experienced a single case since 2010 where the tripping of a large generation unit has led to a supply disruption. In the same timeframe, Ireland reported more than 2,000 outages in total, meaning that most of them did not lead to a supply disruption. 13 countries stated that there has been no single case where an outage has led to a disruption since 2010 (see Table 5). Disruptions due to lack of power have therefore been very rare historically, and there is no evidence that the increased renewable energy deployment has led to more disruptions. Concerns remain going forward that unless additional measures such as e.g. changes in market design, intermittent sources could lead to more disruptions due to lack of power.[10]

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[10] See e.g. Statnett, Fingrid, Energinet and Svenska Kraftnät (2016), Challenges and Opportunities for the Nordic Power System, simulating amongst others that the capacity margin in Finland is likely to fall from 1.400 MW to 90 MW in 2023 in a median year, and drop to negative 680 MW in a cold year once in 10 years.

When the disruptions are related to infrastructure, it is **almost always caused in the distribution grid**. All countries answering this particular question in our surveys stated that disruptions typically happen at distribution level. **Failures in transmission infrastructure happen much more rarely**, however when they do happen, the impacts are **significantly more severe**, sometimes leaving very large geographic regions without access to power. The exception to this is transmission lines between countries (interconnectors), where case examples show that interconnector failure alone very rarely gives rise to significant distress to the power system let alone actual disruptions to consumption. Instead, it leaves the national/regional power market more vulnerable to additional simultaneous failures in e.g. local generation assets (reduced capacity margins), and may increase the power prices in the countries.

We find that about **a third of the minutes of disruptions are planned disruptions** e.g. for maintenance or construction purposes, and **two thirds are unplanned disruptions**. The primary reason for the unplanned disruptions are so called false operation, failure of equipment or material damage (40%) followed by severe weather conditions and natural hazards (30%). **We find very little evidence that disruptions have been due to a malicious attack**. 17 countries report that no disruption was caused by a malicious attack, only Poland, France and Italy report single cases of thefts of infrastructure elements that have caused disruptions.

We estimate that **for the EU in total approximately 600-850 GWh of electricity annually have not been supplied to consumers in the period 2010-2014**. This constitutes both planned and unplanned disruptions.

1.3.2.3 Use and potential of demand side flexibility to avoid disruptions (Output 5)

Traditionally, balancing the power system to ensure the right frequency has been a question of regulating the supply side, i.e. ramping power generators up or down. However, the demand side is increasingly seen as a potential resource for balancing purposes due to several reasons. *Firstly* due to technological developments making demand response easier to use for balancing purposes, and *secondly* due to the expected increase in large-scale demand assets in individual households such as electrical vehicles and heat pumps.

Demand side flexibility is viewed upon with great potential as it is indeed the current inflexibility that gives rise to the discussions about reserve availability, capacity payments etc. If it could be ensured that consumers were easily and cheaply available to communicate and respond flexibly to price variation, most of the issues related to energy system balancing would be solved.

However, there are **still a number of challenges left with respect to large-scale utilisation of the demand side** as a balancing asset such as 1) it is not deemed as reliable as supply assets, 2) it cannot typically be available for as long as supply assets, 3) the demand assets are substantially smaller in size and therefore requires significant coordination efforts to mobilise sizeable capacity, 4) it is geographically less predictable and may be ‘locked into’ local bottlenecks, and 5) it is relatively expensive to mobilise especially household assets as it requires investments in e.g. smart metering equipment, new business models and new regulation and market design models, including e.g.

participation requirements in the balancing market, such as the minimum bid size, which differs across Member States.[11]

Several of these challenges are likely to be overcome e.g. through better coordination and information flow between TSOs on the one hand and DSOs and balance responsible parties on the other hand.[12] What remains to be seen is to what extent the demand side can act as a reliable source of adequacy instead of e.g. a 200-400 MW power generation plant, which will require significant efforts in terms of e.g. aggregation. A more immediate role for the demand side could be to perform services closer to real-time operation, e.g. in fast-responding automatic (frequency controlled) reserves, where requirements on capacity size and availability periods are lower.

It has generally been very difficult to find information of the extent to which demand side assets have contributed as an effective tool to avoid brownouts in actual periods of stress to the system, as this is rarely recorded and/or published by TSOs. To the extent that demand side assets contribute to balancing mechanisms and reserve pools, we expect that these have been called upon in times of severe distress

Some countries engage in specific demand curtailment programmes used in emergency circumstances. These programmes allow for a more controlled disconnection of consumers before an actual brownout that disconnects an entire geographic area. **12 countries seem to have such voluntary demand curtailment mechanisms in place** and in about 8 out of these 12, we have found evidence that these demand side programmes have been activated, see map.

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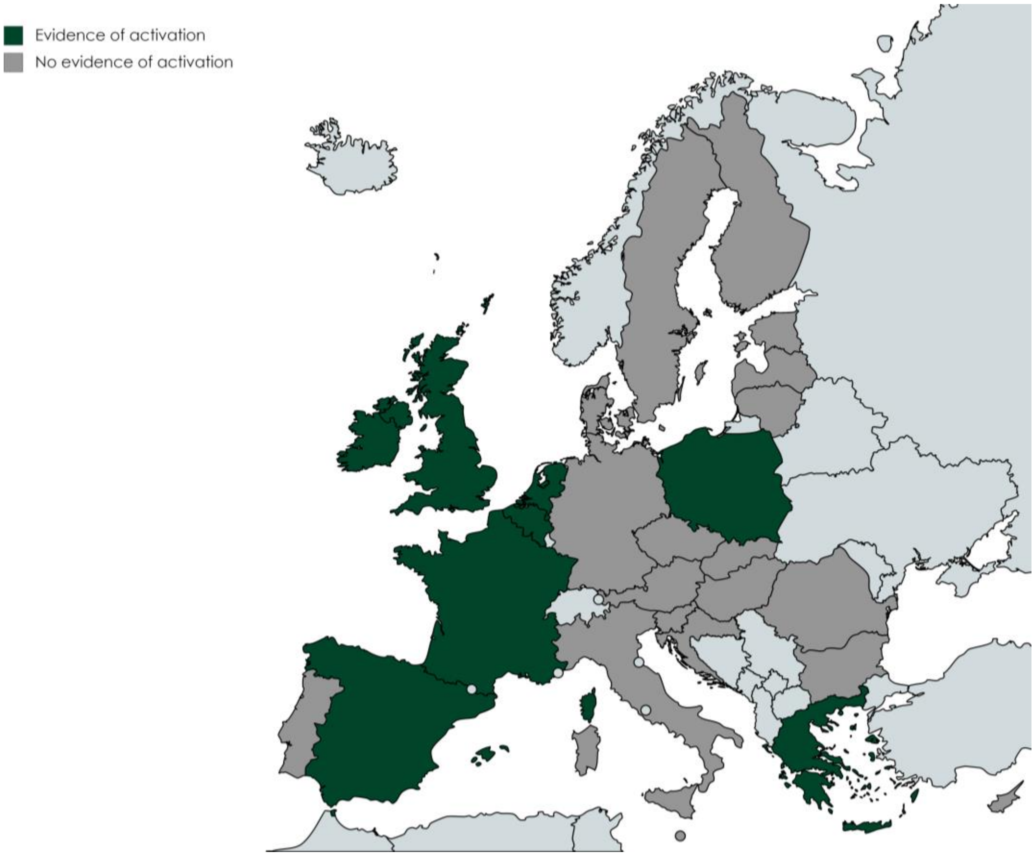
[11] See for example the study "Unlocking flexibility – Nordic TSO discussion paper on third-party aggregators" by Energinet, Fingrid, Statnett and Svenska Kraftnät

[12] E.g. to prevent that a TSO-activation of a local flexibility asset does not lead the local balance responsible party to counteract this to achieve local balance.

Figure 6 : Activation of voluntary demand curtailment mechanisms 2010-2016



1.3.2.4 The socio-economic costs of disruptions (Output 6)

Disruptions impose a welfare loss to society, as consumers willing to pay the price for electricity do not have the opportunity to consume it. That limits the production of commercial consumers and the value of leisure of private consumers, and can in some instances lead to damages of products or machinery. The value of lost load (VoLL) is an estimate for those costs.

The VoLL depends on a wide range of factors. It varies for example depending on the time of day, season and duration of the disruption, as well as with the individual preferences and production functions of the private and commercial consumers affected. The VoLL is moreover typically higher for countries with a high-income level, higher for commercial than for private consumers, and higher for forced than for planned disruptions.

In order to estimate the value placed by consumers on electricity, all the above differences should optimally be taken into account. However, current estimates of VoLL show tremendous variation seemingly driven by differences in methodological approach and data availability and to a lesser extent of the underlying economically driven differences in VoLL. All estimates, and EU averages in particular, should therefore be considered a rough approximation rather than the "true" value.

Based on an assessment of existing estimates combined with an extrapolation, we find that the **household-VoLL is about 5-10 EUR/kWh** at the European average, meaning that a one kWh of non-supplied electricity to an average household in Europe implies costs to that consumer of 5-10 EUR. **For non-households like industrial or commercial consumers, we find an average VoLL of 20-30 EUR/kWh**.

Those estimates show that the disruptions in Europe in the period 2010 to 2014 gave rise to **a loss to consumers of approximately 10 to 25 billion EUR annually**.[13]

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[13] Not considering potential savings in generation cost from not generating the electricity.

2. INTRODUCTION

The « Study on the quality of electricity market data of transmission system operators, electricity supply disruptions, and their impact on the European electricity markets" was launched by DG ENER under the framework contract ENER/A4/516/2014. The contract was assigned to the consortium composed of VVA (lead), Copenhagen Economics, Neon and Deloitte.

The contract was signed on 3rd May 2017 and the study implementation period is 7 months.

2.1 Objectives and scope of the study

The study aimed at filling the existing data gaps on supply disruptions of electricity due to outages on production facilities, transmission or other grid assets.

The study consisted in the collection, completion, calculation, presentation and analysis of data on the current reporting practices of electricity transmission operators, on the existing public European electricity market databases, on the quality of the available market data and on the costs of electricity supply disruptions for customers. The study covered the 28 Member States and the period 2010-2016.

Based on this extensive data collection, the study provides an in-depth analysis of reasons behind and the nature of electricity supply disruptions, the cross-border implications, the impact of voluntary demand curtailments, as well as the costs and losses incurred and how they impact market prices.

Having a better understanding of the causes of disruptions of electricity and their impact on the European market is necessary to contribute to enhancing the electricity security of supply in the EU and to provide updated and evidence-based energy policies.

2.1 Overall approach

The study consisted of two work packages, both covering the 28 EU member states and involving data-intensive analyses, but independent from each other otherwise. The table below summarises the overall methodological approach of the study.

Table 1 : Overall methodological approach

Work Packages	Outputs
1) **Work Package 1**: Evaluation of TSO and ENTSO-E data	**Output 1**: **Analysis of ENTSO-E datasets** Data collection and analysis on the completeness, accuracy, timeliness of the datasets, accessibility and friendliness of TSO and ENTSO-E database. **Output 2: Terms of data management and access** Analysis of legal data provision terms of TSO

Work Packages	Outputs
	and ENTSO-E to check if compatible with the Regulation 543/2013 on submission and publication of data in electricity markets.
2) **Work Package 2**: Analysis of supply interruptions	**Output 3: The extent and source of electricity outages** Information on electricity outage data in 28 EU Member States on a monthly basis and by generation technology, including on plants (generation units), the nature of outages (planned or unplanned and the cause), their length in time, the reduction of the available capacity and the amount of non-generated electricity. **Output 4: Understanding electricity supply disruptions events** information on the extent of electricity supply disruptions in the EU 28, and the reasons for these disruptions. Definition of a typology for significant supply disruption events and identification of the features of these events (cause, length, reduction of available capacity, amount of non-supplied electricity). **Output 5: The use of voluntary demand curtailment** Analysis of the impact of significant events on voluntary demand curtailments and how those contributed to minimilazing the impact of elecitrity supply disruptions. **Output 6: Value of lost load** Value of lost load (VoLL) resulting from the significant electricity supply disruption events, in monetary units and across the EU Member States.
3) **Final report :** Conclusions and recommandations	**Output 7: Final report** Presentation of the final results of the study, definition of concepts, presentation of the nature of data collections, of the limits of the applied methodology, of the solutions adopted to deal with missing or inconsistent data.

2.2 Structure of the report

The structure of the remaining inception report is as follows:

- Chapter 3: Findings for Work Package 1
- Chapter 4: Findings for Work Package 2
- Chapter 5: Annexes

Annexes:

- Annex 1 - Content of Commission Regulation (EU) 543/2013
- Annex 2 – Overview of data items available on ENTSO-E TP
- Annex 3 – Questionnaire for online user survey (Output 1)
- Annex 4 – Survey questionnaire for Output 3 (with electricity producers and TSOs)
- Annex 5 - Survey questionnaire for Output 4 (with national regulators and TSOs)
- Annex 6 – Survey questionnaire for Output 5 (with TSOs)
- Annex 7 – List of stakeholders
- Annex 8 – List of literature

3. FINDINGS FOR WORK PACKAGE 1

Work Package 1 is an evaluation of the ENTSO-E Transparency Platform and consists of two outputs: Output 1 is an analysis of the data quality and user friendliness of the platform by means of a data analysis and a survey among platform users. Output 2 is an analysis of the legal accessibility and terms of use of the platform. The goal of this Work Package is to be constructive and solution-oriented by providing insights that contribute to improving the platform. Neon was responsible for this work package.

3.1 Output 1: Analysis of ENTSO-E datasets

3.1.1 Objective and approach

The objective of this Output is to evaluate the quality of data published through the ENTSO-E Transparency Platform (TP) as well as the user friendliness of the platform itself.

To deliver this assessment, we applied four complementary approaches. First, we reviewed the other previous TP assessments (e.g. ENTSO-E internal quality assessments, ETUG reports, ACER opinions). Then, we carried out a new statistical data analysis of the data for all EU Member States in the period 2015–2016. We carried out an online survey with data users, and received 80 answers. Finally, we conducted semi-structured interviews with experts reflecting the variety of types of users, including market participants, consultants, NGOs, data service providers and researchers, as well as national authorities and EU institutions.

3.1.2 Findings

All reported findings are based on observations and user input obtained between April and October 2017. Since the TP architecture allows updates and improvements for historical data, data quality may have increased since our analysis. Data items are referred to by the name listed on the TP as well as the corresponding article number from Regulation 543/2013.

3.1.2.1 Completeness

Assessing completeness means verifying whether all data items specified in Regulation 543/2013 are available on the TP for all geographic entities that apply and for all time steps since January 5, 2015, when the Regulation came into force. We identified two types of issues regarding completeness:

- Missing data: data that should be published are not (data gaps)
- Information about missing data: users are not informed about data gaps

Additionally, some users requested broader coverage and identified data they would be interested in that go beyond what is prescribed in Regulation 543/2013.

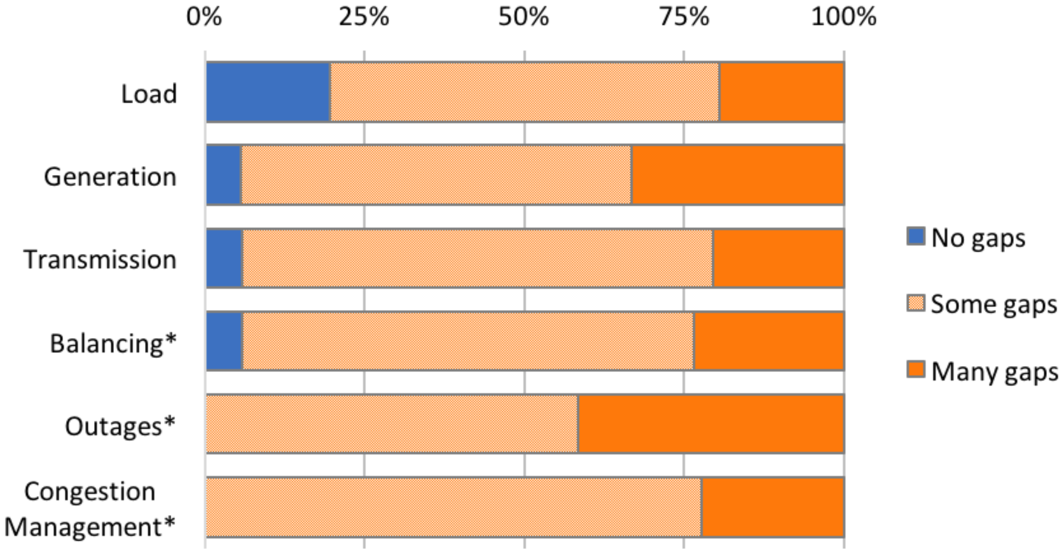
It should be noted that many data items are useful only if they are reported completely. Missing load, price, transmission or generation data even in “only” 1% of all time steps can render the raw time series useless for many use cases. For such time series, anything below 100% completeness would seem unsatisfactory. Even though gaps can be filled using data processing software, doing so could introduce a bias to the data because the gaps might not be random.

(a) Missing data (data gaps)

As visible from Figure 7, online survey respondents reported missing data in every data domain. Users' perceptions of missing data were measured by asking the question "Are there missing observations or gaps in the data?" They were then given the option to answer "There are many gaps", "There are some gaps", "There are no gaps" or "I'm not sure". Since users were not given any instructions or methodology for defining how many gaps constituted each category or how to define a gap, the survey did not measure the objective completeness of the data. It should further be noted that users are not always informed about updates to data after they last worked with them. However, the survey shows user perceptions of missing data on the TP. According to the results, users perceived Outages as the data domain with the most gaps: not a single respondent did not report missing data and more than 40% find "many gaps" in the data. In the following, we will discuss more detailed analyses of items of the data domains Load, Generation, Transmission and Balancing.

Figure 7. Percentage of users who noticed gaps in different data domains.

Key point: For every data domain, at least 80% of users noticed data gaps.



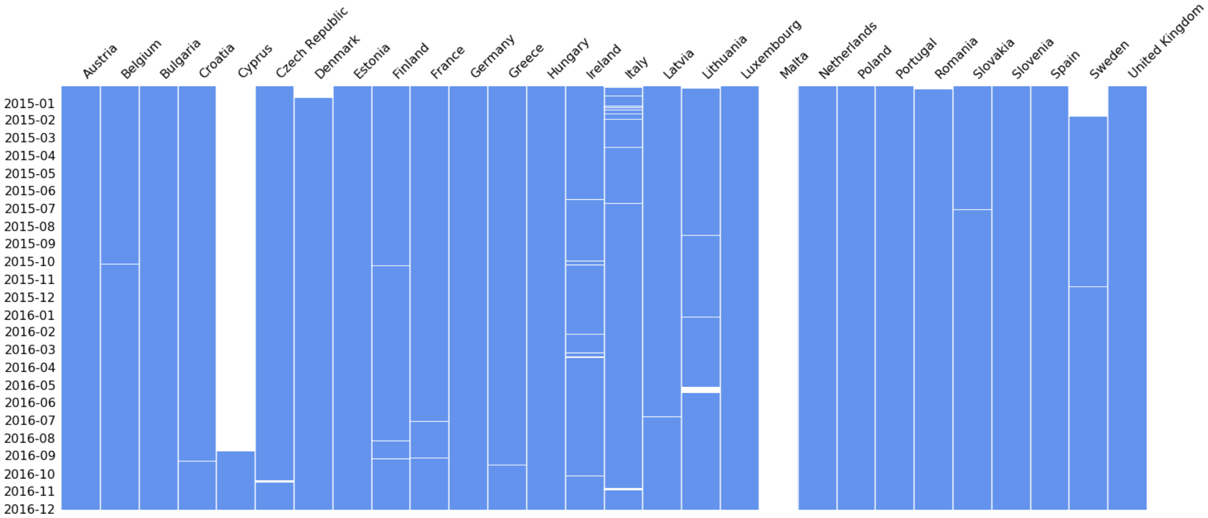
Notes: Data domain names with asterisks represent those for which fewer than 30 users responded.

Load

Within the data domain Load, we focused on the data item "Actual Total Load" (6.1.A). Figure 8 shows the availability of "Actual Total Load" (6.1.A) by country. The pattern of data unavailability suggests different reasons for missing data: for some countries, data came in late at first, but are nearly complete since then (Cyprus, Denmark, Sweden). Other countries have many short gaps (Romania, Slovakia, Spain). Yet other countries feature a larger number of longer gaps that seem to be randomly distributed over the time period (Ireland, Italy, Lithuania). A positive observation is that the "extra hour" in March due to daylight savings time—a notorious weak spot of power system data—does not seem to pose a systematic problem in the "Actual Total Load" (6.1.A) data.

Figure 8. Completeness of "Actual Total Load" (6.1.A) by country.

Key point: The patterns of missing data are different from country to country.



Notes: The figure shows data availability in hourly resolution. Very short gaps might not be visible. For higher resolution see https://neon-energie.de/transparency-platform.

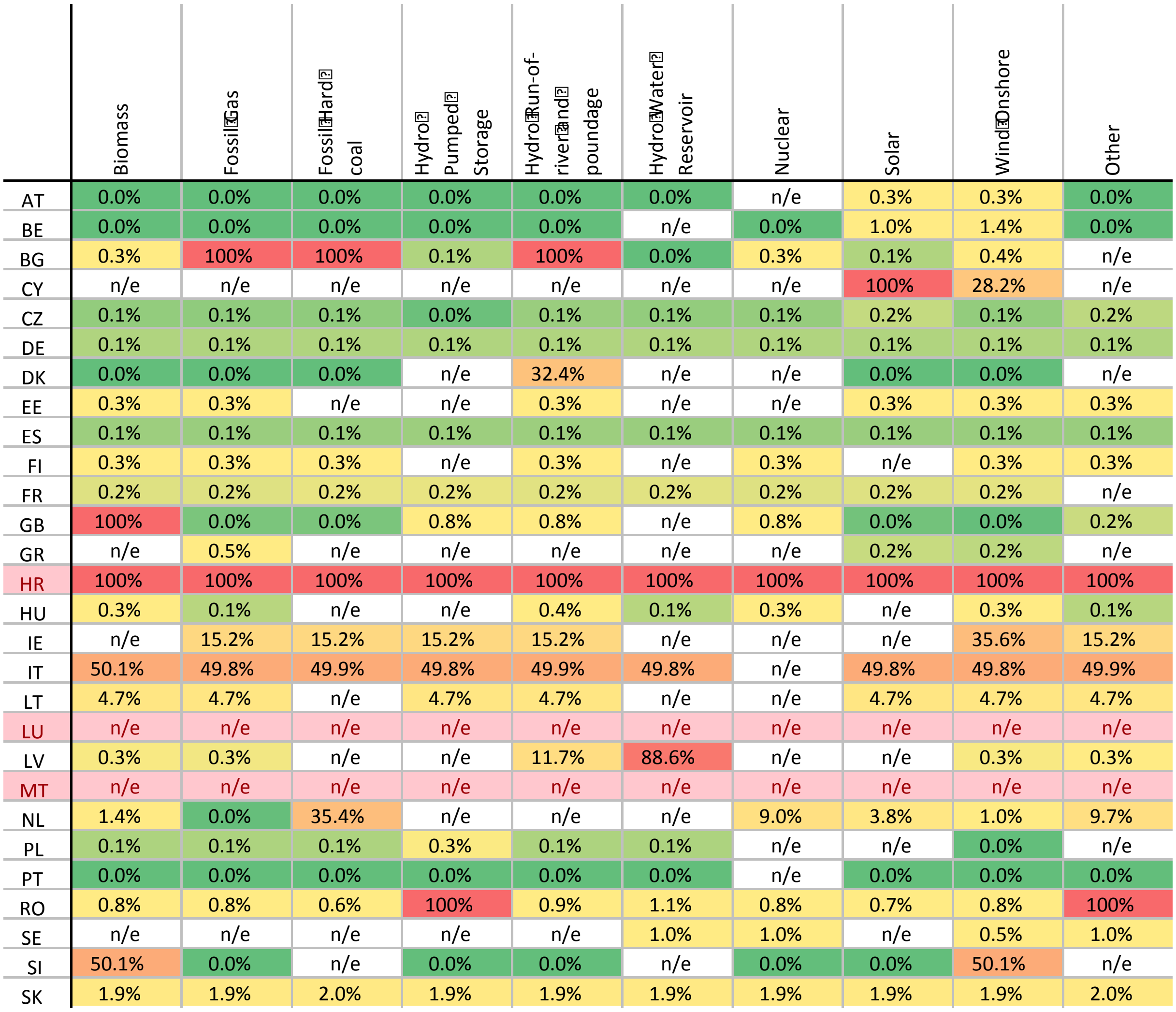
Generation

We studied the items "Aggregated Generation per Type" (16.1.B&C) and "Actual Generation per Generation Unit" (16.1.A). Figure 9 shows the former, focusing on the most common technologies. Coloured cells show the share of observations missing (reported as "N/A" on the TP website). White fields containing "n/e" indicate that generation data from that country and technology are not expected on the TP. Cases of 100% "N/A" also could indicate a misconfiguration where no data are expected; that is, "n/e" should be reported instead. Croatia (all values "N/A") as well as Luxembourg and Malta (all values "n/e") do not report any data for this data item.

Few time series are complete. Coverage is nearly complete in Austria, Belgium, Germany, Denmark and Portugal. In Italy and Slovenia, a year is missing for some or all technologies, resulting in shares of around 50% missing values for the two years covered.

Figure 9. Completeness of "Aggregated Generation per Type" (16.1.B&C) by country.

Key point: For the majority of countries, a significant amount of generation data is missing.



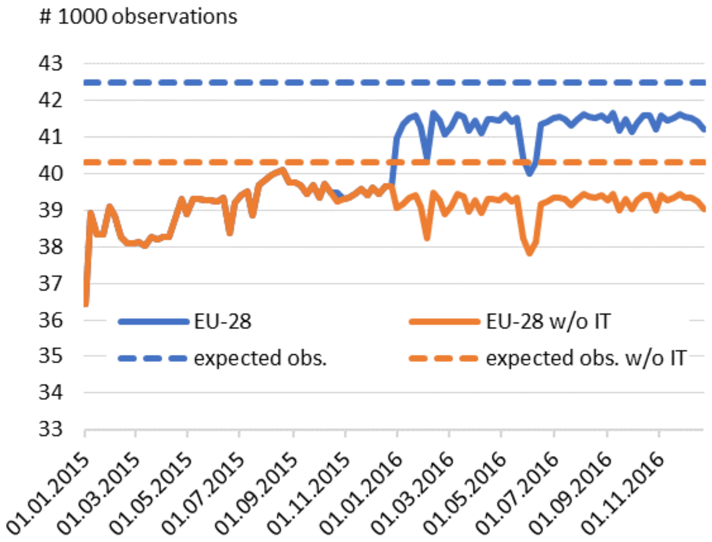
	Biomass	Fossil Gas	Fossil Hard coal	Hydro Pumped Storage	Hydro Run-of-river and poundage	Hydro Water Reservoir	Nuclear	Solar	Wind Onshore	Other
AT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	n/e	0.3%	0.3%	0.0%
BE	0.0%	0.0%	0.0%	0.0%	0.0%	n/e	0.0%	1.0%	1.4%	0.0%
BG	0.3%	100%	100%	0.1%	100%	0.0%	0.3%	0.1%	0.4%	n/e
CY	n/e	n/e	n/e	n/e	n/e	n/e	n/e	100%	28.2%	n/e
CZ	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%	0.1%	0.2%	0.1%	0.2%
DE	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
DK	0.0%	0.0%	0.0%	n/e	32.4%	n/e	n/e	0.0%	0.0%	n/e
EE	0.3%	0.3%	n/e	n/e	0.3%	n/e	n/e	0.3%	0.3%	0.3%
ES	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
FI	0.3%	0.3%	0.3%	n/e	0.3%	n/e	0.3%	n/e	0.3%	0.3%
FR	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	n/e
GB	100%	0.0%	0.0%	0.8%	0.8%	n/e	0.8%	0.0%	0.0%	0.2%
GR	n/e	0.5%	n/e	n/e	n/e	n/e	n/e	0.2%	0.2%	n/e
HR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
HU	0.3%	0.1%	n/e	n/e	0.4%	0.1%	0.3%	n/e	0.3%	0.1%
IE	n/e	15.2%	15.2%	15.2%	15.2%	n/e	n/e	n/e	35.6%	15.2%
IT	50.1%	49.8%	49.9%	49.8%	49.9%	49.8%	n/e	49.8%	49.8%	49.9%
LT	4.7%	4.7%	n/e	4.7%	4.7%	n/e	n/e	4.7%	4.7%	4.7%
LU	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
LV	0.3%	0.3%	n/e	n/e	11.7%	88.6%	n/e	n/e	0.3%	0.3%
MT	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
NL	1.4%	0.0%	35.4%	n/e	n/e	n/e	9.0%	3.8%	1.0%	9.7%
PL	0.1%	0.1%	0.1%	0.3%	0.1%	0.1%	n/e	n/e	0.0%	n/e
PT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	n/e	0.0%	0.0%	0.0%
RO	0.8%	0.8%	0.6%	100%	0.9%	1.1%	0.8%	0.7%	0.8%	100%
SE	n/e	n/e	n/e	n/e	n/e	1.0%	1.0%	n/e	0.5%	1.0%
SI	50.1%	0.0%	n/e	0.0%	0.0%	n/e	0.0%	0.0%	50.1%	n/e
SK	1.9%	1.9%	2.0%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	2.0%

Notes: Share of missing values (reported on TP as "N/A") for selected technologies. Due to space constraints, we have restricted the figure to a subset of all technologies. Latvia operates one hydropower plant that was classified as "Hydro Water Reservoir" until 25.03.2015 and as "Hydro Run-of-river and poundage" afterwards, leading to two columns where one of two values is always "N/A" or "n/e".

Figure 10 shows how the completeness of "Aggregated Generation per Type" (16.1.B&C) evolved over time. It shows the number of observations per week aggregated over all countries and production types and compares this to the expected total if all data were reported. Under the assumption that no country has decommissioned all plants of a certain type, the number of expected observations does not change over time. The number of actual observations per week seems to increase from 2015 to 2016, indicating improved completeness. However, this pattern is due to the appearance of Italian data in 2016, which were missing in 2015 altogether. Disregarding the Italian data, the overall completeness of the data shows some ups and downs, but seems to stabilize around 1000 missing observations per week.

Figure 10. Weekly number of "Aggregated Generation per Type" (16.1.B&C) observations.

Key point: We cannot identify a trend toward improvement of completeness over time.

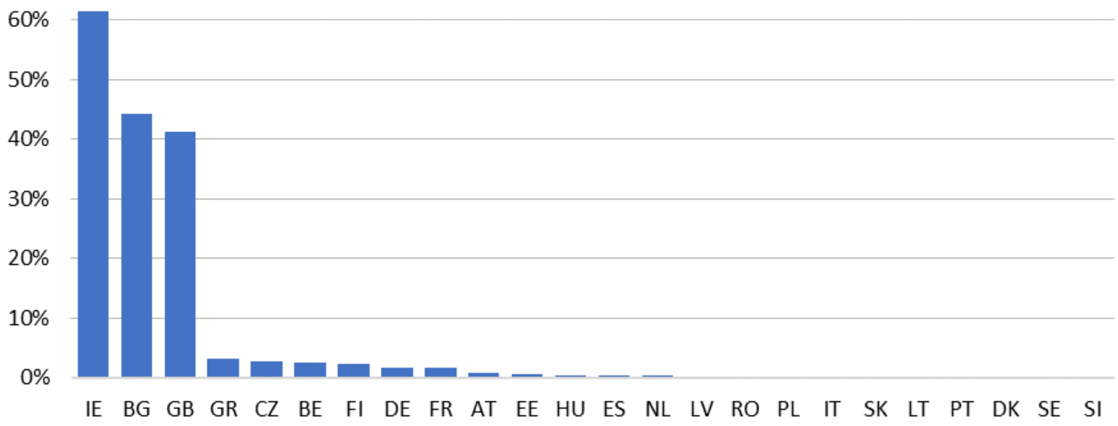


Notes: In a week, the expected number of observations 42,504 = 168 hours x 253 country–type combinations. Excepting Italy, it is 40,320 = 168 hours x 240 country–type combinations. The total number of country–type combinations on the FTP server is 260; however, this includes combinations that are always marked as "n/e" on the TP website and are thus disregarded.

We assessed the data item "Actual Generation per Generation Unit" (16.1.A) for the year 2016. On average, 5% of observations are missing. Less than half of all units report data without gaps. Figure 11 displays the generation units that reported the most missing data in 2016. Some units provided hardly any data; there are more than 100 units for which at least 40% of all observations are missing. Most of them are situated in the United Kingdom, suggesting a systematic problem with the reporting there.

Figure 11. Missing "Actual Generation per Generation Unit" (16.1.A) in 2016, averaged by country.

Key point: In Ireland, the United Kingdom and Bulgaria, generators on average provided less than 60% of all data.



Source: Own figure based on data provided by Dave Jones, Sandbag.

Notes: Figure shows the share of missing observations by country for EU Member States. There are no data for Irish generation units after 24.05.2016 and none for Bulgarian units before 16.05.2016, leading to high percentages of missing values. In the United Kingdom, generators on average provided little more than half of all data. No data at all are provided for Cyprus, Luxembourg, Malta and Croatia, possibly due to no generators >100 MW existing in these countries. Generation units located in Sweden, Hungary, Poland, Romania, Latvia, Slovakia and Slovenia provided virtually all (<0.5% missing) data.

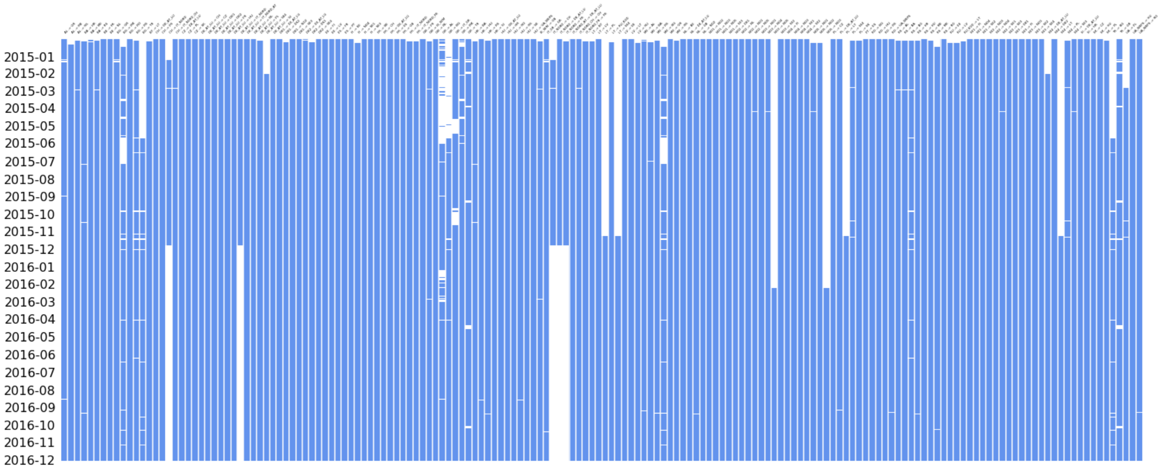
Responses by interviewees and survey participants are consistent with our findings. In addition, it was pointed out that the 100 MW reporting threshold for individual units seems to be applied inconsistently—sometimes to entire power stations, in other cases to individual electricity generators. More issues with completeness included reporting gaps in German gas plants, Spanish solar production and for all production types in the Netherlands.

Transmission

Within the data domain Transmission, we evaluated the data items "Day-ahead Prices" (12.1.D) and "Scheduled Commercial Exchanges" (12.1.F). "Scheduled Commercial Exchanges" (12.1.F) is one of the patchier data items, as Figure 12 illustrates. For some time series, a year of data is missing, which is the case for some of the Italian, Lithuanian and Norwegian borders. Others exhibit frequent shorter gaps, e.g. borders between Bulgaria and Greece and their respective neighbours.

Figure 12. Completeness of "Scheduled Commercial Exchanges" (12.1.F) by bidding zone borders.

Key point: Exchange data are patchy with different patterns of missing data.

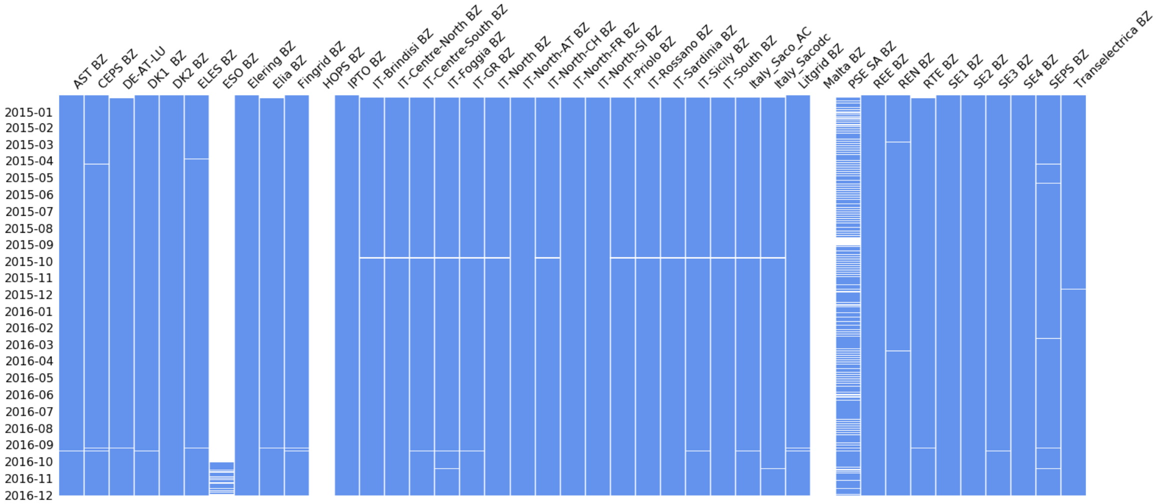


Notes: The figure shows data availability in hourly resolution. Very short gaps might not be visible. For higher resolution see https://neon-energie.de/transparency-platform.

As visible in Figure 13, "Day-ahead Prices" (12.1.D) show fewer gaps than the other data items; however, there is only one complete time series of day-ahead prices (Spain). Italy alone is made up of 18 bidding zones, most of which have a period of missing data in October 2016. No price data are expected for bidding zones that have not introduced a power exchange. This was the case in Bulgaria (ESO BZ) and Croatia (HOPS BZ) prior to January/February 2016 and still is the case in Malta. However, Bulgaria (ESO BZ) reports prices only from November 2016 and Croatia not at all. Overall, there is no general trend of improvement over time.

Figure 13. Completeness of "Day-ahead Prices" (12.1.D) by bidding zone.

Key point: For almost all bidding zones, day-ahead prices are incomplete.



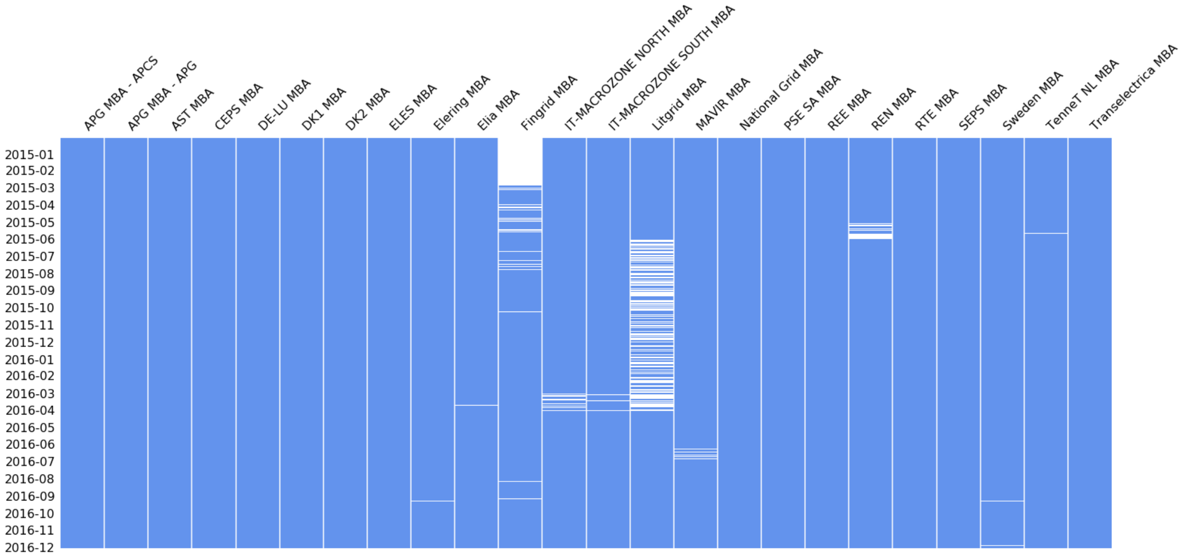
Notes: On average, 5% of observations are missing, with some gaps in almost all bidding zones. Until March 2017, price data for Poland (PSE SA BZ) were not expected for hours with zero energy exchange with neighbouring countries, which was the case 25% of the time in 2015–2016. The figure shows data availability in hourly resolution. Very short gaps might not be visible. For higher resolution see https://neon-energie.de/transparency-platform.

Responses by interviewees and survey participants are consistent with our findings. Noted issues included incomplete "Physical Flows" (12.1.G) and "Scheduled Commercial Exchanges" (12.1.F).

Balancing

From the Balancing data domain, the data item "Total Imbalance Volumes" (17.1.H), which is reported per market balance area, was chosen for analysis (Figure 14). The Finnish TSO Fingrid provides data from March 2015 onwards and has frequent gaps. Overall, however, completeness is better than in any other data item we assessed: for two-thirds of all balancing areas, fewer than 0.2% of all observations are missing. About one-quarter of all imbalance volume time series are complete.

Figure 14. Completeness of "Total Imbalance Volumes" (17.1.H) by market balance area.
Key point**: For most balancing areas, imbalance volumes are nearly complete.**



Notes: Data from Lithuanian TSO Litgrid are uneven between June 2015 and April 2016 in the CSV files retreived from the FTP server but complete when accessed through the GUI. The figure shows data availability in hourly resolution. Very short gaps might not be visible. For higher resolution see https://neon-energie.de/transparency-platform.

Responses by interviewees and survey participants are consistent with our findings but also point out issues with other items in the data domain, including incomplete "Amount of Balancing Reserves Under Contract" (17.1.B). One user familiar with the balancing working group found it problematic that it is comprised of TSO users with no market participants represented.

(b) Reporting data gaps and public documentation of issues

Users not only have raised concerns about incompleteness but also emphasized that there is no information available about the status and degree of completeness and no warnings about incomplete data. This forces each user to monitor completeness individually.

When users encounter gaps, there is no process to publicly flag missing information as a warning for other users. There is also no direct way of contacting Data Providers or Primary Data Owners. The only way to inform the Data Providers of gaps is through the ENTSO-E service desk. However, there is also no public record of service desk inquiries or issues. As a result, TP users waste resources trying to determine whether data are sufficiently complete for analyses. This was one of the most persistent complaints we received from users; it is also noted in an ETUG summary of user feedback.

Additionally, some users have suggested that the reason for the missing data should be published to facilitate its correction; for example, if it is because a TSO has not submitted the data, the TP user could call the TSO directly rather than being routed through the TP service desk, which likewise must answer redundant calls. Publishing such data could help create accountability for those institutions that have a history of failing to completely report data.

(c) Broadening the scope

Some stakeholders have an interest in additional data that could be available on the TP. This is different from the missing data reported above because these suggestions go beyond what Regulation 543/2013 prescribes to be published. While these are therefore not issues of incompleteness with respect to the Regulation, we believe reporting user needs and preferences is valuable and gives an impression of what users would consider to be a complete database.

The most common requests include a variety of price data, renewable forecasts published earlier and for longer timeframes, net transfer capacity values and detailed generation per unit for plants below 100 MW.

However, most users preferred to focus on improving the quality of the existing data items rather than adding any more items at this stage.

3.1.2.2 Accuracy

The accuracy analysis aims to identify whether data are “correct”. We compared values on the TP to values reported elsewhere. It should be noted that differing values may result from differing data definitions rather than being proof of inaccurate values; however, our results concern cases in which the data were reasonably comparable. We found four major issues related to the accuracy of the TP:

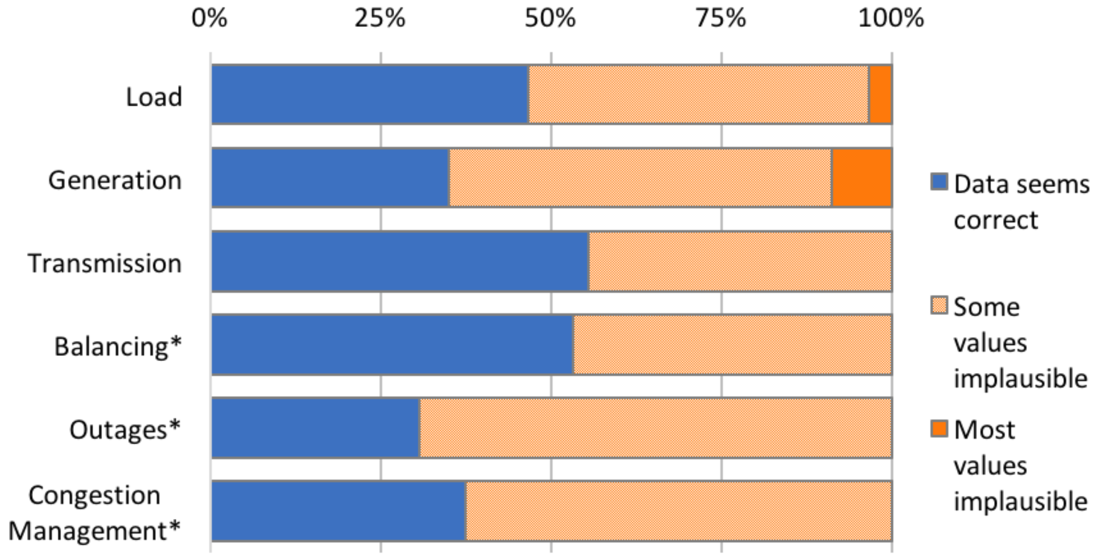
- Inconsistencies with other ENTSO-E data,
- Inconsistencies with other data sources,
- Information about inaccuracy: users are not informed about incorrect data and
- Inaccurate data definitions.

From January to June 2017, there were 68 service desk requests regarding discrepancies, differing values and incorrect data. In the ETUG survey, 18% of users characterised their trust in the reliability of TP data as “little”, with another 41% responding “a moderate amount”; more than 54% of users had noticed data inconsistencies while using the TP. In its opinion on the first update of the MoP, ACER noted that despite improving other aspects of the TP, ENTSO-E had failed to address improvements in assuring data quality.

In our own survey, half of all respondents reported TP data to be inconsistent with other sources, mentioning the ENTSO-E Ten-Year Network Development Plan, Yearly Statistics and Mid-term Adequacy Forecast; Eurostat; SKM SYSPOWER; balancing data provided by RTE; installed capacity per production unit published on regional REMIT platforms; planned production published on EEX; sum of generation from BDEW and national TSO and industry reports. According to our online survey, users noticed at least some inaccuracies in all data domains, as displayed in Figure 15. Users were asked the question “Do you find data on the platform to be accurate (correct)?”. They were then given the options “Most values seem implausible”, “Some valuables seem implausible”, “Data seems correct” and “I’m not sure”. Since users were not given instructions or methodology for defining how many implausible values constituted each category, the survey did not measure the objective accuracy of the data. It further should be noted that users are not always informed about rectifications of the data after they last worked with them. However, the survey results show *users' perceptions* of accuracy on the TP.

Figure 15. Percentage of users who noticed implausible values in different data domains.

Key point: For all data domains, about half or more of users have noticed implausible values.



Notes: Data domain names with asterisks represent those for which fewer than 30 users responded.

(a) Comparison with other sources

One way to check whether TP data are accurate is to compare them to other trusted sources. However, for many data items other sources do not exist, are blocked by a paywall, are proprietary or are not available in one central spot. We therefore focused on a few data items for which we compared TP data with sources such as ENTSO-E's Power Statistics (formerly "Data Portal"), Eurostat and data collected from individual TSOs' websites. For some of these data items, it is possible that the definitions differ depending on the source; however, we believe the results give a valid analysis of data inconsistencies.

Load

We compare the data item "Actual Total Load" (6.1.A) to two other sources of load data: ENTSO-E provides load data in sections of its website separate from the TP called "Data Portal" (for data from years until 2015) and "Power Statistics" (years after 2016). It is our understanding that the data provided by the Data Portal and the Power Statistics are sourced and processed separately. Monthly aggregated load data are available under the titles "Monthly consumption"[14] (Data Portal) and "Monthly Domestic Values"[15] (Power Statistics). A second source of load data is Eurostat's "Supply of electricity - monthly data (nrg_105m)"[16]. These sources differ in two important aspects:

- TP data are delivered close to real time (one hour after the operating period), while the other sources undergo revisions.
- TP data require total load, while the Data Portal/Power Statistics may report a share of the total, as indicated by the possibility to report a country-specific "Representativity Factor".

The first difference implies that we can expect random deviations between TP and the other sources resulting from close-to-real-time estimation errors. These errors should not be systematic, i.e. they should average out over longer time periods. The second difference implies that the Data Portal/Power Statistics data and Eurostat data in those countries that have a Representativity Factor smaller than 100% could be smaller than TP values. The reported Representativity Factors[17] are always 100% for all countries, however; thus, these sources should be reporting total load.

In almost all countries we find significant, persistent deviations among all three sources; in most cases, TP numbers are smaller than the other statistics (Figure 16). Deviations in the double-digit percentage range are not uncommon. Moreover, deviations vary among countries: in Slovakia, TP load is somewhat larger than both other sources while in Austria, it is about 20% smaller.[18] This suggests that the deviations are not due to a difference in data definition among sources.

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[14] https://www.entsoe.eu/data/data-portal/consumption/Pages/default.aspx

[15] https://www.entsoe.eu/data/statistics/Pages/default.aspx

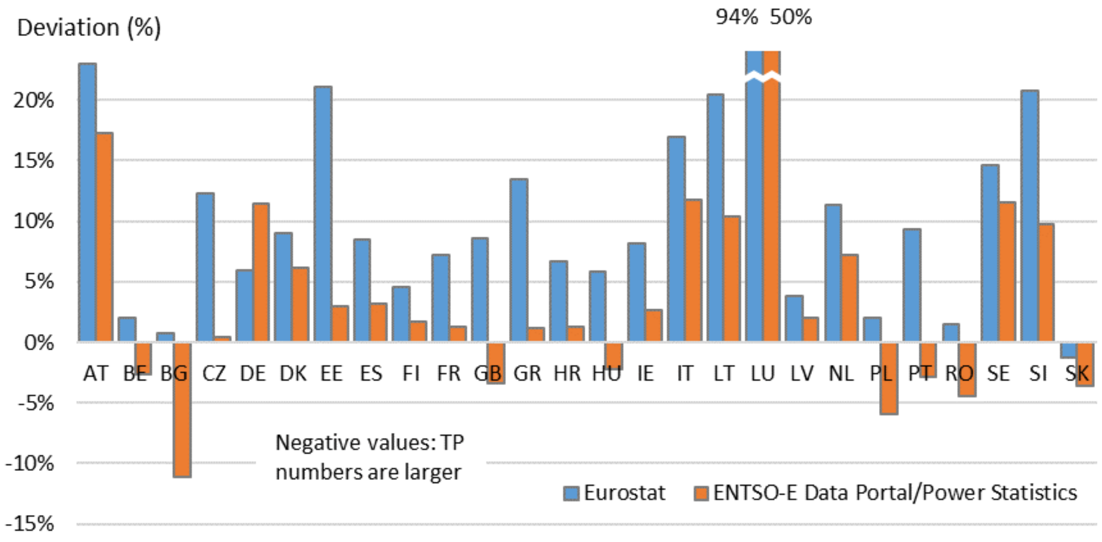
[16] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_105m. Eurostat does not report electricity consumption explicitly: as we learned upon enquiring with their help desk, Eurostat explained that in their Electricity the data item "Gross inland consumption" should in fact be read as net imports. Assuming that electricity consumption equals gross generation + imports, we thus calculate electricity consumption by adding "Gross electricity generation - Total" + "Gross inland consumption".

[17] https://www.entsoe.eu/data/statistics/Pages/monthly_domestic_values.aspx

[18] For the Austrian case, we were informed by ENTSO-E that "the reason for the deviation in Austria results from different definitions of the respective sources. On the Transparency Platform, Total Load includes only data of the control area APG. Instead, the values on Power Statistics include data for the whole country (also including data of large industry with own production units and railroad consumption, which are not directly connected to the grid of APG)."

Figure 16. Deviation of load between TP and other sources.

Key point: "Actual Total Load" (6.1.A) values are inconsistent with other sources' load data, including ENTSO-E Power Statistics. The deviations are often significant in size (>10%).



Notes: 2015–16. Blue bars are calculated as "Eurostat minus TP" and orange bars as "Data Portal/Power Statistics minus TP".

Generation

We compared the data item "Aggregated Generation per Type" (16.1.B&C) to other sources of generation data: for Germany, we compared all technologies to data published by two official German sources. To get a comparable dataset for yearly generation, net generation is taken from the German Federal Statistical Office (Destatis)[19]. Generation data by wind and solar and most biomass units are missing in this dataset since it only includes generation by units with an installed capacity >= 1 MW[20]. For these production types, gross data, which includes consumption by power plants, are taken from AG Energiebilanzen[21]. Since differences between net and gross generation are minor for renewables, this is deemed a reasonable approach.

Figure 17 shows the result of the comparison. We find differences between the two datasets for most production types. Differences for individual production types could be due to diverging rules on assigning individual power plants to production types but should cancel each other out when aggregating all production types. This is partly the case, the

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[19] https://www-genesis.destatis.de/genesis/online/data?operation=abruftabelleAbrufen&selectionname=43311-0001

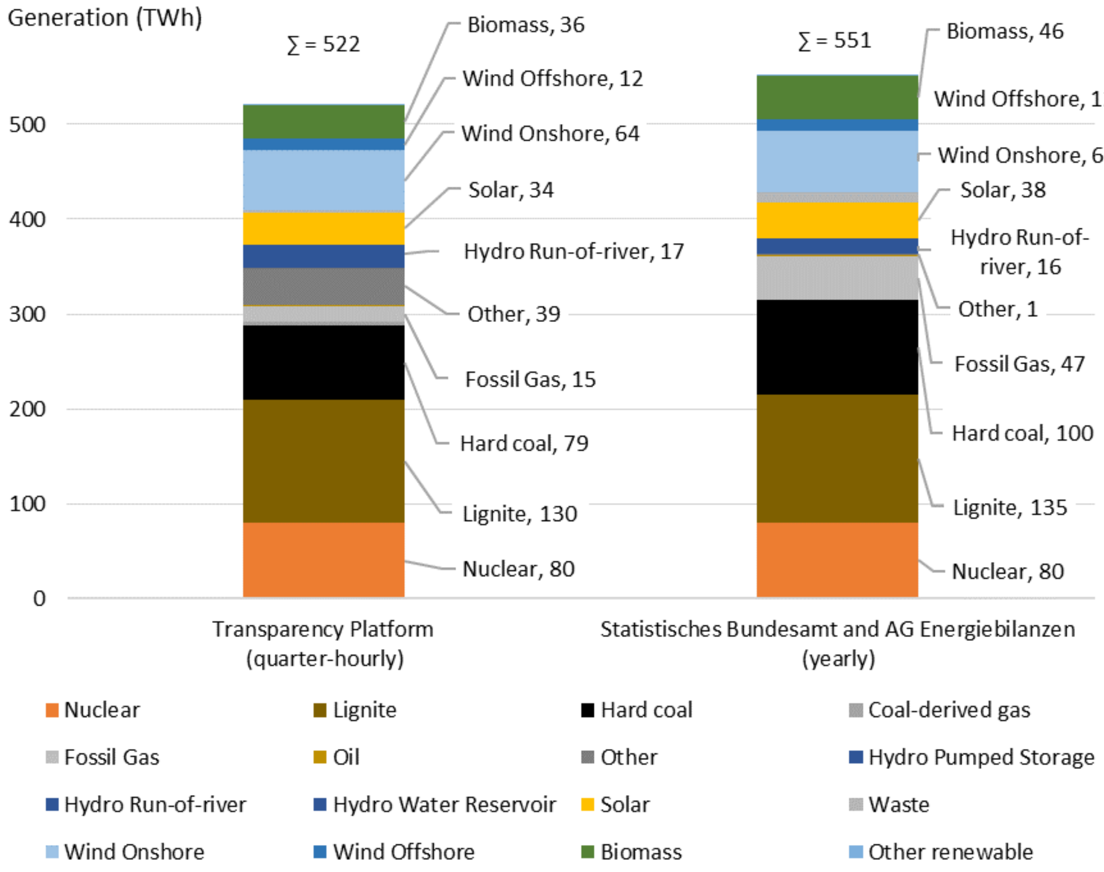
[20] https://www.destatis.de/DE/Publikationen/Qualitaetsberichte/Energie/MBElektrizitaetsWaermeerzeugungStromerzeugungsanl066K.pdf?__blob=publicationFile#page=4

[21] http://www.ag-energiebilanzen.de/index.php?article_id=29&fileName=20170811_brd_stromerzeugung1990-2016.xlsx

most significant example being fossil gas: on the TP 15 TWh are reported for fossil gas—67% less than the 47 TWh reported by Destatis. This is counteracted by a larger value for "Other" generation on the TP (39 TWh compared to 1 TWh on Destatis). Combined cycle gas turbines are reported as "Other" generation on the TP, explaining this discrepancy. For hard coal, the TP reports 78 TWh compared to 100 TWh on Destatis. Differences for renewable and nuclear generation are minor, with practically identical reported generation for wind and solar. When summing up all technologies, however, total generation as reported by Destatis is higher by 29 TWh than the TP data (551 TWh - 522 TWh), the reason for which is unclear.

Figure 17. Comparing "Aggregated Generation per Type" (16.1.B&C) with 2016 German generation data from Destatis and AG Energiebilanzen.

Key point: TP reports smaller values for fossil gas and hard coal compared to other sources.



For some countries, we collected hourly resolution wind and solar generation data from the websites of their respective TSOs[22]. As TSOs also submit those data to the TP under

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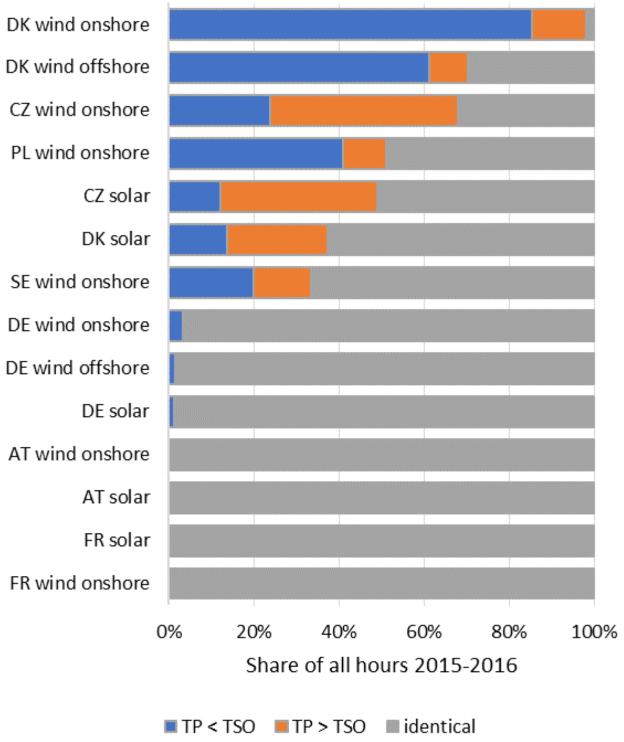
[22] http://open-power-system-data.org/data-sources#8_Wind_and_solar_power_time_series

"Aggregated Generation per Type" (16.1.B&C), we expect that both sources should be identical. Figure 18 shows that this is the case for several countries, notably France and Austria. Additionally, solar data from Germany as aggregated from four individual TSO websites are almost always identical to the corresponding TP data (16.1.C) for Germany. However, for other countries, the two respective sources deviate regularly. Czech, Danish and Polish wind generation data (16.1.C) reported on the websites of the respective national TSOs often report different values than on the TP. Danish onshore wind generation (16.1.C) is practically never identical. This inconsistency is not due to different coverage, as for all countries in which deviations occur, they are sometimes positive and sometimes negative. In the case of Poland, according to ENTSO-E, differences can be explained by different calculation methods: hourly wind generation on PSE's website is calculated as the average of quarter-hourly observations, while on the TP, hourly averages are based on more frequent observations. The TP values can thus be regarded as more accurate.

Figure 18. Frequency of deviations of selected generation data between TP and TSOs.

Key point: Some TSOs publish identical data on their websites and on the TP; others do not.



Notes: All countries for which we have collected data are listed. The selection was made based on availability and user friendliness of TSO data. Sometimes wind generation for one country is reported with up to two decimals precision in one source but as integers in the other. In order not to count this as a deviation, differences up to 1 MW are regarded as identical.

Figure 19 compares TP wind generation data (16.1.C) with Eurostat's "nrg_105m"[23] statistics as well as ENTSO-E's "Detailed monthly production"[24] from the Data Portal

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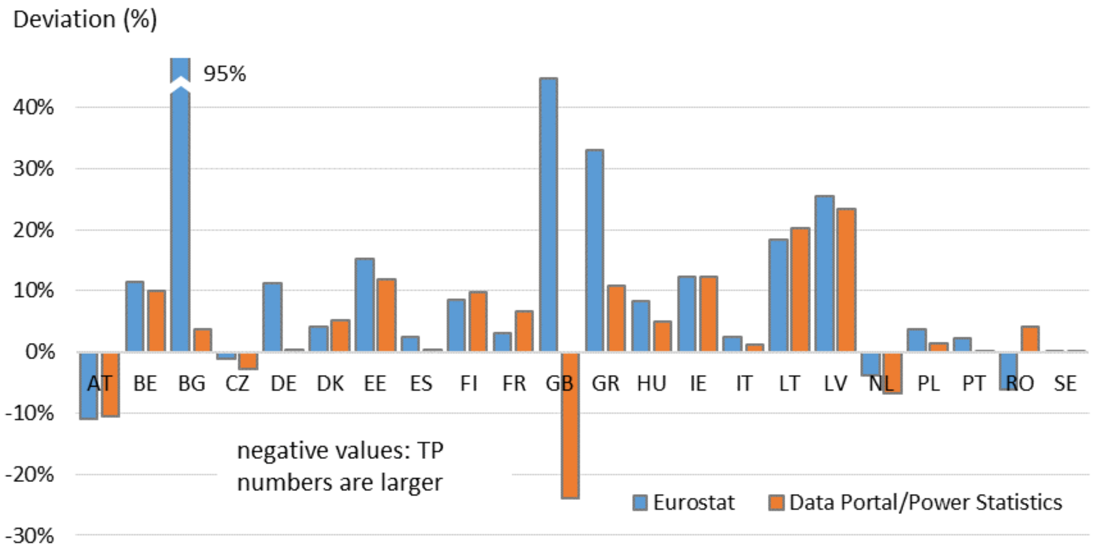
[23] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_105m

(through 2015) and "Monthly Domestic Values"[25] from the Power Statistics (from 2016 onwards) for those countries in which the data are complete enough on the TP to allow for a comparison. In all countries, we find inconsistencies; however, some cases are less worrisome than others. France sticks out as a positive example and the United Kingdom (GB)[26] as a negative. During interviews, experts reported that GB data are problematic because offshore and/or plants connected at the distribution level are excluded from certain statistics, but we could not find any written documentation of this discrepancy.

Figure 19. Deviation of wind generation between TP and other sources.

Key point: TP wind generation data (16.1.C) often deviate significantly (>10%) from other sources, including ENTSO-E Power Statistics.



(b) Other accuracy issues

In some cases, inconsistencies can be identified by comparing with the TSO data or with data from a vendor. Both the ETUG summary of user feedback and many of the experts we interviewed identified national TSO data as often conflicting with values reported on the TP. However, in other cases, the only source for the data is ENTSO-E, and while data users may be sceptical of data accuracy they also cannot verify values.

In our interviews and user survey, users mentioned issues with data in the Generation and Load data domains. Reported inaccuracies included values for "Aggregated Generation per Type" (16.1.B&C), especially in the Netherlands, and out-of-service

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[24] https://www.entsoe.eu/data/data-portal/production/Pages/default.aspx

[25] https://www.entsoe.eu/data/statistics/Pages/default.aspx

[26] "GB" (not "UK") is the official ISO 3166-1 alpha-2 country code for the United Kingdom of Great Britain and Northern Ireland. Great Britain (excluding Northern Ireland) has the ISO 3166-2 code "GB-GBN".

production units in “Installed generation capacity per unit” (14.1.B) not labelled as such. Other issues included implausible generation values, including solar production (16.1.C) at night and values reported in “Day-ahead Generation Forecasts for Wind and Solar” (14.1.D) identical to those reported in “Aggregated Generation per Type” (16.1.B&C) for wind and solar. Users also expect the sum of generation (16.1.A/16.1.B&C) to correspond with the sum of “Actual Total Load” (6.1.A) and “Scheduled Commercial Exchanges” (12.1.F), which does not seem to be the case.

(c) Reporting inaccuracies and public documentation of issues

As in the case of completeness, users are not informed about inaccuracies, nor can they inform other users if they identify problematic data. Additionally, there is no established procedure for addressing inconsistencies between the MoP and the TP website. All requests are routed through the service desk and are not published.

(d) Inaccuracy in data definitions

Regulation 543/2013 specifies data definitions, but at a relatively high level. More details are given in the Detailed Data Descriptions, which are an annex to the MoP. However, these leave room for interpretation. Additionally, since they are an annex to the MoP, any changes to the data definitions require the same (lengthy) procedure as changing the MoP, even if they only serve as clarification.

These unclear data definitions lead to inaccurate data with subsequent confusion on the user side along with inconsistent interpretation by Data Providers. Users we contacted had issues with definitions, including of forecast net transfer capacity, a lack of standardization among TSOs of data definitions and opaque measurement and estimation methodologies. One example is the case of “Aggregated Generation per Type” (16.1.B&C), in which generation by combined cycle natural gas power plants is not reported under “Fossil Gas” but under “Other”. However, users only learned about this after inquiring at the service desk[27] as it is not mentioned in the documentation files.

3.1.2.3 Timeliness

Assessing timeliness means confirming that data are published on the TP within reasonable timeframes, ideally those specified in Regulation 543/2013. We relied on user input for the timeliness assessment, in particular from market participants. We summarize the issues with timeliness as follows:

- Outage data and UMMs
- Overwriting forecasts
- Delays in data availability

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[27] From an email from the ENTSO-E service desk, Jul 4, 15:02 CEST: “Other means other conventional and in our case it includes combined cycle gas turbines. Definition: Others = Total generation – (a+b+c)

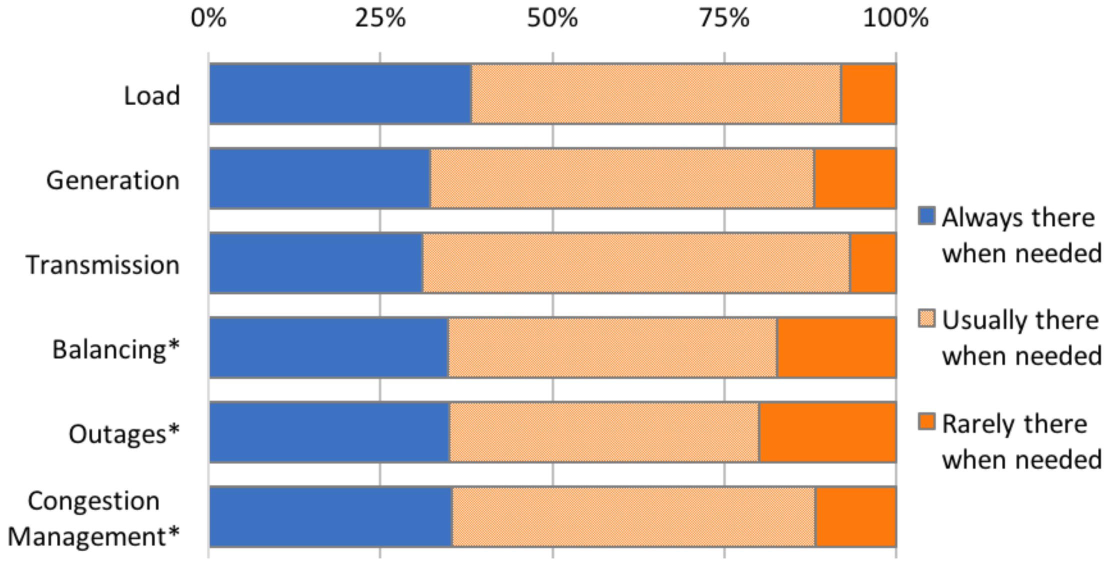
a) Renewable energy (based on projections and forcasts [sic]).
b) Power Stations directly connected to the High-Voltage Grid (Measurements).
c) Fossil Coal-derived gas (Schedule based, no measures)”

Often, there is a trade-off between timeliness and accuracy: publication of data shortly after real time often requires relying on estimation and extrapolation. Later, more accurate measurements become available. In the energy sector, it is not uncommon for some statistics to be revised during a period of up to three years.

Issues with timeliness are most relevant for users working on a close-to-real-time basis; that is, mostly market participants. Figure 20 shows the results of the online survey regarding user perceptions of whether data were published in an acceptable timeframe. Users were asked the question "Do you find data on the platform to be available when you need it?". They were then able to answer "Data is rarely available when I need it", "Data is usually available when I need it", "Data is always available when I need it" or "I'm not sure". Since users were not given any instructions or methodology for defining how many untimely data values constituted each category, the survey did not measure the objective timeliness of the data. It should further be noted that users are not always informed about accelerations of the data publication process after they last worked with the given data. However, the survey results show *users' perceptions* of timeliness on the TP. There were several cases of users who stated they would use the TP more if it reliably published data on time. Users interested in historical data, including academics, found that data were published in an acceptable timeframe. However, these users mentioned that data updates were not marked as such and obscured historical information.

Figure 20. Percentage of users assessing timeliness for different data domains.

Key point: For every data domain, fewer than 40% of users reported that data were always there when needed.



Notes: Data domain names with asterisks represent those for which fewer than 30 users responded.

Users interested in real-time data found that TSOs often published data on their websites more quickly than they appeared on the TP.

(a) Outage data and UMMs

Information on planned and unplanned outages of generation and production units (15.1.A–D), consumption units (7.1.A&B) and the transmission grid (10.1.A–C) are reported in the form of Urgent Market Messages (UMMs). These messages must identify the concerned units or transmission assets, the start- and end date of the event and the installed and available capacity during the event. The UMMs must be published as soon as possible, i.e. no later than one hour after an unplanned outage occurred or after a decision is made regarding a planned outage. Each outage as well as updated information is published separately as a new UMM. Whereas the UMMs can be downloaded individually for generation and production units and transmission assets, unavailabilities of consumption units are aggregated by bidding zone or control area.

Most market participants whom we interviewed identified UMMs as an area of concern for a number of reasons: many users are missing a versioning scheme or timestamp that would allow coherently connecting the individual UMMs. There is no functionality to allow generation plants to combine information on a single power plant into one "profile" or message. Furthermore, users were concerned about duplicate UMMs reported for single generation facilities, inconsistencies when trying to download UMM information via API and FTP, slow reporting times on the part of power plants, inconsistent information compared to other data sources, information that was not provided in a useful order and country-specific issues in Belgium, Germany, the UK, Italy and the Netherlands.

Publication requirements for outages and other UMMs stem not only from the Transparency Regulation but also from Regulation (EU) No. 1227/2011 (REMIT)[28]. As a consequence, UMMs are reported not only on the TP, but also on so-called Inside Information Platforms[29] (e.g. EEX Transparency or Nordpool REMIT UMM). Some market participants expressed dissatisfaction that the TP is not intended to be an inside information platform.

(b) Overwriting forecasts

Another issue mentioned by users is that data are overwritten by updates even though the historical values also may be relevant for analysis. Users complained of historical data being overwritten by updates without an indication of whether there was an update, when it was made and where historical data would be available. Although historical data values must be archived according to Article 3.1 of Regulation 543/2013, they are not accessible on the TP for users. One example, as identified in a presentation entitled "Manual of Procedures Revision" given at an ETUG meeting, is "Day-ahead Generation Forecasts for Wind and Solar" (14.1.D). As it exists now, day-ahead 18:00 forecast values are overwritten by intraday 8:00 and then possibly more recent forecasts.

In its summary of user feedback to ETUG, ENTSO-E identified not only the overwriting as an issue but also that no indication was given on the TP of such revisions, a comment repeated by our interviewees. The most prevalent concern was that day-ahead "Scheduled Commercial Exchanges" (12.1.F) are not reliably available as they are

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[28] http://data.europa.eu/eli/reg/2011/1227/oj

[29] https://www.acer-remit.eu/portal/list-inside-platforms

overwritten with intraday scheduled flows instead of reporting day-ahead and intraday values separately as had been the case prior to the introduction of the TP in 2015. This reportedly will be rectified in the latest MoP update.

(c) Delays in data availability

Users have singled out data from Belgium, Bulgaria, Ireland, Italy and the Netherlands as noticeably delayed.

3.1.2.4 User friendliness

User friendliness is different from completeness, accuracy and timeliness in two ways: first, it concerns the platform itself, rather than the data contained in it. Second, it is more subjective and its assessment cannot be accomplished by a statistical analysis of the data. Nevertheless, through our own experience during this and previous research and consulting projects, through reviewing assessments and through the online survey and the interviews we conducted, we are confident that we are able to report a representative and robust picture of which aspects of the TP users find satisfying and where they see the need for improvements. We have categorized comments regarding user friendliness into six broad categories:

- Website and GUI, including ease of finding data, data presentation and ease of accessing data for downloads;
- Automatic downloads, including useful documentation and reliable access;
- Data files;
- Displaying data availability, including why data is unavailable;
- Data documentation and
- User support.

Of these, data documentation received the largest number of critical comments.

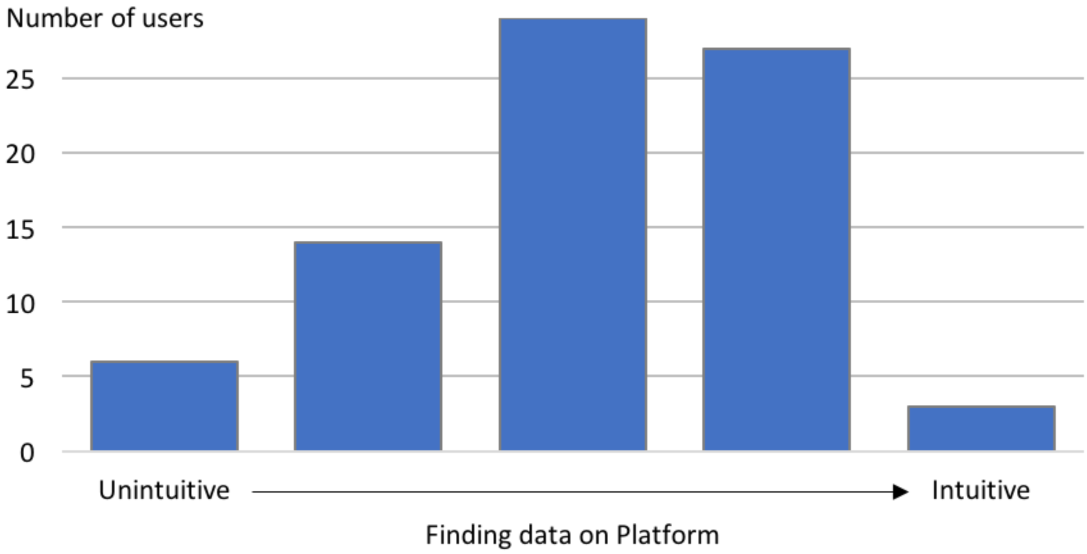
(a) Website and GUI

Navigating the website

According to the ETUG user survey, about 71% of TP users find navigating the website at least moderately easy. Our own survey revealed similar results; as displayed in Figure 21, users rated finding data on the TP an average of about 3.1 (1–5 scale; 5 intuitive). We find the grouping of data items on the website to be not always intuitive for first-time users; one example is “Day-ahead Prices” (12.1.D), which is categorized under “Transmission”.

Figure 21. Number of users rating intuitiveness of finding data on TP.

Key point: Few users report finding data on the TP completely intuitive but on average, users find it fairly intuitive.

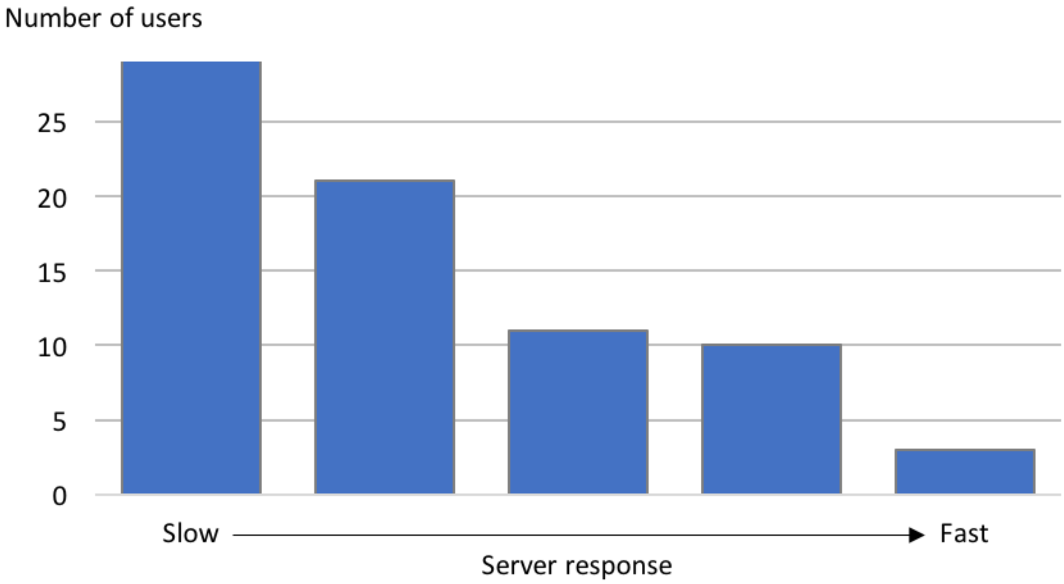


Notes: Scale of 1-5.

Response time and download speed

Several users, both in interviews and via the online survey, reported slow server response and frequent time out errors, an issue also reported by the ETUG user survey. This is not only an issue of convenience, but can jeopardize functionality: if the TP is unstable, it is not always possible to scrape data as soon as it is posted.

Figure 22. Number of users rating speed of server response times.
Key point: Users report server response to be slow.



Notes: Scale of 1-5.

Data selection and filtering

Users find it difficult to download the exact data they want. Several users would like more and better implemented options to display and filter subsets of the data, an issue also reported by the ETUG user survey. A related need is the possibility to download data from multiple geographic entities at once rather than being restricted to one at a time—the lack of this option is an obstacle for users who must rely on the GUI to download larger amounts of data.

Other website issues

When navigating the website, users often are presented with tables not showing any values. The reason is not necessarily that data are missing: the GUI allows selecting all sorts of combinations of data item, geographical entity, point in time and possibly other (data item-specific) criteria for many of which data are not expected. This seems to be the case for many of the default views shown upon first selecting a data item. Another issue stems from the fact that users must log in before being able to download data from the GUI: if they first navigate to the data they are interested in and then decide to log in, they are returned to the homepage and must find the previously accessed data item once again. Users also suggested making the website more visually appealing and graphically oriented; one best-practice example cited in the survey was the Fraunhofer ISE website Energy Charts[30].

(b) Automatic download

The web interface (GUI) is one out of six ways to download data. Expert users who have implemented access via FTP or the Restful API expressed satisfaction with these two download options—one interviewee said the Restful API "is what works best about the TP website." [2]

However, users with less experience or without an in-house IT department supporting them often had trouble implementing automatic access. Maybe more problematically, many users are not aware that these options exist, likely because automatic download options are mentioned only in one of several FAQ collections on different subdomains of the ENTSO-E website. In the case of the FTP, ENTSO-E does not publicize it as a download method because it is in a test phase.

In our user survey, users rated the usefulness of the GUI on average about 3.3, the FTP on average about 4.1 and the Restful API on average about 3.9 (1–5 scale; 5 very useful). Figure 23 displays how users rated these three download options. FTP and API download options were reported as very useful by nearly half of users. However, fewer users were familiar with FTP and API options than GUI.

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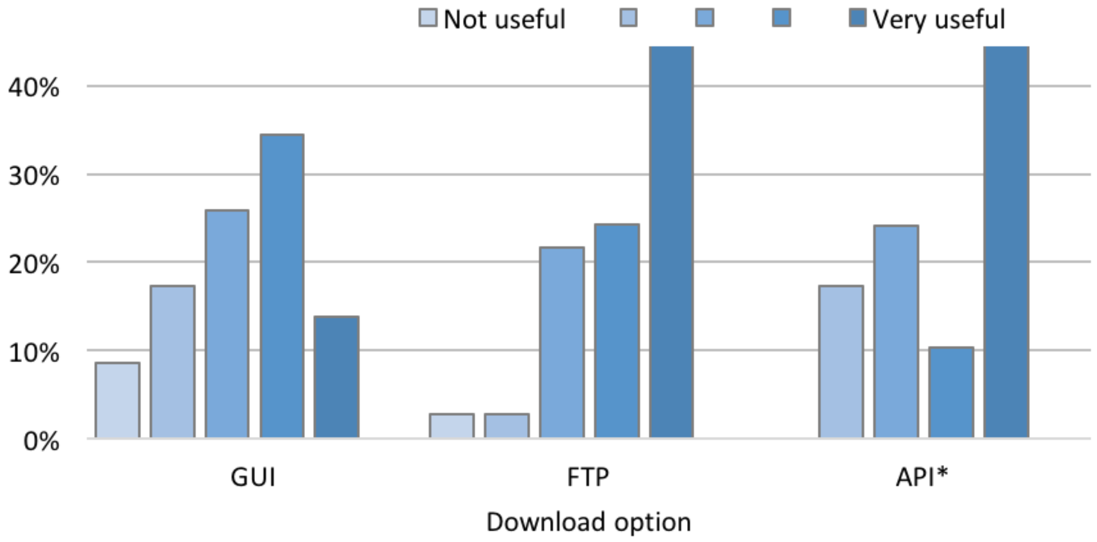
[30] https://energy-charts.de/

Figure 23. Percentage of users rating usefulness of download options.

Key point: FTP and API download options were reported as very useful by nearly half of users.



Notes: Scale of 1–5. The asterisk indicates that fewer than 30 users responded to the question regarding the API download option.

The data websites Quandl[31] and Kaggle[32] were mentioned in the survey as best-practice examples of platforms with a focus on data integration, automation and speedy processing. RTE and Nordpool were also mentioned as positive examples. Overall, users were happy with FTP and API download options, although there were issues including unreliable availability of all data items and an inconvenient process for downloading updated values via API, overly technical API documentation and missing information via FTP.

(c) Issues with data files

Users are split in their opinion on XML files; some find them useful while others find them inconvenient. For all file types, file-naming conventions could be improved, which today include "spaces and uppercase and lower-case letters all in the mix", as one survey respondent wrote. It was also suggested to allow CSV users to choose date format, field separator and time period. When downloading CSV or XLSX data, data in 15-min, 30-min and 60-min resolutions are provided in one single file, which can be burdensome to work with. [11] [14]

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[31] https://www.quandl.com/

[32] https://www.kaggle.com/datasets

(d) Displaying data availability and “master data”

As there is no central area/data matrix, users often spend time clicking through to see whether a data item is available in a given area. This might be the most limiting shortcoming for first-time users: there is no easy way to get an overview of what is available on the TP.

In their February 2017 opinion on the first revision of the MoP, ACER requested that a list of data providers per data item and geographical area be provided.

An independent but related issue is the fact that the so-called Reference and Master Data are not available to users. In their opinion on the MoP update, ACER mentions bidding zones, control areas and borders and a list of generation units as examples of such data. In ACER’s opinion, making this information explicitly available to users would complement existing download options. This was also brought up by interviewees, who were interested in maps of bidding zones, control areas and borders (and how these differ from one another) as well as data sources.

(e) Data documentation

Users mentioned unclear, insufficient and hard-to-find data. One user summarized that “there are some stubs available on the website, but in general the documentation is…poor: what is ‘load’? Which power plants are counted in a specific fuel-type [16.1.B&C]?” This is in line with user feedback reported in the ETUG survey: “more detailed data information was consistently suggested (close to data items/centrally): improved data definitions, methodologies, publication times, possible disclaimers, why a data item is not expected, contact info for data providers, matrix of data by provider/data availability”.

Another issue is the difficulty of accessing data definitions. In our user survey, nearly 60% of respondents had not heard of the Detailed Data Descriptions. Without investigation, users also do not learn about the fact that the existence, content and governance of the TP are due to Regulation 543/3013, as it is not mentioned on the website. Numerous TP users said that documentation and metadata are difficult to find. A consensus among experts and other users was that documentation and metadata should be available from the same place as the data items are.

(f) User support and contacts

The TP does not publish contact details for or the identity of Data Providers or Primary Data Owners. All requests are channelled through the TP service desk, which forwards questions to Data Providers or Primary Data Owners. The service desk then responds by email to the requestor. This procedure has several shortcomings:

- As noted above, other users are not warned about quality issues. This causes users to be unaware of existing problems and could lead to multiple requests about the same issue.
- If addressed through the service desk, TSOs are often hesitant to reply, because on the grounds of non-discrimination they are not allowed to share information

with a market participant exclusively. However, they rarely make such information available to the public via their own websites, either. [1] [survey]

- While most requests are addressed within a few days, some remain unanswered for several weeks without explanation.

3.1.3 Conclusions and recommendations

3.1.3.1 Priorities

Missing, inaccurate or inconsistent data affect all types of users. Beyond this, different users have different requirements and priorities. "Light users" have different requirements and face different problems than "frequent users". This section provides a list of issues by user type.

(a) Light users

Light users access the TP once or a couple of times per year. They are researchers or analysts who do a one-time assessment for which they require TP data. They use the GUI to download data manually. According to ENTSO-E, there are 8800 users registered for the TP. Given this large number, it seems plausible that the majority of these are light users. The main problems they encounter seem to be the following:

- Problems with the GUI, including unintuitive navigation, slow response times and error messages, lack of filter options and lacking possibility to download multiple countries at once;
- Hard-to-find data descriptions and documentation;
- Lack of a central area/data matrix that indicates data availability;
- Lack of information about automatic download options and
- Long historical time series are missing and pre-2015 values are not integrated.

(b) Frequent users

Frequent users access the TP on a regular basis, sometimes multiple times per day, usually through the Restful API. They are often large market participants who also are obliged to provide data. Their companies often have IT departments that support their gaining automatic access; often, TP data are retrieved automatically and integrated into an internal database. Some market participants have dedicated staff or even teams working only on transparency data. Such users also may be members of ETUG. Through ETUG meetings, they are informed about the structure, problems and processes of the TP. The problems that frequent users encounter include the following:

- Inconsistent interpretation of data definitions by different Data Providers;
- Confusing outage data and UMMs as well as cross-border transmission flows and schedules;
- Data are often used for close-to-real-time decisions (trading, dispatch), so timeliness in general and
- Users expect to be able to use the TP as their primary source of information for outage data/UMMs but they cannot because the data do not satisfy the REMIT requirements.

3.1.3.2 Suggestions for improvements

The individual issues outlined in the sections on completeness, accuracy and timeliness should be improved upon. The objective should be to increase completeness of time series data such as load, prices and generation to 100%. Inconsistencies with other data sources should be resolved or explained. The provision of event-driven data, i.e. outage data (7.1.A&B, 10.1A&B, 15.1.A–D) should be improved due to its importance for market ac-tors: the messages should be displayed in a sensible order, duplicates are to be avoided and older versions of UMMs should be retained and not overwritten. All this could be achieved by implementing a versioning system or by including a timestamp indicating when the message was published. Furthermore, it should be possible to display all outages for a particular unit in one place as implemented e.g. at Nordpool REMIT UMM.[33]

In the following, we present further suggestions for improvements that do not pertain to individual data items, but rather to cross-cutting issues related to usability, incentives and governance.

(a) Improve information and navigation

The issue. An issue for many users, especially those who are not among the large utilities that participate in ETUG, is a lack of well-structured information on the TP. Information is available, but it is scattered throughout the website, cannot be found through search engines and is sometimes buried in PDF documents. Navigation on the website can be unintuitive and makes sense only once one knows the legal background of the TP. Some information is available only to ETUG.

Our proposal. The landing page of the TP should include an introductory text explaining the purpose of the TP and the fact that its existence, content and governance are due to Regulation 543/3013. We furthermore propose making information available where users look for it; making all ETUG-only information available to the public, including ENTSO-E’s continuous quality assessment and providing a well-maintained, easy-to-find and searchable Q&A page that includes all data definitions. We recommend working with a specialist in search engine optimization to make sure that web search engines can crawl and index the Q&A page and rank it highly in search results. Detailed Data Descriptions should not be more than one click away from the data they refer to and vice versa. In addition, we propose introducing a public help forum to replace the bilateral service desk procedure, as many online product providers have done (e.g. Google Product Forums[34]); see also following subsection.

(b) A crowd-sourced public data quality log

The issue. Users who believe they have identified inaccurate or missing data are supposed to contact the TP service desk, which then checks and/or communicates with the Data Provider. Other users are not made aware of the reported issue.

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[33] https://umm.nordpoolgroup.com

[34] https://productforums.google.com/forum/#!home

Our proposal. We propose establishing a public data error log. Registered users should be able to post an item on the list if they encounter issues with completeness, accuracy or timeliness of data or with the usability of the platform. The TP service desk, the Data Provider and other users can respond and comment; all comments are public. Once the issue is solved the service desk flags the item as "solved". The posting and comments remain online. Such a crowd-sourced public data log has multiple benefits:

- Users are warned about issues and can use data with additional care.
- Data providers are warned immediately about issues and have the chance to respond quickly. They also can explain that there is not an issue if that is the case.
- Other users can post solutions or explanations.
- A log creates transparency about structural problems and hence provides an incentive for Data Providers to improve the quality of their data and processes.
- It is a great way to source users' ideas for improvements.

(c) Automatic quality reporting

The issue. There is no public automatic reporting on completeness, accuracy and timeliness.

Our proposal. We propose having ongoing, regular and public reporting on at least completeness and timeliness (and maybe some aspects of accuracy). It should be easy for users to learn which data items are complete and whether recent additions have arrived on time. The reports should be linked prominently on the TP landing page and be accessible from each data item directly. Ideally, this table also would list the reason for the problem. It is our understanding that automatic quality reporting is a capability the TP already has; however, it is used only internally, possibly due to push-back from Data Providers. Such reporting would be complementary to the user-generated data quality log suggested above and share the same benefits.

The combination of a user-reported data quality log and automatic reports would not fix all problems relating to data quality, but it would save users time and could work as a form of accountability for those parties that fail to provide high-quality data.

(d) Machine-readable metadata

The issue. Metadata are data (information) that provide information about other data. Three types of metadata exist: descriptive metadata, structural metadata and administrative metadata. It is our understanding that metadata, including sources, release dates and licences, are not available in many cases (e.g. XLSX, CSV download via GUI or FTP) in a machine-readable form.

Our proposal. We propose providing metadata in JSON format as a complement to XLSX and CSV files for every data item and applicable geographic entity. Metadata should include at least the following information: unit of measurement, data source (Primary Data Owner), Data Provider, contact person, licence, link to Detailed Data Descriptions and—if applicable—to further (data item and/or data source-specific) documentation. We recommend considering whether the CSV files could be organized to comply with the Tabular Data Package standard[35] published by Open Knowledge.

(e) Governance, ownership and incentives

The issue. To us, the governance structure of the TP seems to be the underlying cause of many of the issues discussed above. Dispersed ownership and lack of incentives seem to lead to little attention to users. To us, it seems that responsibility and accountability are lacking:

- ENTSO-E points out that it maintains the technical database; all data quality issues are a matter for Data Providers.
- Data Providers are hard to contact and, to our knowledge, face no material incentives to improve quality.
- National Regulatory Authorities (NRAs) apparently lack the capacity or the incentive to monitor data quality properly and to impose sanctions on non-complying Data Providers.
- ACER lacks the mandate and the capacity to monitor data quality continuously; in addition, ACER recommendations are not binding for ENTSO-E.

Our proposal. Building a useful power system data platform is a complex task. It can never be a one-shot project, but rather requires intensive improvements over a long period. It is burdensome and costly. We recommend improving incentives through transparency and—ultimately—sanctions and adapting the governance structure to focus more on users. We recommend that:

- ENTSO-E get a clear mandate to specify data definitions further to improve consistency among Data Providers.
- Users be able to publicly report issues.
- Data quality be systematically monitored, with reporting by Data Providers and all monitoring reports made public.
- NRAs receive yearly reports about compliance of all Data Providers of their jurisdiction. These reports should be public as well.
- At some point, Data Providers face monetary sanctions for non-compliance with quality requirements and submission deadlines. If NRAs are responsible for imposing such sanctions, the size of the penalties should be public.
- ETUG’s role be expanded and formalized.
- Users beyond market participants—in particular, civil society and academia—be represented formally in ETUG, following the spirit of the Aarhus Convention[36].

The objective of this study was to evaluate the quality of data published through the ENTSO-E Transparency Platform as well as the user friendliness of the platform itself. By providing this analysis and suggesting the above improvements, we hope that we can help the TP become even more useful for its users.

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[35] http://frictionlessdata.io/

[36] http://ec.europa.eu/environment/aarhus/

3.2 Output 2: Terms on data management and access

3.2.1 Objective and approach

This section presents a summary of a legal opinion that assesses legal aspects of using energy data published on the ENTSO-E Transparency Platform (TP). The full legal opinion authored by lawyer Till Jaeger of the law firm JBB Rechtsanwälte, is available as an Annex to this report.

This output addresses the following questions:

- Is the TP protected under copyright or the *sui generis* database right?
- What kind of use is currently legally permitted?
- Who is the rightholder?
- How can legally reliable reuse of TP data be granted in the future?

3.2.2 Findings

3.2.2.1 Legal protection of the Transparency Platform database

Defining "database". The Database Directive 96/9/EC contains the statutory framework for the protection of databases. Databases are defined as a "*collection of independent works, data or other materials arranged in a systematic or methodical way and individually accessible by electronic or other means.*" (Note that this refers to the collection of data, rather than the software or hardware used to store it.) It seems evident that the data provided on the TP are a database in this sense.

Protection of databases. The protection of databases is twofold:

- *Copyright* (Article 3). Databases which, by reason of the selection or arrangement of their contents, constitute the author's own intellectual creation shall be protected as such by copyright. As the transparency regulations specify which data have to be selected for publication and how to arrange them, there is little scope left for Data Providers for unique intellectual creation resulting in classical copyright protection. Hence, copyright protection seems unlikely.
- *Sui generis right* (Article 7). Independently, the maker of a database that shows that there has been a qualitatively and/or quantitatively substantial investment in either the obtaining, verification or presentation of the contents is granted a so-called "sui generis database right" or simply "sui generis right". This right was newly introduced at that time and does not exist outside the EU. The sui generis database right is similar to copyright; however, it is not granted for an intellectual creation but for the financial and professional investment made in obtaining and collecting the contents. This seems to be fulfilled in the case of the TP. Thus, any person who wants to reuse it has to assume that the database is protected by the *sui generis* database right. This protects the maker of a database from "extraction and/or re-utilization of the whole or of a substantial part" of it.

Conclusion. The energy data provided on the TP constitute a database and are protected under the *sui generis* database right.

3.2.2.2 What kind of use is currently allowed

Use cases. Different types of users use the TP for different purposes, ranging from electricity trading to system planning, research and policy advice. They also might use the TP in different ways: studying raw data, running statistical analysis of data, using data as input in computer models and/or sharing raw or processed data with others.

Assessing legal use. The maker of the database has the exclusive right to reproduce and distribute the database and to make this available to the public. Therefore, and as a default, any such use is not permitted except when (i) a statutory limitation on the *sui generis* database right applies or (ii) the maker of the *sui generis* database grants a license to the user. Therefore, any use case has to be evaluated in three steps:

- Is the respective act of reusing the data covered by the exclusive rights of the rightholder (or is the use outside the scope of the protection)?
- Are any statutory exceptions to the *sui generis* right applicable (e.g. some kinds of private use, scientific research)?
- Is the respective act of reusing the data allowed under the license provided by the maker of the database?

Covered by protection? When downloading data from the website of a Data Provider, the downloading person is creating a new copy of the data. This reproduction affects the rights of the owner of the *sui generis* right if the database is copied as a whole or a qualitatively or quantitatively substantial part of the database is copied.

Statutory exceptions applicable? Some Member States, notably Germany, permit by means of law downloading substantial parts for private or scientific use for non-commercial purposes. Differentiating "private" from "commercial" use is notoriously difficult. Private use has been interpreted very narrowly by courts in the past. In any case, it is clear that data use by companies (be it utilities, financial actors or consultancies) as well as contract research – even if conducted by universities – does fall under the scope of "commercial purposes". In particular, it seems evident that all market participants are using TP data for commercial purposes. Therefore, it seems certain that exceptions from database right protection apply to a minor share of TP users at best.

Allowed under licence granted? For the vast majority of TP users, the only way to legally download the TP database is if they are granted a licence. In this context, "licence" means the grant of a right to use the database with the scope of the right specified in the licence. The "General Terms and Conditions for the Use of the ENTSO-E Transparency Platform" is governing the use of data published on ENTSO-E's website. This is not a classical licence agreement but it stipulates which uses shall be allowed. There is no explicit clause for a grant of rights but the permission. However, one could argue that it is implicitly assumed ("*when using of the Transparency Platform Data for any purpose whatsoever*"). Therefore, it remains unclear to which extent a re-use is permitted. As a consequence, most users cannot be sure that they are currently using the TP database legally.

Other use cases. Usually, downloading data is only the first step of using it. Other types of use, in particular making it available to others (through the internet or a company's intranet), do fall under the scope of the database right, as well. While the legality of the download itself remains unclear, it is very clear that ENTSO-E does not provide users with the right of any other use. In particular, using the TP database as part of an Open Data project that requires publishing data under an open license is not permitted under the license granted by ENTSO-E.

Conclusion. Most use of the TP is likely to be commercial—including all use by market participants but also contract research conducted by universities. Statutory exceptions do not apply to commercial use. Therefore, using a "substantial" part of the TP database only would be permitted if a licence were granted by the maker of the database. This is currently not the case, as ENTSO-E does not grant such use rights without doubt and the scope of allowed usages remains unclear. As a consequence, most use of the TP going beyond the mere download can be seen as constituting a copyright infringement. In other words, most users cannot use TP data in a legally safe manner.

3.2.2.3 Who is the rightholder?

Multiple rightholders. ENTSO-E points out that the "Primary Data Owner" of the data may be the rightholder of the *sui generis* right. According to our understanding, the data published on the ENTSO-E Transparency Platform stem from several sources and are stored in several differing databases:

- Transmission system operators, power plant operators and other Primary Data Owners
- Energy exchanges and other "intermediaries" (which might be at the same time Primary Data Owners) that serve as Data Providers
- ENTSO-E

According to our analysis, it seems likely that all three actors are making a substantial investment in either the obtaining, verification or presentation of the contents of the TP database. As a consequence, they all hold *sui generis* right on (parts of) the database.

Implications. Consequently, third parties interested in the reuse of the data would need the permission of the Primary Data Owners, the permission of the Intermediaries and the permission of ENTSO-E. Taking into account the significant number of Primary Data Owners and the missing consent of the rightholders about under which licence conditions such data shall be publicly available a legal reuse of the database of ENTSO-E is practically impossible. Additionally, if one or more rightholders refuse to license their data, an interested party would have to exempt such data to be allowed to reuse the remaining parts for which the respective rightholders allowed the use. To provide a practical example: if ENTSO-E would like to license its database under a Creative Commons licence for free reuse, the permission of all rightholders would be needed. If one or several Primary Data Owners refuse such licensing, ENTSO-E would have to identify the respective data and restrict the Creative Commons licence to the remaining part of the database. The parts of the database licensed under the Creative Commons licence need to be identified as taking part in such licensing to allow practically the reuse.

Conclusion. It seems likely that both ENTSO-E and Primary Data Owners and possibly intermediaries that have transferred the data hold *sui generis* rights on the TP database.

3.2.3 Conclusions and recommendations

Provide no licence. If ENTSO-E would drop all references to copyright and related rights from the Terms of Use of the TP, all rightholders would still retain their rights. In particular, downloading or re-using data otherwise beyond the existing statutory exemptions would not be legally possible.

Directive on Copyright in the Digital Single Market. In 2015, the Commission released a Communication entitled "A Digital Single Market Strategy for Europe", followed in 2016 by a proposal for a "Directive on copyright in the Digital Single Market". As proposed, however, the Directive would not introduce new statutory exemptions that allowed legal use of energy data.

Amending the Copyright Directive. New statutory exemptions could be included in Directive 96/9/EC. Such an amendment would be complicated and seems unrealistic.

Open data licensing. We believe the best option for legally reliable reuse of TP data is open data. "Open data" is the idea that data should be available to everyone to use and republish without restrictions of usage rights and license fees. Whether a database can be considered open data depends on the licence applicable. A number of such licences exist, one example being the Creative Commons Attribution 4.0 (CC-BY-4.0) licence. For this to happen, all rightholders have to grant an open (inbound) licence to ENTSO-E, which then can grant an open (outbound) licence to users.

Conclusion. The best way forward seems to be to grant an open licence of the TP database. This requires, however, consent of all rightholders.

4. FINDINGS FOR WORK PACKAGE 2

Work Package 2 was implemented by Copenhagen Economics and VVA. VVA was principally leading the data collection for Outputs 3, 4 and 5, while Copenhagen Economics was leading the analysis of the results in Outputs 3, 4, 5, and completed Output 6.

Security of electricity supply is a key concern for European Member States, and a concern that has spurred a number of countries to pursue subsidies to put forward capacity (as opposed to energy) to the market. Security of supply is however not just about having enough generation capacity available (*adequacy* in the literature), but also about having a well-functioning grid that is robust to different types of stress such as congestion and physical failure through e.g. damaged cables or lines. In stress situations that are at risk of evolving into a disruption, certain policies or measures such as voluntary demand curtailment can help reduce the stress in the grid, and therewith avoid the disruption. Every time there is lack of electricity supply, there is a loss to society through avoided consumption possibilities.

While important, there has so far not a clear picture of the extent of disruptions nor their causes, potential mitigation and their market impact. This study will provide a better understanding of those issues, which are important in policy formation:

Regarding their causes:

- Are disruptions primarily caused by lack of generation?
- Are disruptions primarily caused by grid issues?

Regarding their mitigation:

- Are voluntary demand curtailment programmes effective solutions to avoid disruptions? If so, their initiation could be promoted and/or accelerated across Europe. If their effectiveness depends on the design of the programmes, then the effective design should be promoted.

Regarding their socioeconomic impact:

- How much harm do disruptions do to consumers in Europe? The value of lost load reflects the welfare loss caused by a disruption and is therefore an indicator for the scale of the problem.

To answer those questions, we will in this work package analyse how outages, disruptions, voluntary demand curtailment and the value of lost load are linked to each other. In this study, we use the following definitions:

- **Outages** (output 3) are events where a power generation or production unit is out of service. Outages can be planned, for example for the maintenance of units, or forced, for example as a consequence of technical malfunctions in the unit. Outages can, but do not necessarily, lead to a situation where consumers are out of power.

We also consider malfunctions of interconnectors as outages. The reason is twofold: firstly, interconnectors increase the capacity available to a market and are in that role more similar to production units than to the transmission or distribution grid. Secondly, malfunction of an interconnector does not necessarily entail a situation where consumers are out of power, and can therefore not be called a disruption following the definition used in this study. Here, again, interconnectors show similarity to production units. We will however treat interconnector outages separately as they cannot be clearly allocated to one country.

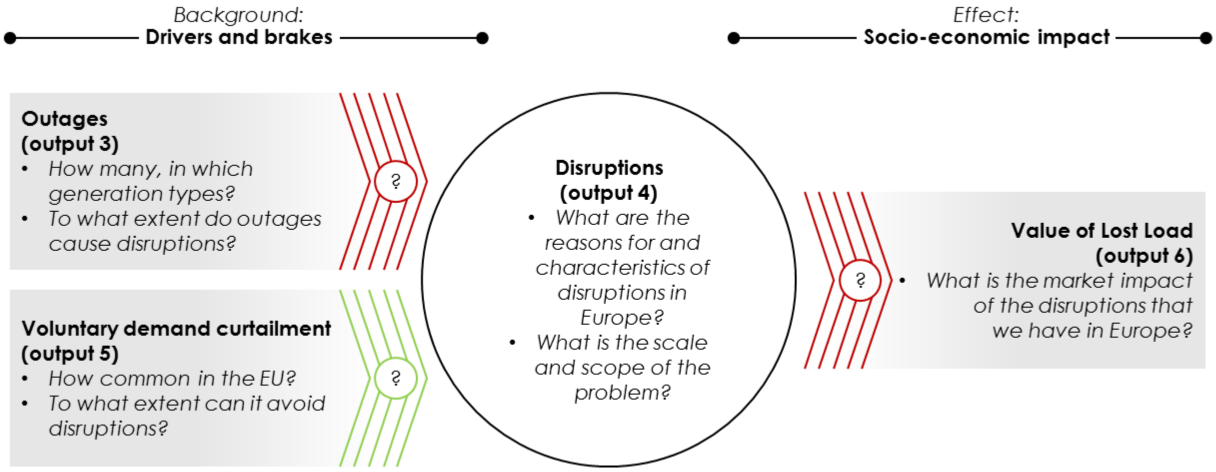
- **Disruptions** (output 4) are situations where consumers cannot consume the amount of electricity they would like to demand; such situations typically mean that consumers are out of power, as in blackouts or brownouts. Disruptions can happen at electric underground cables, overhead lines or transformer stations, each either on DSO or TSO level. As described above, we do not include malfunctions of interconnectors as disruptions, but as outages instead.

- **Voluntary demand curtailment** (output 5), often referred to interruptible contracts, are agreements between electricity consumers and electricity supplier and/or TSO/DSO that allow the latter to curtail the electricity delivered to this consumer (or to cut it completely) in case of emergency.

- The **Value of Lost Load** (output 6) is an indicator for the welfare loss due to a disruption. It is provided in EUR per kWh of non-consumed electricity due to the disruption.

The following figure reflects the overall relationship between outages (output 3), disruptions (output 4), voluntary demand curtailment (output 5) and value of lost load (output 6). In the following chapters, we will disentangle and test those relationships.

Figure 24 : How disruptions are related to outages, voluntary demand curtailment and the value of lost load



Source: Copenhagen Economics illustration

4.1 Output 3 – The extent and source of electricity outages

4.1.1 Objective and approach

The objective of Output 3 is to provide information electricity outages in European Member States and their characteristics.

The data on outage includes information on plants (generation units), the nature of outages (planned or unplanned and the cause), their length in time, the reduction of the available capacity and the amount of non-generated electricity (by Member State and generation technology on at least a monthly basis). The information was collected in three steps. First, we downloaded and analysed the outage data from the ENTSO-E Transparency platform (TP), which constitutes the bulk of the data obtained. The limit for reporting outage data to the transparency platform is 100 MW,[37] so we have limited information about outages below 100 MW. Then we carried out desk research on publications from ENTSO-E and from electricity providers' websites. To complement the information, we launched a survey with ENTSO-E TP data providers, TSOs and electricity providers, and received responses from 18 Member States.

4.1.2 Findings

4.1.2.1 Overview and overall extent of the issue of outages in Europe

The reported outages per year and the capacity reduction and non-generated electricity associated with it vary considerably across European countries, as the following figures Figure 25, Figure 26 and Figure 27 show. Important to note, those figures show absolute values that are not scaled to the countries size or installed capacity. A detailed overview on all figures, absolute and scaled, can be found in Table 2.

In the period of 2015 to 2016, the United Kingdom reported the highest absolute number of outages with almost 6,500 outages per year, Germany coming second with 3,750 reported outages see Figure 25. The other Member States report much fewer outages, down to less than ten per year like Bulgaria and Luxembourg[38]. The EU28 median number of outages per year is 249. Considering the installed capacity in the country, which reflects the country's size, Malta has the highest number of outages, see Table 2.

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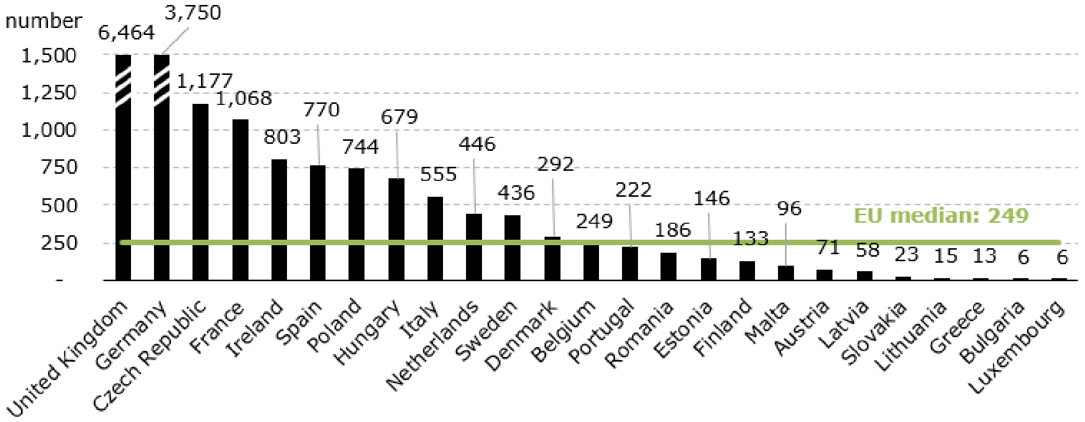
[37] Following the Commissions Regulation No. 543/2013. This threshold is to a large extent to reduce compliance costs, to prevent administrative costs of reporting very small outages. With increasing deployment of renewable energy sources that are often below 100 MW, and potential closure of many of the traditional power plants, reported outages above 100 MW is likely to capture a smaller amount of the total generation fleet. Lowering the threshold would allow the outage statistic to capture more of the outages going forward, but would also constitute higher reporting and compliance costs. In addition, it can be noted that comparing outages over time will be less accurate if/as the generation fleet changes to a higher share of outages below the threshold, which are therefore outside the reporting obligation.

[38] Although reporting outages to the ENTSO-E Transparency Platform is obligatory following Regulation 543/2013 since January 5, 2015, data gaps have been identified (see Work Package 1), and could only partly be filled through the survey to electricity producers and TSOs (see Annex). The possibility that low figures – like for Bulgaria – are due to incomplete reporting can therefore not be excluded with certainty.

Figure 25 : Average number of outages per year, 2015-2016

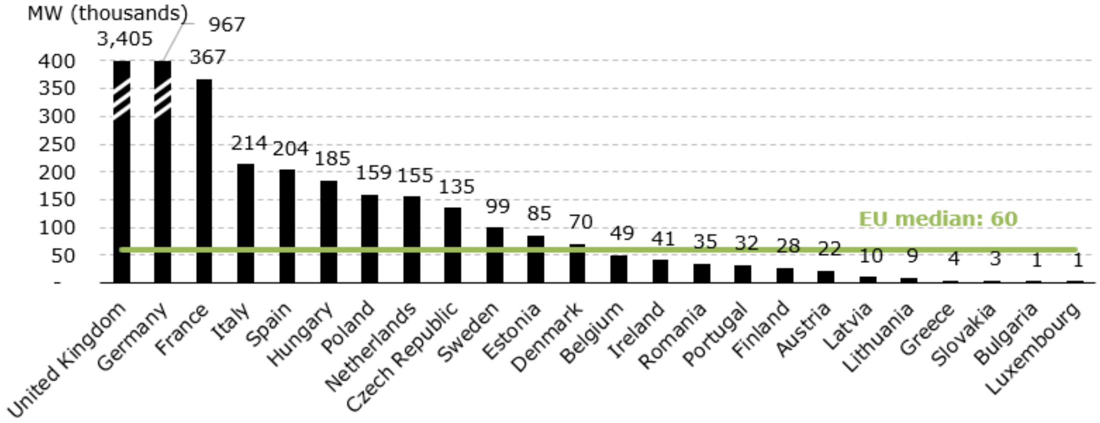


Note: The bar for the UK and Germany is not shown in its full size, as indicated by the white stripes, to avoid that the rest of the figure becomes too small and difficult to read. The number of outages for those two countries can be seen from the data labels. Croatia, Cyprus and Slovenia did not report any outages in 2015 or 2016.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

Looking at the total reduction of available capacity due to outages per year, the United Kingdom lies again in the very top, with a total reduction of available capacity more than three times as high as the second country, Germany, see Figure 26. The median across Europe is a total reduction in available capacity per year of 60 GW.

Figure 26 : Total reduction of available capacity per year, 2015-2016 average



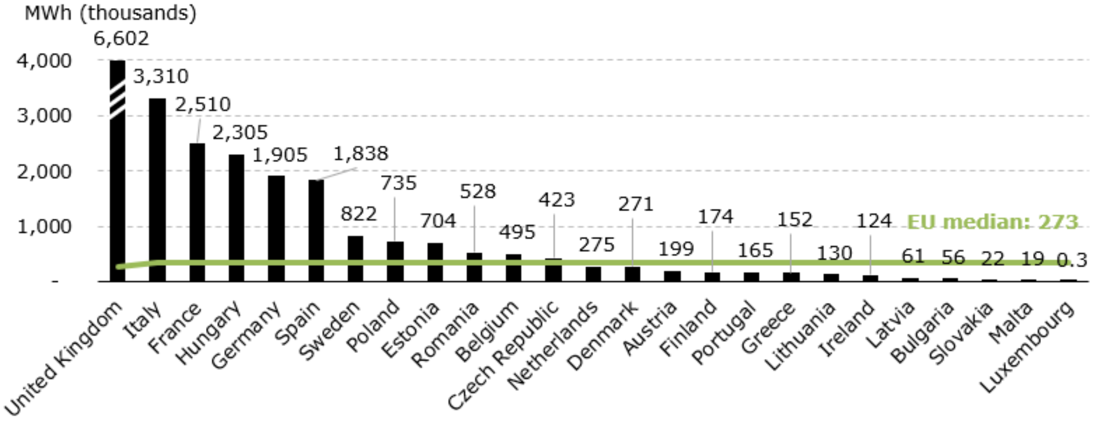
Note: The bar for the UK and Germany is not shown in its full size, as indicated by the white stripes, to avoid that the rest of the figure becomes too small and difficult to read. The number of available capacity for those two countries can be seen from the data labels. Croatia, Cyprus and Slovenia did not report any outages in 2015 or 2016, and Malta did not report the outages' reduction in capacity.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

Combining the reduction in available capacity and the duration of an outage allows for calculating the amount of electricity that has not been generated due to an outage. This value varies from 6,600 GWh (United Kingdom) to 250 MWh (Luxembourg) in total, see

Figure 27. Seen in relation to the countries' sizes, Hungary and Estonia have the highest index for non-generated electricity per year, see Table 2.

Figure 27 : Total non-generated electricity per year, 2015-2016 average



Note: The bar for the UK is not shown in its full size, as indicated by the white stripes, to avoid that the rest of the figure becomes too small and difficult to read. The non-generated electricity for the UK can be seen from its data label. Croatia, Cyprus and Slovenia did not report any outages in 2015 or 2016.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

Table 2: Detailed figures on outages in Europe, 2015-16

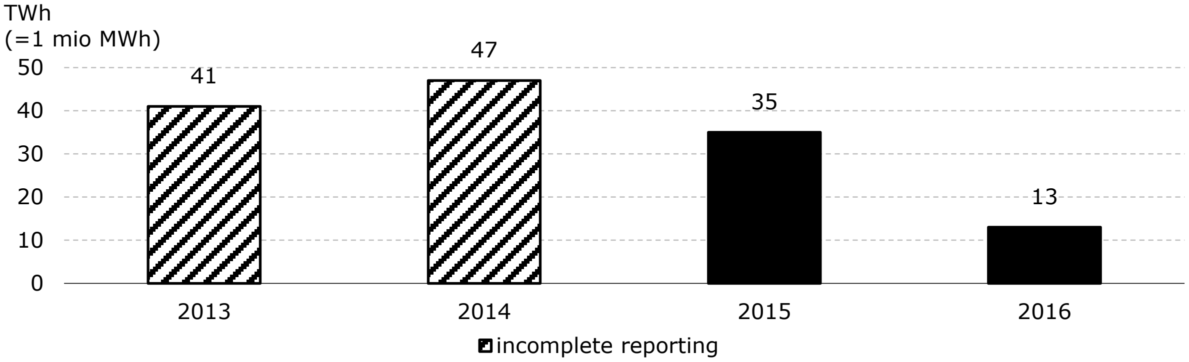
Country	number of outages per year [#]	number of outages per installed MW of capacity	reduction of available capacity per year [MW]	reduction of available capacity [MW] per installed MW of capacity	Total non-generated electricity per year [MWh]	Total non-generated electricity [MWh] per installed MW of capacity
Austria	71	3	22,099	1	198,763	9
Belgium	249	12	48,903	2	495,304	24
Bulgaria	6	0	1,494	0	55,932	4
Croatia	n/a	n/a	n/a	n/a	n/a	n/a
Cyprus	n/a	n/a	n/a	n/a	n/a	n/a
Czech Republic	1,177	58	134,901	7	423,239	21
Denmark	292	20	70,313	5	271,263	18
Estonia	146	54	84,855	31	703,894	261
Finland	133	8	27,582	2	173,887	10
France	1,068	10	366,567	4	2,510,439	24
Germany	3,750	18	966,673	5	1,904,903	9
Greece	13	1	4,087	0	152,137	9
Hungary	679	82	184,835	22	2,305,232	279
Ireland	803	82	41,229	4	124,237	13
Italy	555	6	213,746	2	3,310,171	35
Latvia	58	21	10,388	4	61,308	22
Lithuania	15	4	9,390	3	130,369	36
Luxembourg	6	21	886	3	252	1
Malta	96	158	n/a	n/a	19,326	32
Netherlands	446	14	155,180	5	274,775	9
Poland	744	20	158,726	4	734,599	20
Portugal	222	11	31,705	2	165,028	9
Romania	186	8	35,425	2	528,408	23
Slovakia	23	3	3,388	0	22,362	3
Slovenia	n/a	n/a	n/a	n/a	n/a	n/a
Spain	770	7	203,667	2	1,838,258	17
Sweden	436	11	99,055	3	821,589	21
United Kingdom	6,464	110	3,404,937	58	6,602,081	112
EU28 median	**249**	**12**	**59,608**	**3**	**274,775**	**20**
EU28 total	**18,402**	**742**	**6,280,026**	**170**	**23,827,757**	**1,022**

Note: All figures are per year (2015-16 average). Total installed generation capacity was not available for Cyprus and Malta, and was extrapolated based on their number of households.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

In total, outages in Europe caused 32 TWh of non-generated electricity in 2015, and 12 TWh in 2016, see Figure 28.[39] The figures for 2013 and 2014 are both significantly higher, although the data for those years is not complete. This clearly supports the hypothesis that there is a decreasing trend over time, or at least from 2013-2014 to 2016.

Figure 28 : Total non-generated electricity per year in Europe



Note: Croatia, Cyprus and Slovenia did not report outages in any of the years. 2015 is the first full year where the reporting of outages to ENTSO-E is mandatory; the data for 2013 and 2014 is therefore incomplete in the sense that it only shows the outages that were reported voluntarily. The real total non-generated electricity in those years might be much higher, meaning that the decline over time to 2016 is much more significant than it seems in this figure.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

4.1.2.2 Comparing planned and forced outages

Outages can be planned or forced. Planned outages mean that the production unit is taken off grid in a controlled manner and on purpose, for example due to maintenance. Forced outages are non-controlled outages that can occur for example due to technical disfunctions.

Whenever a planned outage is scheduled, arrangements can be made to make sure that the drop in electricity production does not cause problems in the transmission or distribution grid, for example due to too low supply; other production units can for example be ramped up in time. Those arrangements cannot be made for sudden, forced outages, which is why those are much more problematic and typically cause more stress to the grid.

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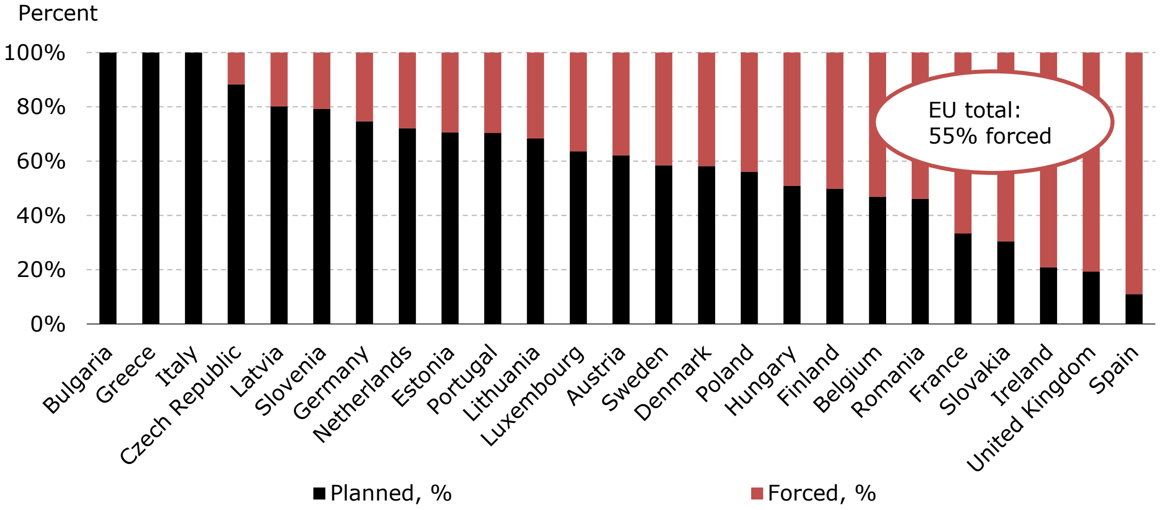
[39] The data from the ENTSO-E Transparency Platform provides country-level information on outages. However, the reported outages in relation to the installed capacity in some countries seem surprisingly low, especially for Greece and Bulgaria, also in the years 2015 and 2016, where reporting has been mandatory. We followed up on this issue with ENTSO-E directly, and it seems that ENTSO-E cannot ensure with certainty whether the data is complete for all countries and years. Based on this, we decided not to draw conclusions from country-level comparisons. Conclusions can still be drawn from EU totals (which will be a conservative estimate) or shares per generation type, as there is no reason to assume that there is a bias between years or generation types.

Looking at all reported outages in the EU in the period of 2010 to 2016, the number of forced outages dominates: 55% of all outages were forced. On country level, Spain, the UK and Ireland have the largest share of forced compared to planned outages, see Figure 29. In those three countries, more than 3 out of 4 outages are forced.

Figure 29 : Share of planned vs forced outages in Europe, 2010-2016



Note: Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced. Bulgaria, Greece and Italy did only report planned outages.

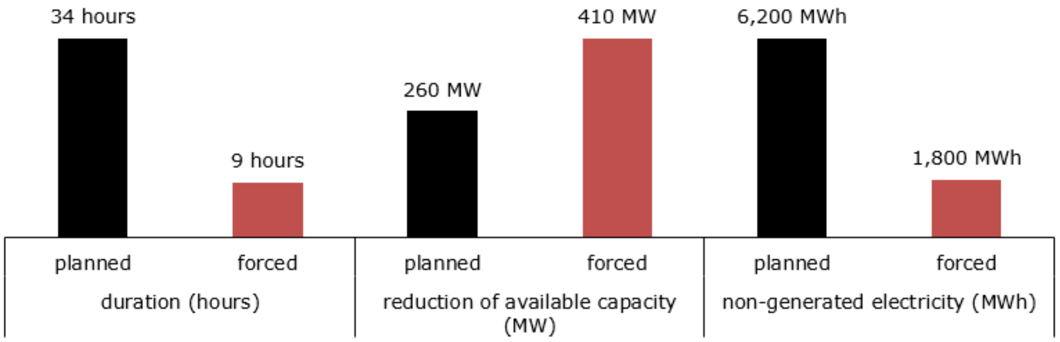
Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

Forced outages differ from planned ones not only in their impact, but also in their characteristics. An average planned outage in Europe in the period 2010 to 2016 lasted 34 hours, while the duration of an average forced one was only a quarter of that, namely 9 hours, see Figure 30. This large difference is reasonable, as there is no need to keep planned outages as short as possible. Planned outages are announced in advance, and replacements for the reduction in capacity can be found. There are also cases where production units go off grid for a longer period, for example combined heat and power plants during the summer, when the heat is not needed. Those very long planned outages will pull the average duration upwards. For forced outages in turn, there is an incentive to keep them as short as possible.

The average reduction in available capacity is much higher for forced (410 MW) than for planned outages (260 MW) in Europe. A potential explanation here might be that with maintenance, parts of the generation unit (for example single blocks) can go offline while parts of the unit continue producing electricity. When forced, outages might hit the full unit.

The reduction of available capacity combined with the duration of an outage result in the non-generated energy, which is 6,200 MWh for an average planned outage, and 1,800 MWh for an average forced outage.

Figure 30 : Characteristics of an average outage in Europe, planned vs forced, 2010-2016

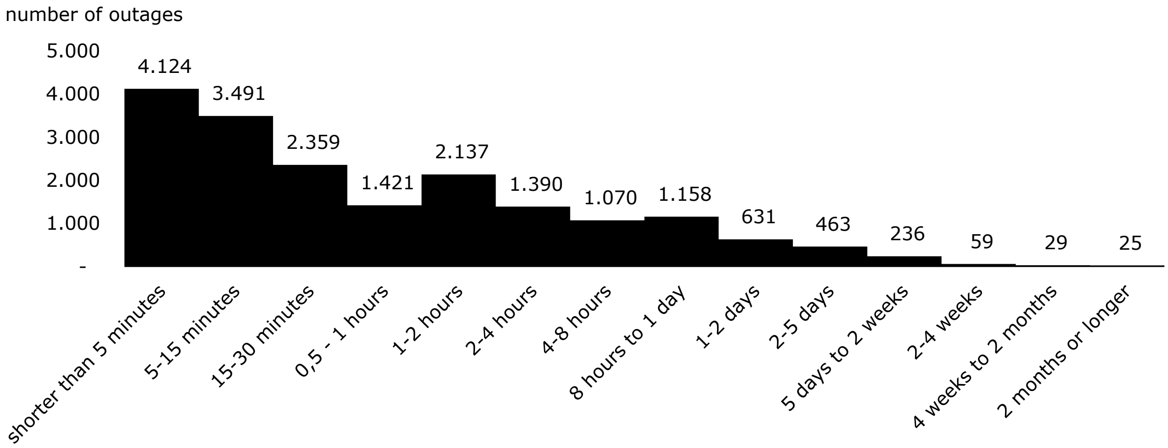


Note: Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

An average duration of 34 hours for planned outages can seem rather low against the backdrop that some maintenance work takes several weeks or even months. The reason for this average is that a large number of very short planned outages has been reported – e.g. more than 4,000 outages with durations below 5 minutes – see Figure 31.

Figure 31 : Histogram over the durations of planned outages, 2010-2016



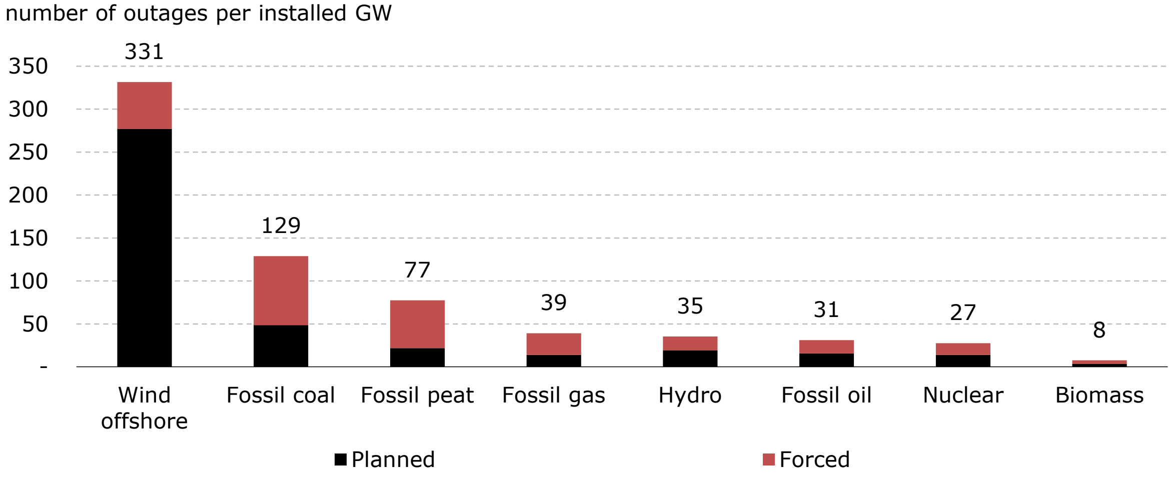
Note: Lower boundaries are included, upper boundaries excluded (i.e. an outage of exactly 4 hours will be shown in the category 4-8 hours, not in the category 2-4 hours). Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

4.1.2.3 Comparing outages of different generation technologies

Looking at absolute numbers, then most outages occur in production units using fossil fuels for electricity generation, in particular coal and gas. However, those generation types are also the ones with the most installed capacity across Europe. Accounting for the installed capacity, offshore wind causes most total outages, namely on average 331 per year per installed GW, see Figure 32. Most of those outages are planned ones. Fossil coal, peat and gas come second, third and fourth, with 129, 77 and 39 outages per installed GW on average. Those generation technologies have in common that their outages are dominated by forced down times.

Figure 32 : Generation type shares of planned and forced outages, 2010-2016



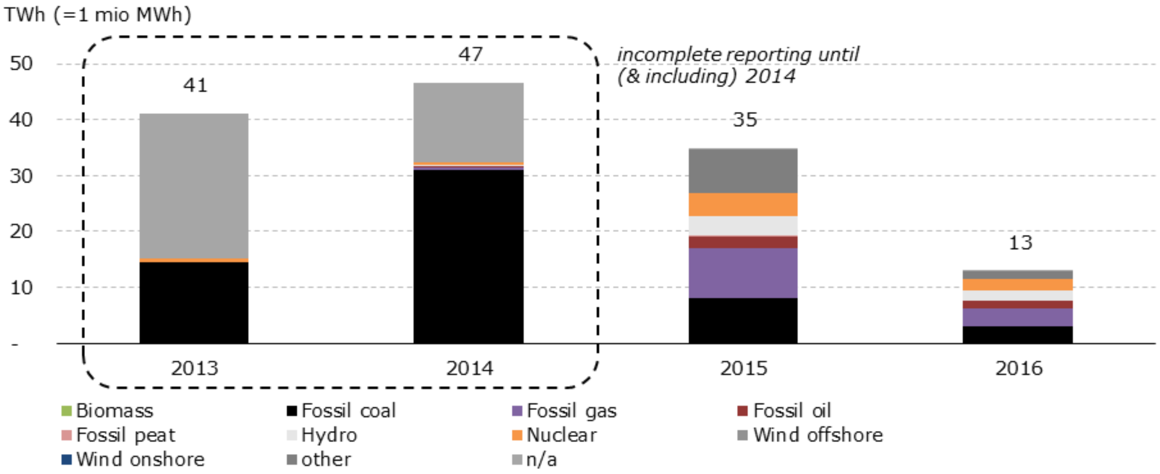
Note: Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

Production units using fossil fuels are also the main contributors to the total non-produced electricity in Europe. In 2015, outages at units using fossil coal, gas, oil, and peat led to 19 TWh of non-produced electricity, which is more than half of the total of 35 TWh, see Figure 33. Fossil coal and gas units each account for about a quarter of the total. Hydro power units and nuclear power plants add another quarter. While the total non-produced electricity due to outages decreases significantly from 35 TWh in 2015 to 13 TWh in 2016, the relative pattern remains almost unchanged: fossil fuel units make up more than half of the total, followed by nuclear and hydro power plants. Renewable energies (biomass, wind on- and offshore) cause less than 1% of the non-generated electricity in both years.

Worth noting is that the non-generated electricity due to outages of fossil coal plants decreased significantly from 2014 to 2015.

Figure 33 : Non-generated electricity by generation type per year in Europe

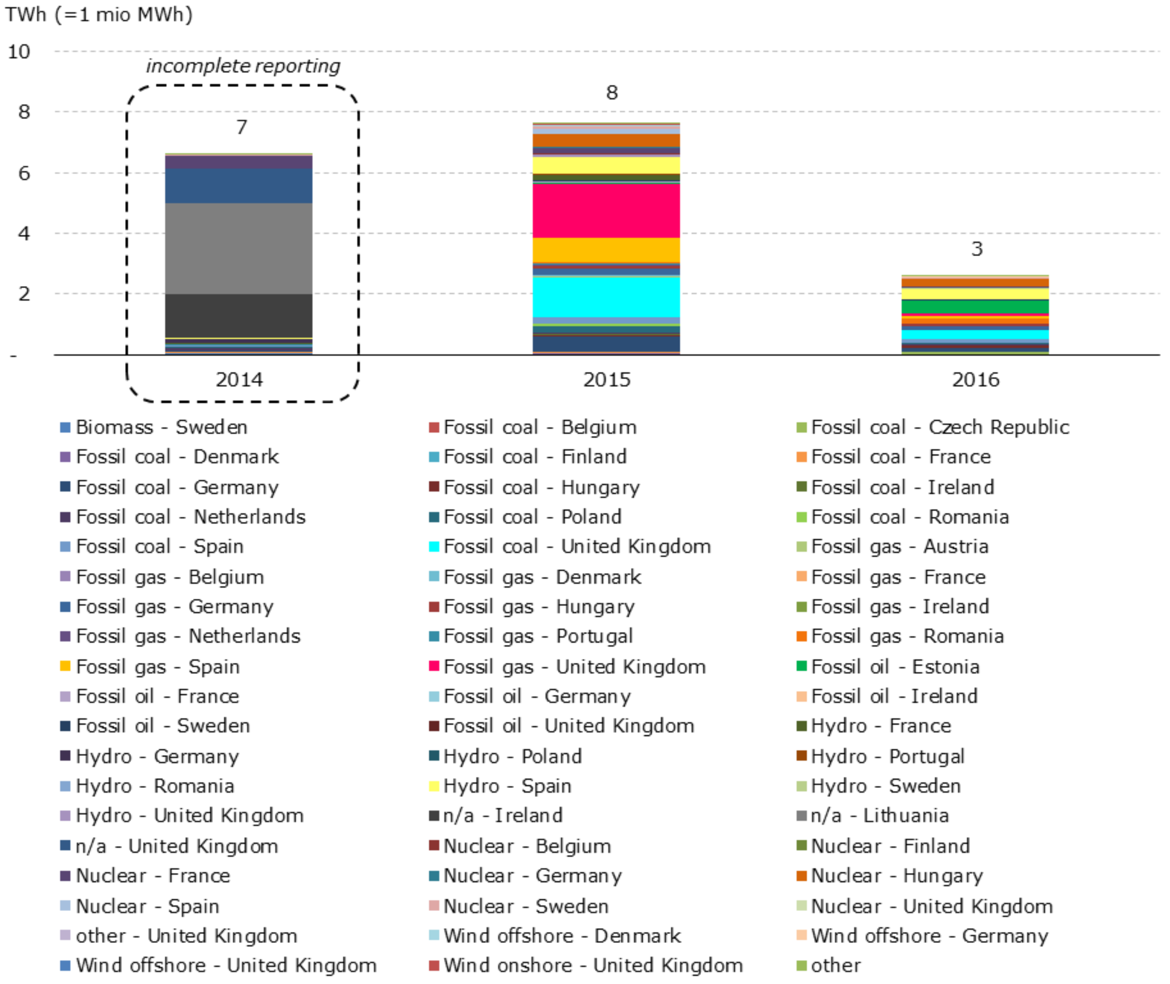


Note: Croatia, Cyprus and Slovenia did not report outages in any of the years. 2015 is the first full year where the reporting of outages to ENTSO-E is mandatory; the data for 2013 and 2014 is therefore incomplete in the sense that it only shows the outages that were reported voluntarily. The real total non-generated electricity in those years might be much higher, meaning that the decline over time to 2016 is much more significant than it seems in this figure.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

The non-generated electricity from forced outages makes up only a smaller share of those numbers. In 2015, less than 8 TWh have not been generated due to forced outages in Europe, and less than 3 TWh in 2016, see Figure 34. While outages of many different generation technologies in many different Member States have contributed to that sum, the United Kingdom is worth mentioning with extensive forced outages of fossil gas units (1,8 TWh of non-generated electricity) and fossil coal units (1,3 TWh of non-generated electricity) in 2015.

Figure 34 : Non-generated electricity (forced outages) by generation type and Member States



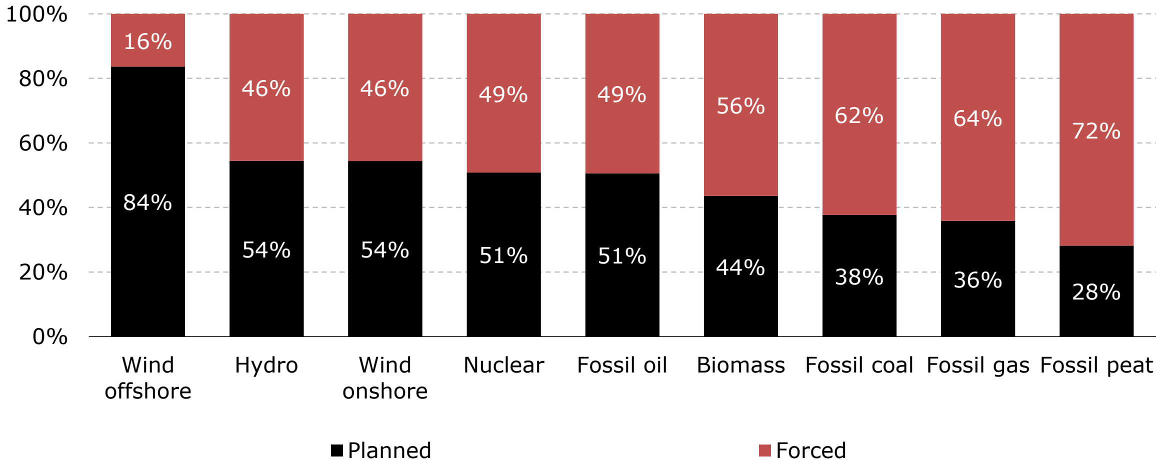
Note: Croatia, Cyprus and Slovenia did not report outages in any of the years. 2015 is the first full year where the reporting of outages to ENTSO-E is mandatory; the data for 2014 is therefore incomplete in the sense that it only shows the outages that were reported voluntarily. The real total non-generated electricity in those years might be much higher, meaning that the decline over time to 2016 is much more significant than it seems in this figure.

“other” in this figure contains all those categories with less than 5,000 MWh of non-generated electricity. In alphabetical order, that is: Biomass (Hungary, Belgium, Finland), fossil coal (Slovakia, Portugal, Sweden, Austria), fossil gas (Sweden, Latvia, Lithuania, Poland, Finland, Czech Republic), fossil oil (Finland, Denmark), fossil peat (Finland, Ireland), hydro (Austria, Belgium, Luxembourg, Ireland, Latvia, Lithuania, Czech Republic), other (Netherlands, Ireland), Wind offshore (Belgium), Wind onshore (Sweden).

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

There is a tendency that renewable energy sources cause relatively fewer forced outages than non-renewable energy sources, see Figure 35. Both wind (offshore and onshore[40]) as well as hydropower have less forced outages than planned ones; offshore wind features a remarkably low rate of forced outages of only 16 percent, which is however mainly driven by a very high number of planned outages, as we could see in the figure before. For fossil fuels, most outages are forced ones. 62 to 72% of all outages in generation units fired by fossil coal, gas and peat are forced.

Figure 35 : Share of forced vs planned outages per generation type, 2010-2016



Note: Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

For how long an outage will last depends largely on two interrelated things: the generation technology as well as whether it is a planned or forced outage. Whenever an outage is planned, arrangements can be made in advance to compensate for the non-generated electricity, making sure that supply will meet demand. In cases of planned outages, it is therefore not necessarily prioritised to keep it as short as possible. There are even situations where fossil-fuel based generation plants are taken down for longer periods on purpose, for example combined heat and power plants in warm summer periods where the heat is not needed and where electricity consumption tends to be low.

Figure 36 (upper figure) shows that fossil-fuel based generation plants have indeed the longest down times, with 42 hours on average per outage for coal, 24 for oil, 18 for peat and 17 for gas. The planned outages for wind parks in turn take only 1.3 hours and 0.4 hours on average for onshore and offshore wind respectively.

The picture for forced outages looks different. In cases of forced outages, no arrangements can be made in advance to compensate for the loss of generation, which

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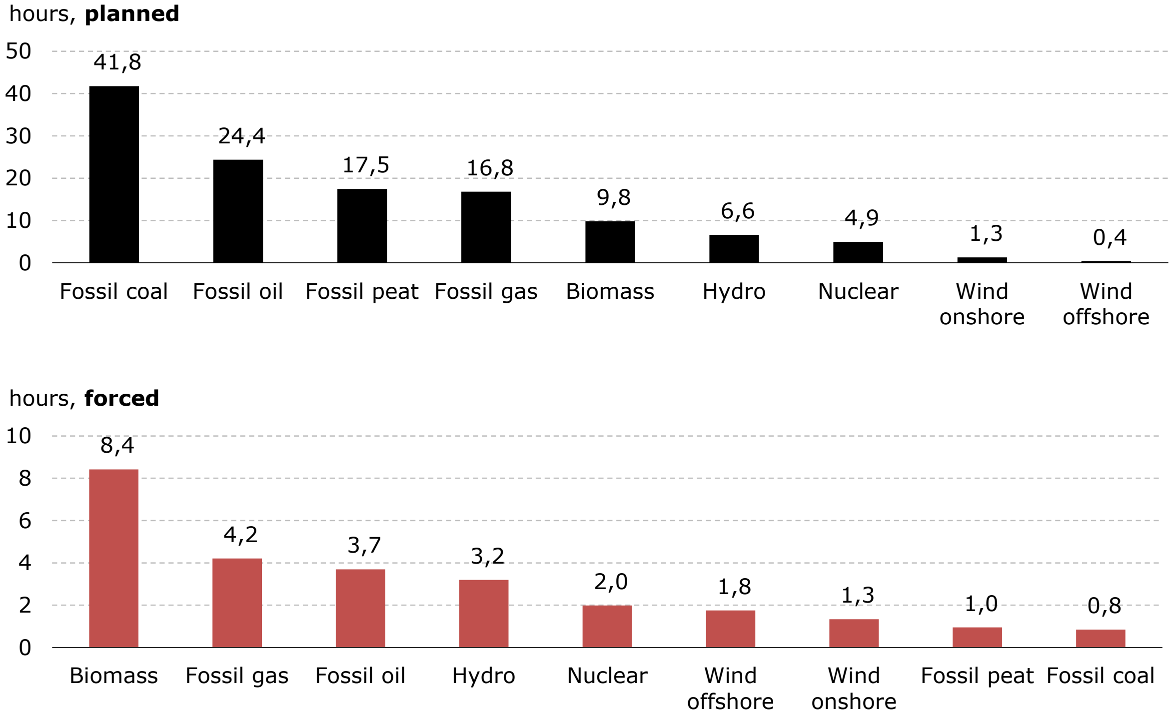
[40] Note that there are very few reported outages for onshore wind that is above 100 MW, so data availability is low.

means that one typically tries to fix those outages quickly and keep the duration short. The data shows that, as expected, forced outages tend to be generally shorter in duration than planned ones. The range for forced outages goes from 0.8 to 8.4 hours, as it was 0.4 to 41.8 for planned ones. The data furthermore shows no longer higher values for fossil fuels when looking at forced outages; here, biomass features the highest with a duration of 8.4 hours on average per disruption in the period 2010-2016.

Figure 36 : Average durations of forced (upper figure) and planned (lower figure) outages per generation type, 2010-2016

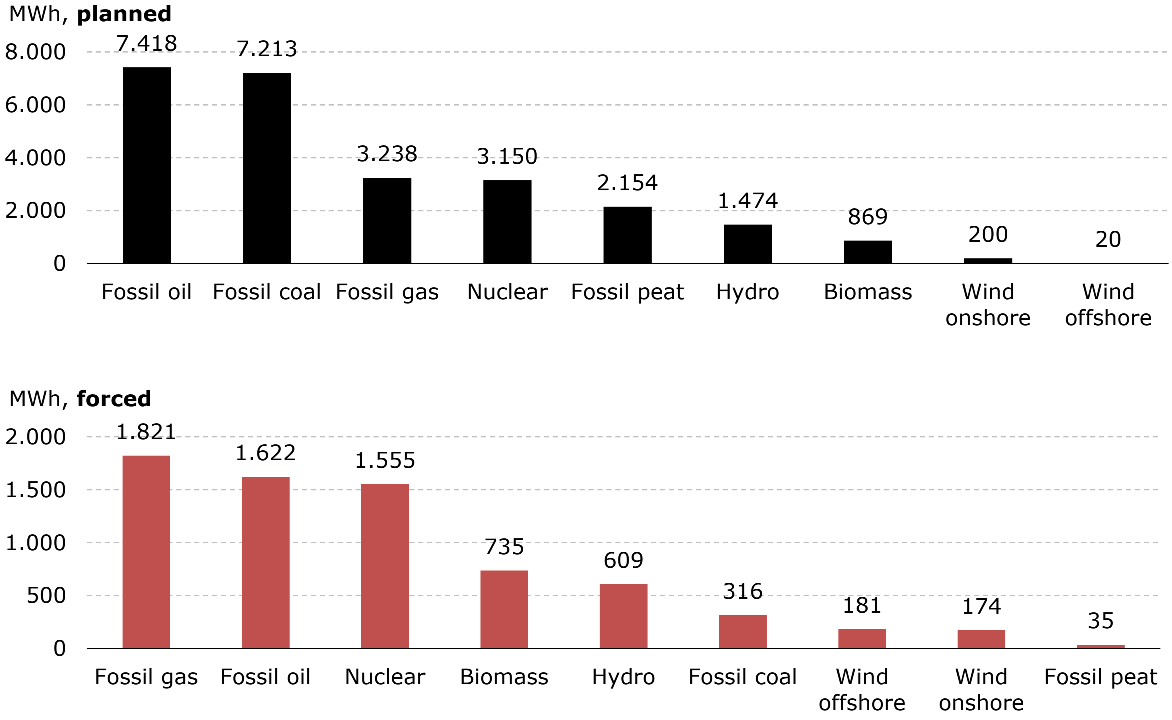


Note: Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

Combining the duration with the reduction in available capacity results in the non-generated electricity, which is typically provided in MWh. This number reflects how much electricity supply is lacking, and gives therefore particularly for forced outages an indication for the impact on the market. For planned outages, fossil coal and oil have the largest non-generated electricity per outage. This is to some extent due to their long average duration, and is not necessarily a problem, as other generators can fill in this gap if the outage is known well in advance. The non-generated electricity per forced outage is a more crucial indicator. Here, fossil gas and oil are highest with more than 1,800 and 1,600 MWh of non-generated electricity per outage, see Figure 37. Nuclear generation plants come third right after fossil oil. From the figure before we know that the duration alone cannot entail those results, which indicates that if those technologies have an outage, then the affected capacity is quite large.

Figure 37 : Average non-generated electricity for planned (upper figure) and forced (lower figure) outages per generation type, 2010-2016



Note: Croatia and Cyprus did not report any outages. Malta did not report whether its outages were planned or forced.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform and survey answers.

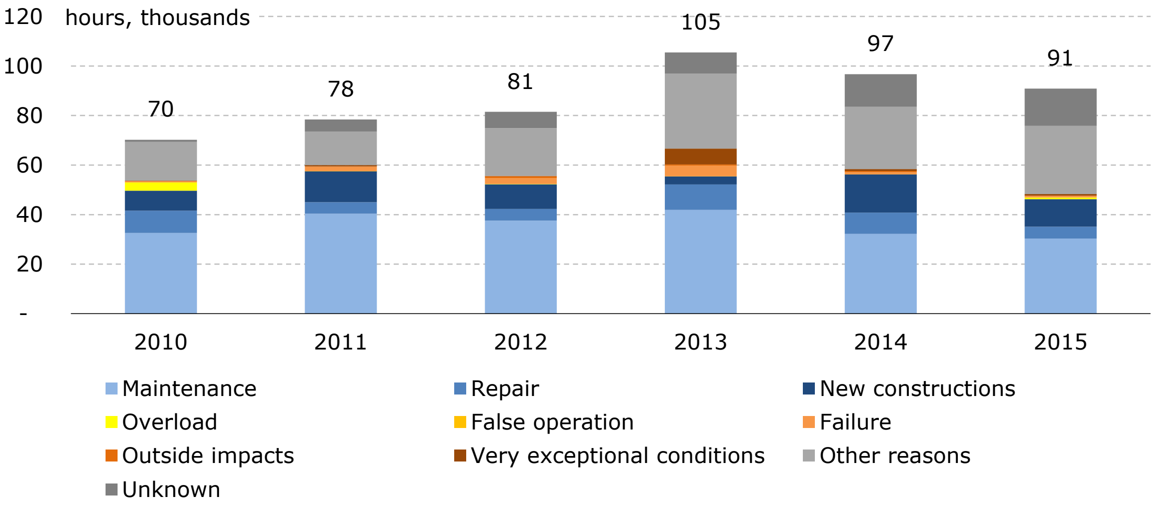
Among the observations where the generation type has been provided (the data depicted in the figures above), planned outages clearly cause more non-produced electricity than forced ones. However, considering all outages – also those where the generation type was not provided, which are mostly forced – this conclusion turns around. In fact, of non-generated electricity due to registered outages 2010-16, 41% has been due to planned outages, and 59% due to forced ones.

4.1.2.4 Outages at interconnectors

Seen from a country's perspective, an interconnector can be thought of as similar to a generation plant: it increases the overall capacity available on the supply side of the power market. Similarly, an outage of an interconnector is also very similar to having an outage in a large generation unit. That is, capacity that was thought to be available to the market is no longer available.

In the period of 2010 to 2016, unavailabilities have been reported at 68 different international tie lines in Europe,[41] affecting almost all Member States.[42] The total duration of interconnector outages in Europe amounts to roughly 70,000 to 105,000 hours every year, see Figure 38. Most outages in terms of duration have been reported in 2013, where international tie lines have been unavailable for 105,000 hours in total. That corresponds (mathematically) to about 630 weeks, or 12 years, meaning that at any time of the year, there were 12 interconnectors unavailable on average. There appears to have been an upward trend before, and a downward trend after 2013.

Figure 38: Total duration of interconnector outages, 2010-2015



Note: Incomplete data for 2016, therefore shown until 2015.

Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

Similarly to generation units, an outage in an interconnector does not necessarily constitute a problem. For example, it might not have been the case that power would have flowed on the cable if it had been working. Nonetheless, when an interconnector is not working, it effectively removes a part of a country's supply curve/merit curve, thereby making it more vulnerable for further outages in generation units.

As data on the non-available capacity per outage and therewith for the non-transferred energy is not available, we can only use information on the duration of interconnector outages – which, too, is an important indicator and allows to draw founded conclusions. The data clearly shows that planned interventions such as maintenance, repair and new constructions (blue colours) account by far for a larger share of those hours than forced outages from overload, false operation, failure, outside impacts or very exceptional conditions (yellow/orange colours), see Figure 38. In fact, the latter seem to make up only a very small part, while maintenance alone accounts for more than 40% on average in the period 2010-2015. Unknown or other reasons (grey) have been reported frequently, too, which limits the conclusions that can be drawn regarding the causes.

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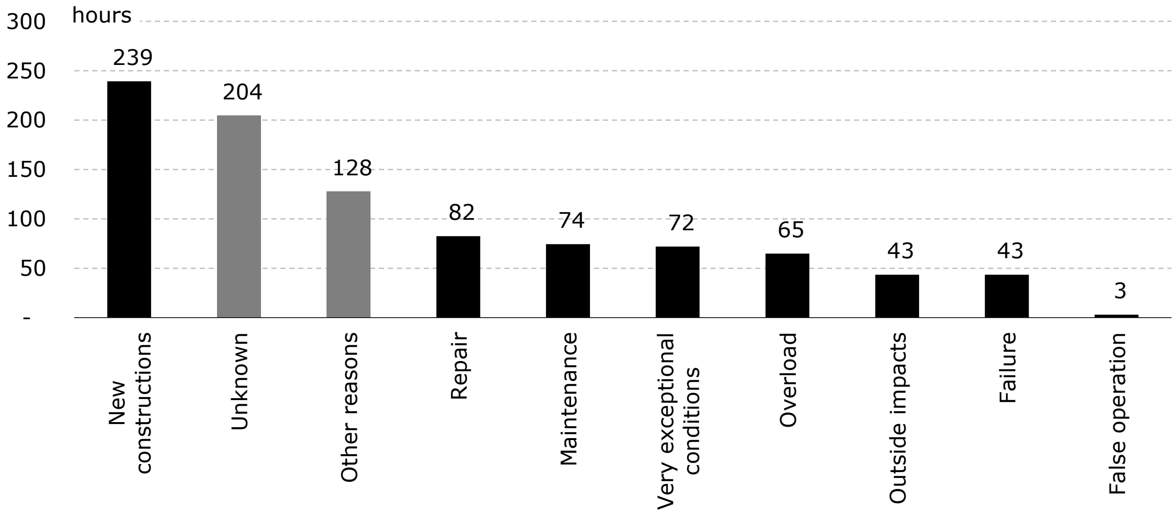
[41] This data includes all international tie lines in Europe that report to ENTSO-E, also tie lines from or to European countries that are not EU28 Member States.

[42] With the exemption of Cyprus and Malta. The lack of data here could be due to incomplete reporting.

Considering the duration per reported outage, outages due to new constructions take by far the longest with almost 10 days on average. Repair and maintenance typically cause unavailablities of little over 3 days. All forced outages in turn tend to be shorter; a false operation is on average fixed in 3 hours, failures or outages due to outside impacts after less than 2 days. Outages due to very exceptional conditions or overload are the longest in this group; they take up to 3 days on average, see Figure 39.

Figure 39 : Average duration per interconnector outage, 2010-2016



Source: Copenhagen Economics based on data from the ENTSO-E Transparency Platform.

4.1.3 Conclusions

In 2016, approximately 886 GW of power generating capacity were installed in the EU. Outages mean that not this full total will be available for production all the time. In fact, more than 14,500 outages have been reported in Europe each year (2015-2016 average), which corresponds to 17 outages each year per installed GW of production.

When taking into account the length of the individual outages, we estimate that the total non-generated electricity due to outages in the EU in 2016 was about 13 TWh. This means electricity that could have been generated if the power plants had not been out for whatever the reason. This corresponds to the 886 GW of power generating capacity in Europe being completely out for around 15 hours in the whole year of 2016, or to 0.17% of Europe's capacity being out constantly. This number is significantly lower than just a few years back, having been reduced from about 41 TWh in 2013, 47 TWh in 2014 and 35 TWh in 2015. The decline is likely to be even higher than this, as data availability for 2013 and 2014 was significantly lower than for 2015 and 2016.

Forced outages constitute the majority of the non-generated electricity, about 59%, and they occur significantly more frequently. About 60% of all outages are forced events, however the duration of the outage is significantly shorter (about 9 hours on average compared to 34 hours for planned downtime). Moreover, forced outages typically happen for much larger assets than planned. Indeed, the average affected capacity for forced outages is about 410 MW compared to about 260 MW for planned outages. This suggests that larger generation assets are more susceptible to outages than smaller ones.

In terms of fuel-based generation assets, fossil-fuel assets have by far the longest duration for planned outages of about 20-40 hours on average, compared to less than 1 hour for wind turbines, 5 hours for nuclear plants and about 7 hours for hydro plants. On the other hand, the fossil-fuel based generation assets seem to be around the average to bounce back from a forced outage, taking on average about 2.8 hours, similar to hydro and nuclear. That is faster than biomass but slower than off- and onshore wind assets using 8.4, 1.8 and 1.3 hours respectively.

Wind turbines mark the two extremes regarding how prone they are to outages. Onshore wind has the lowest total number of outages with 2 per installed GW, offshore the highest with 331 outages per installed GW – of which most are planned ones though. Both on- and offshore wind are among the fastest generation technologies to be up and running again after an outage, both planned and forced. The combination of very few and very short outages for onshore wind may to some extent compensate for the fact that the utilisation of wind capacity is significantly lower than traditional plants due to varying wind load factors.

Just as outages at generation units, unavailabilities of interconnectors limit the capacity available to a country. Interconnectors have been unavailable for roughly 87,000 hours every year (2010-2015 average), which means that 10 interconnectors are unavailable in Europe at all times on average. Works at the cables and lines, especially maintenance (otherwise repair and new constructions) account for the majority of those unavailabilites, while forced outages (due to overload, false operation, failure, outside impacts or very exceptional conditions) only play a minor role. Outages due to works at the cables and lines tend to take longer; the longest durations are due to new constructions, where an outage takes almost 10 days on average. All forced outages can be fixed much quicker, after 3 hours to 3 days on average.

4.2 Output 4 – Electricity supply disruption events

In this chapter we will investigate on the issue of electricity supply disruption events in Europe, their scale (how many, how long, how severe) and scope (how spread across Europe). We will analyse the reasons for and characteristics of those disruptions.

4.2.1 Objective and approach

The aim of Output 4 is to provide information on the extent of electricity supply disruptions in recent years in the EU, and the reasons for these disruptions. The overall objective is to enable the Commission to understand the context and circumstances of disruption events in the EU, including (but not exhaustive) in which countries they are most prevalent, and whether they are caused by grid-related incidents, lack of generation capacity or something different.

The information was collected in two steps. First, we carried out desk research of literature and databases at EU level (e.g. ACER, CEER, ENTSO-E TP and Monthly Statistics Reports) and national level (e.g. publications of NRAs and TSOs). Then, we complemented the information with a survey with NRAs and TSOs and received responses from 25 Member States.

4.2.2 Findings

Electricity supply disruptions can occur from two sources: the lack of generation to meet demand, or problems with the infrastructure (reliability). The latter can occur either at transmission or distribution level. Depending on the infrastructure level, the likelihood that a malfunction leads to an actual disruption (with consumers out of power) will vary, see Table 3.

Table 3 : Infrastructure levels of malfunctions and their likelihood of causing disruptions

Infrastructure level	Examples for causes for malfunctions	Likelihood of disruption in case of malfunction	Intuition
Distribution level	Tree falling on a distribution (overhead) line, malfunction of a transformer station, storms damaging the (overhead) lines	high, but smaller area	Distribution lines and cables are often the sole source of supply to a (small) area
Transmission level	Outage in an interconnector in the transmission grid, snow or storms damaging overhead transmission lines	low to high, larger area	Typically, a transmission line or cable – especially an interconnector – is not the only source of supply to an area. In case of a malfunction, electricity is supplied through other transmission cables or lines

Source: Copenhagen Economics illustration

Disruptions on transmission level occur much more seldom, but often have a large effect on the market. Several cases of transmission level events are covered as case studies towards the end of this chapter.

In the following, we first evaluate a range of indicators for disruptions based on data provided by the Council of European Energy Regulators (CEER), before analysing disruptions based on reported single events.

Two good indicators to gain an overall understanding of the extent of disruptions across Europe on an aggregated national level are:

- the number of disruptions per year; this indicator is often referred to as System Average Interruption Frequency Index (SAIFI).
- the total duration of disruptions per year; this indicator is often referred to as System Average Interruption Duration Index (SAIDI).

To obtain a representative indicator that accounts for differences in the countries' sizes and number of customers, as well as for local disruptions that affected only parts of the country (which is typically the case), the number and duration of disruptions in a country must be weighted. The weighting methods applied across Europe differ, but show a strong trend towards weighing based on the number of customers. 23 out of the 28 EU Member States use a weighing method that is fully or partly based on the number of customers, see Table 4. Other weighting methods are based on the affected power or the number of affected transformers.

Table 4 : Weighting methods for disruption indicators across Europe

weighting method	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	United Kingdom
number of customers	x	x	x		x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x	x
power affected		x		x						x			x			x					x				x		
transformer stations	x																	x					x				
other						x		x	x																		

Note: No information available for Croatia.

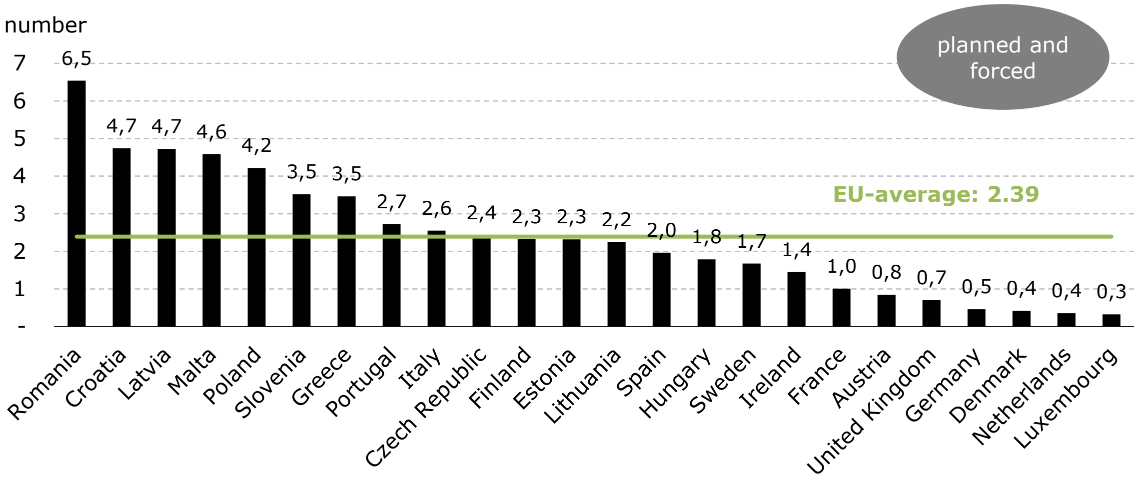
Source: CEER (2016) 6th CEER Benchmarking report on the quality of electricity and gas supply.

The weighting means that the indicators can, for illustrative purposes, roughly be interpreted as per-person numbers. Important to bear in mind is that this interpretation is not perfectly consistent, as while following the same overall approach, the weighting methods differ slightly between countries.

We focus on significant disruptions in this study. For the national-level indicators, we define significant disruptions as (1) "long" disruptions during which (2) consumers were out of power. With that definition, we follow the approach taken by CEER, which focuses on such "long" disruptions in its reporting. "Long" disruptions mean typically three minutes or longer; 24 of the European Member States use that duration threshold. The four Member States reporting disruptions in a different way are Denmark and the Netherlands, which report all disruptions of at least 1 minute and 5 seconds respectively, as well as Cyprus and Malta, which do not have a classification.

For the period of 2010 to 2014, Romania has had the highest average number of significant disruptions with more than 6.5 disruptions per year, see Figure 40.

Figure 40 : Average number of disruptions (planned and forced) per customer, 2010-2014



Note: The graph shows a weighted indicator. The weighting is described in Table 4, and allows for an overall interpretation of the indicator as "per customer". No data available for Belgium, Bulgaria, Cyprus and Slovakia. The average is a simple average across countries and is calculated based on the EU28-countries with available data.

Source: Copenhagen Economics based on CEER data.

Romania is followed by Croatia, Latvia, Malta and Poland, which still have on average more than 4 disruptions per year. Slovenia, Greece, Portugal, Italy and the Czech Republic have less than 4 disruptions per year, but are still above the EU average of 2.4. Luxembourg, the Netherlands, Denmark, Germany, the UK and Austria recorded the lowest average number of significant disruptions with a number smaller than 1.

Looking at the minutes lost due to significant disruption events shows a similar overall pattern, see Figure 41. The minutes lost per year range from 17 (Luxembourg) to 844 (Romania), with the (weighted)[43] EU average being 136 minutes lost per year over the period of 2010 to 2014.

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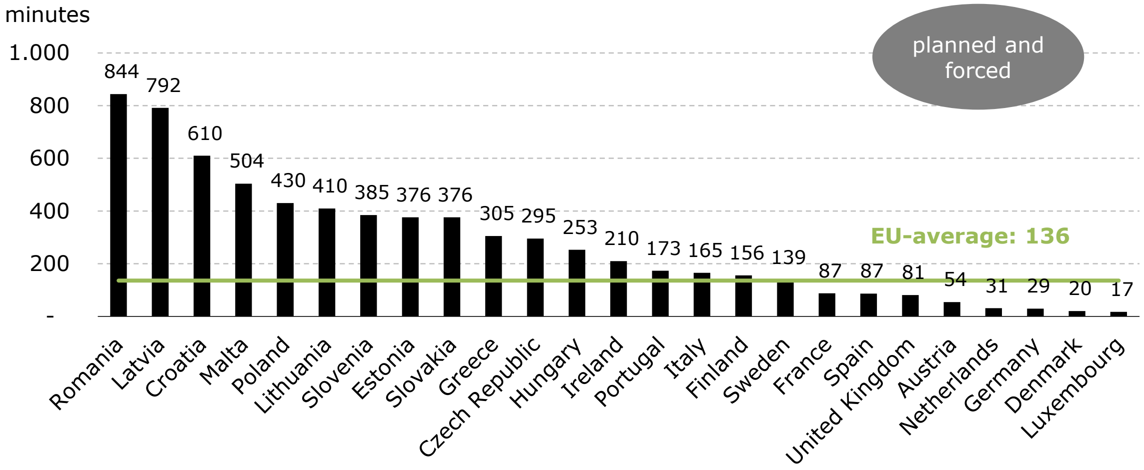
[43] Weighing based on the total electricity consumption of each country (2010-2014 average)

Figure 41 : Average minutes lost per year and customer due to significant disruptions (planned and forced), 2010-2014



Note: The graph shows a weighted indicator. The weighting is described in Table 4, and allows for an overall interpretation of the indicator as "per customer". No data available for Belgium, Bulgaria, Cyprus. The EU-average is a weighted average across countries and is calculated based on the EU28-countries with available data. The weighting is based on total electricity consumption of each country.

Source: Copenhagen Economics based on CEER data.

Romania, Latvia, Croatia, Malta and Poland remain the top five, which means that they have both the most as well as the longest disruptions in the European comparison. Also, the countries reporting the lowest numbers remain the same. The Baltic countries Latvia, Estonia and Lithuania all have a worse position when looking at minutes lost instead of number of disruptions, which indicates that disruptions in those countries take longer than the EU average. In comparison, the Mediterranean countries Italy, Portugal and Spain have improved, indicating that significant disruptions in those countries are rather short in the European comparison.

When making some simplifying assumptions[44] and using (Member State level-) electricity consumption data, we can translate those average minutes lost per year into a rough estimate of how much electricity has not been supplied to consumers in the period of 2010 to 2014. Roughly 550 to 850 GWh of electricity have not been supplied to consumers per year, see Figure 42.

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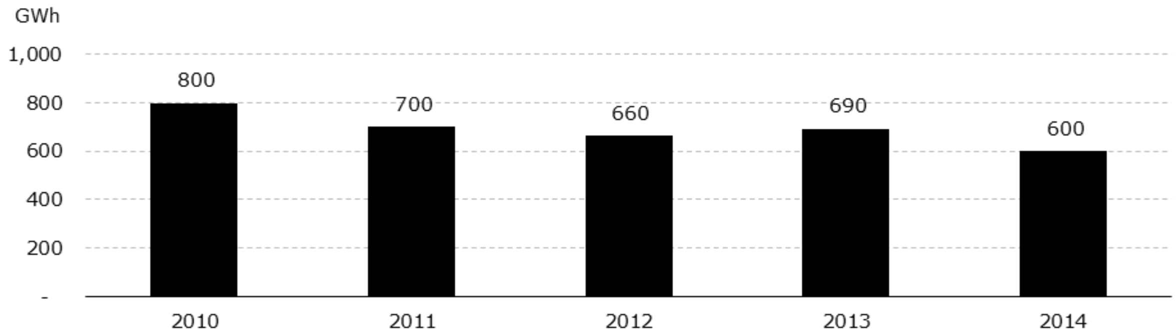
[44] Applying the minutes lost per year per country to the average consumption per minute in this country, we implicitly assume that the disruption hit during a time (of day and year) of average consumption, as well as that it hit average consumers. The non-supplied electricity will be higher if the disruptions happened during peak demand times, and hit primarily consumers with above-average demand (and vice versa). Also, this calculation contains a small inconsistency arising from the fact that the Member States use slightly different weighting methods, as explained in the table above, and should therefore be used as a very rough estimate.

Figure 42 : Rough estimate for the non-supplied electricity due to disruptions in the EU, 2010-2014

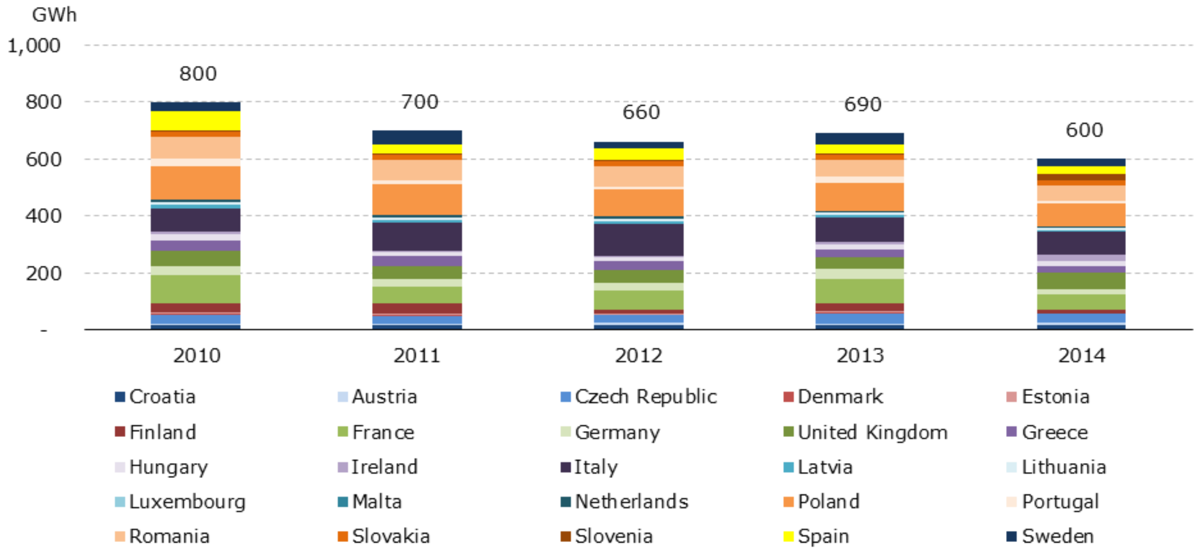


Note: no data available for Belgium, Bulgaria, and Cyrpus

Source: Copenhagen Economics based on CEER and Eurostat data.

Those totals for the non-supplied electricity in Europe are the result of disruptions across all Member States. The countries with most non-supplied electricity through the years are, as one might expect looking at totals, larger countries like France, the UK, or Italy, see Figure 43. Compared to their size and energy consumption, Germany features rather low non-supplied electricity each year, while the numbers for Poland are comparably high.

Figure 43 : Rough estimate for the non-supplied electricity due to disruptions per Member State, 2010-2014



Note: No data available for Belgium, Bulgaria and Cyprus.

Source: Copenhagen Economics based on CEER and Eurostat data.

The frequency of significant disruptions in Europe has shown a slight downward trend, see Figure 44. A simplified interpretation of the average indicator for frequency will be to say that an average European resident experienced 1.7 disruptions in 2010, and 1.4 disruptions in 2014.[45] The average duration per disruption in Europe decreases in the first two years of the period, from around 90 to around 80 minutes per disruption, but increases again back to around 90 in 2014. There is neither an upward nor a downward trend.

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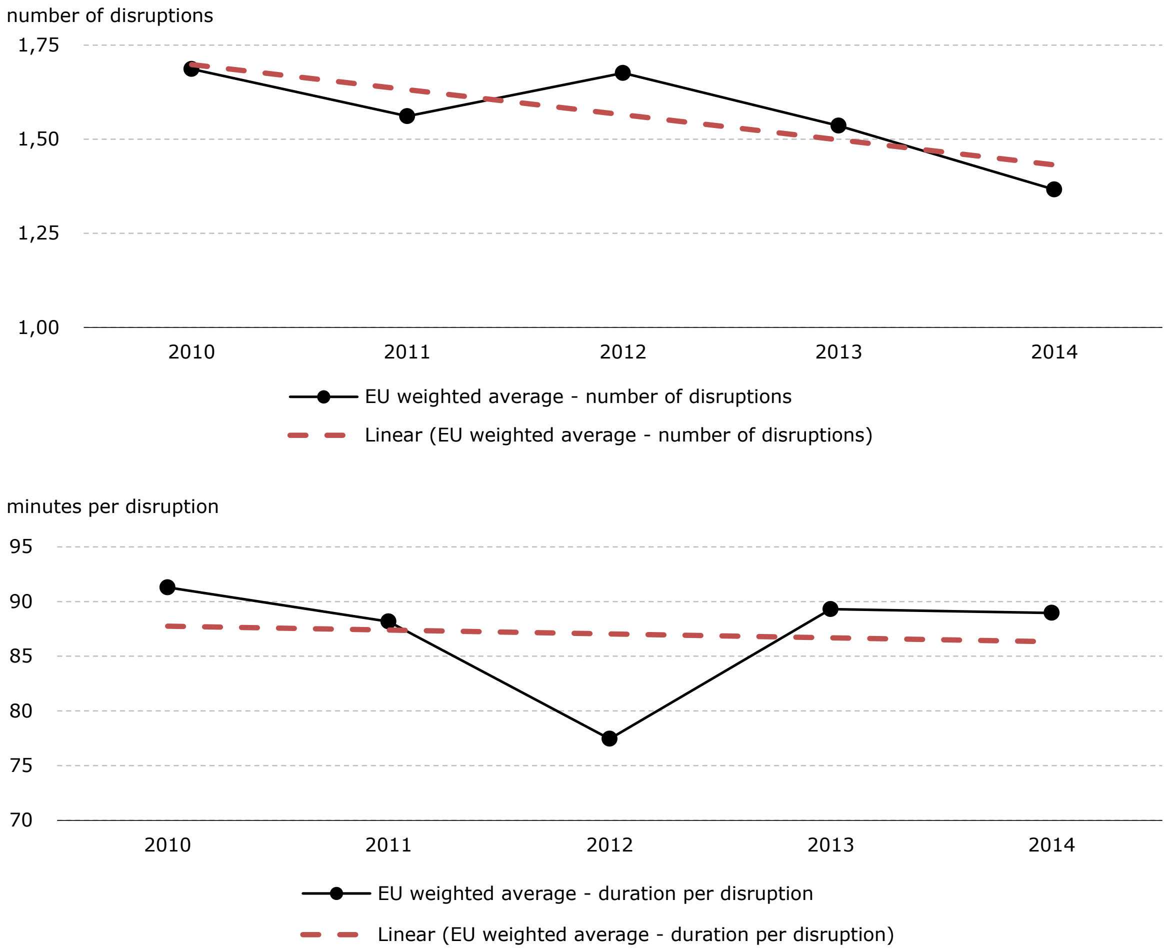
[45] This interpretation however should be used as a reference point for understanding only, as it contains a small inconsistency arising from the fact that the Member States use slightly different weighting methods, as explained in the table above.

Figure 44 : Development of significant disruption events in terms of frequency and duration in the EU, 2010-2014



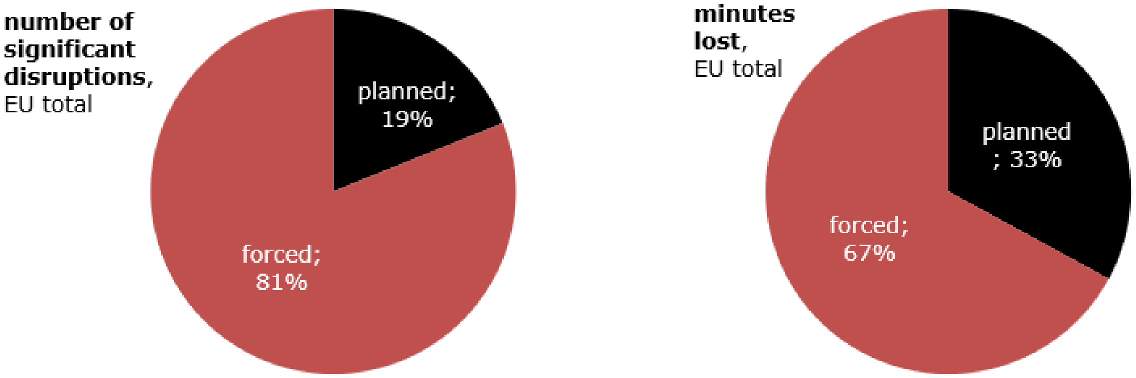
Note: The average across EU countries is weighted with total electricity consumption. No data available for Belgium, Bulgaria and Cyprus. For Slovakia, no data on duration is available, and the data on minutes of disruptions is incomplete and has been extrapolated for some years. The latter also holds for Luxembourg, where, however, only the year 2010 needed to be extrapolated from the rest.

Source: Copenhagen Economics based on CEER data.

For electricity consumers – both commercial and private – it makes a considerable difference whether a disruption is announced in advance, as typically done in case of planned disruptions, or whether it is forced disruption without notice. If informed in advance, consumers can plan accordingly and to a certain extent reduce the negative impact of a disruption. From a socio-economic perspective, forced outages are therefore more problematic than planned ones.

Forced disruptions dominate over planned ones in Europe, see Figure 45. Measured in number of significant disruptions, 4 out of 5 are forced ones; measured in minutes lost, two thirds of all disruptions are forced ones. This difference between the measurements indicates that forced disruptions are typically shorter in duration than planned ones.

Figure 45 : Share of planned vs. forced significant disruptions in Europe 2010-2014

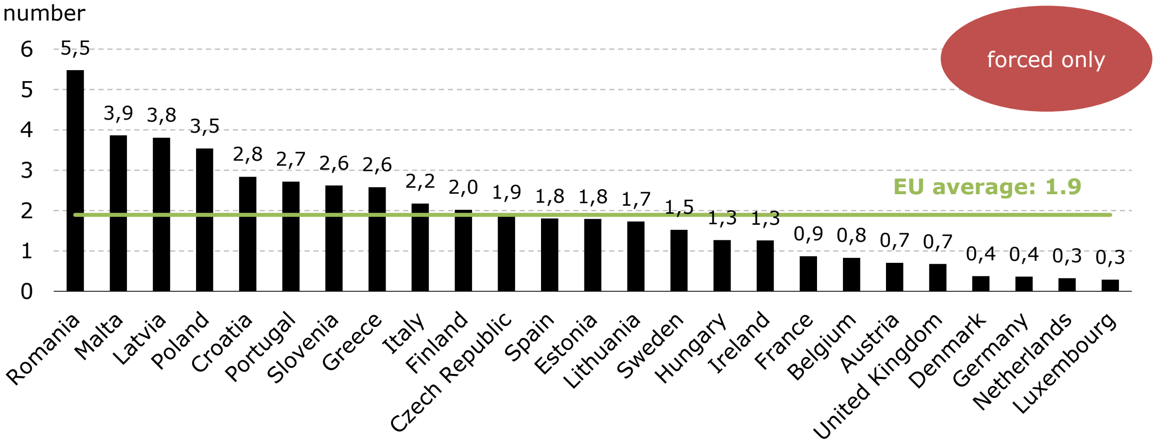


Note: No data available for Belgium, Bulgaria, Cyprus and Slovakia. For Luxembourg 2010, averages of 2011-2014 have been used.

Source: Copenhagen Economics based on CEER data.

The average number of significant forced disruptions varies from 5.5 for Romania to 0.3 for Luxembourg, see Figure 46. The European average is at 1.9.

Figure 46 : Average number of significant forced disruptions per customer, 2010-2014

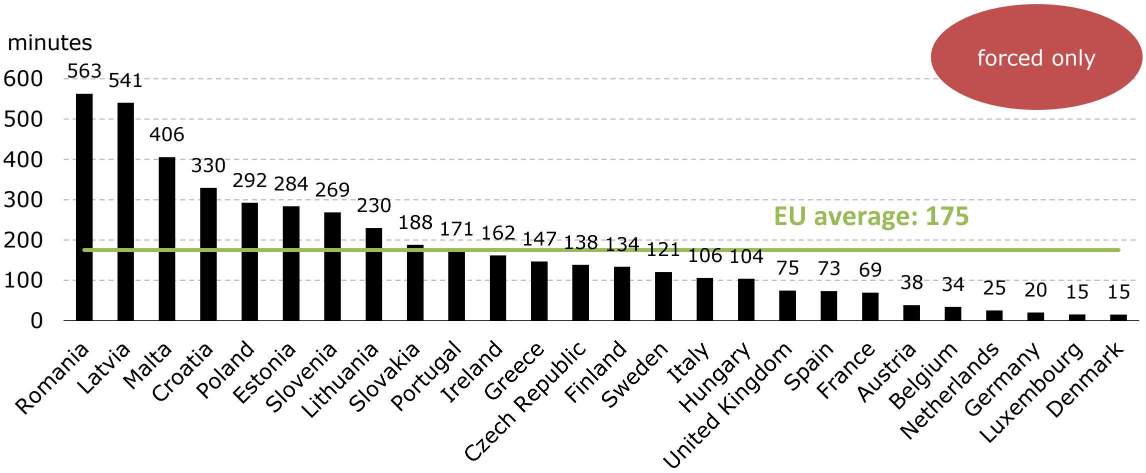


Note: The graph shows a weighted indicator. The weighting is described in Table 4, and allows for an overall interpretation of the indicator as "per customer". No data available for Bulgaria, Cyprus and Slovakia. The average is a simple average across countries calculated based on the EU28-countries with available data.

Source: Copenhagen Economics based on CEER data.

Looking at the minutes lost per year due to significant forced disruptions shows a similar pattern, see Figure 47. Consumers in Romania are on average 563 minutes each year out of power due to forced disruptions; that is the highest value within the EU. Denmark features the lowest value with 15 minutes on average. The European average is at 175 minutes lost.

Figure 47 : Average minutes lost per year per customer due to significant forced disruptions, 2010-2014

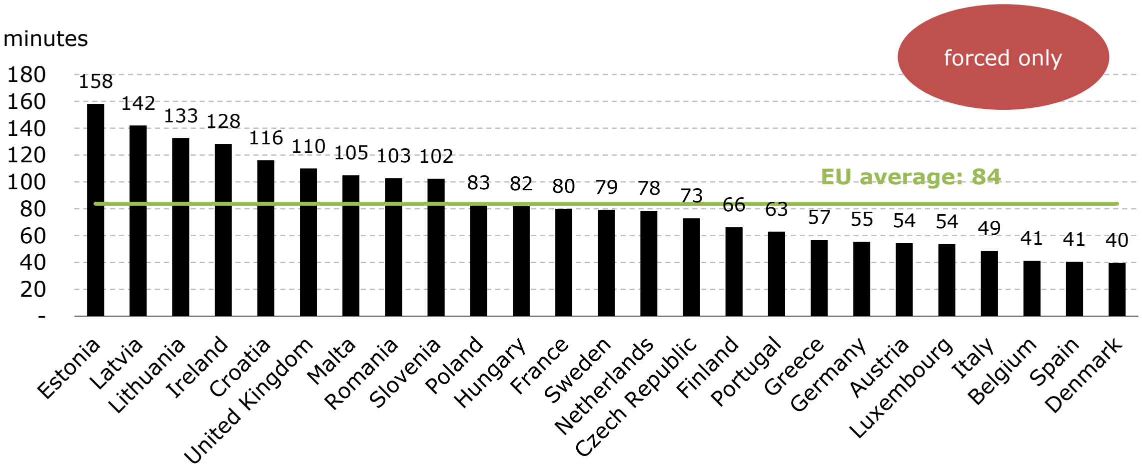


Note: The graph shows a weighted indicator. The weighting is described in Table 4, and allows for an overall interpretation of the indicator as "per customer". No data available for Bulgaria and Cyprus. The average is a simple average across countries and is calculated based on the EU28-countries with available data.

Source: Copenhagen Economics based on CEER data.

The average duration of forced disruptions in Europe is 84 minutes, see Figure 48.

Figure 48 : Average duration per significant forced disruption, 2010-2014



Note: No data available for Bulgaria, Cyprus and Slovakia. The average is a simple average across countries and is calculated based on the EU28-countries with available data.

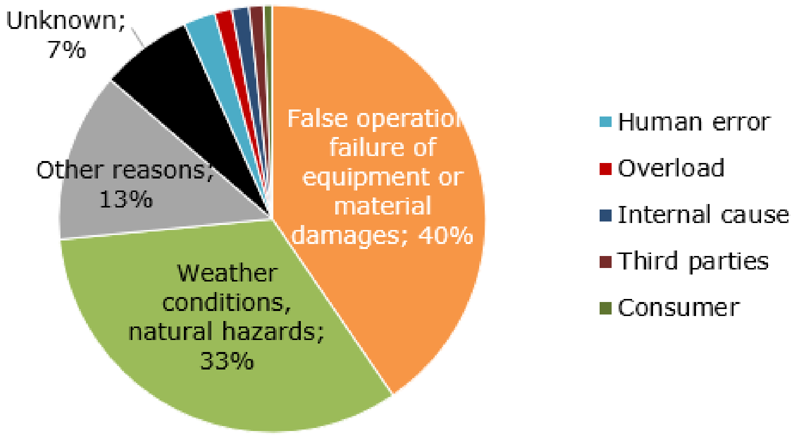
Source: Copenhagen Economics based on CEER data.

In the following, we will move away from overall indicators and will analyse disruptions based on reported single events. The data sources for the following figures are the ENTSO-E Monthly Reports, as well as a survey that we sent to TSOs, DSOs and NRAs in the 28 Member States. As not all countries reported all of their disruptions, using this data to draw conclusions on absolute magnitudes would most probably mean that we significantly underestimated disruptions in Europe. However, assuming that there is no structural bias, i.e. that the collected data is a representative subset of the EU, we can draw conclusions on relative magnitudes and shares.

The dataset contains 388 observations for 2010 to 2016 from 22 Member States in total. Due to limited data, we decided not to exclude any further observations, and report all disruption events that we obtained data for. The fact that we defined a « disruption » as an event where consumers are out of power means that we automatically focus on those events that mattered for society; we therewith apply an implicit filter for significance on all events.

Disruptions can occur from different causes. Of all the single disruption events reported, most are due to false operation, failure of equipment or material damage (40%), followed by severe weather conditions and natural hazards (33%), see Figure 49. Only 2% of the disruptions were reportedly due to human errors.

Figure 49 : The reasons for disruption events



Source: ENTSO-E Monthly Statistics Reports as well as a survey to European TSOs, DSOs and NRAs

In our survey, we investigated in particular to which extent disruptions are caused by outages, or have been linked to malicious attacks. To the question whether any disruptions were caused by outages, 13 of the 18 countries that responded stated that none of their disruption events has been linked to an outage, see Table 5.

Table 5 : Disruptions caused by outages – the Member States' responses

Have any disruptions been caused by outages?	Member States' responses
No	**13 countries:** Austria, Belgium, Czech Republic, Estonia, Finland, Italy, Latvia, Lithuania, Luxembourg, Portugal, Slovakia, Slovenia, Spain
Yes	**5 countries:** • **Ireland** reports that two supply disruptions since 2010 were due to under frequency disturbances caused by the tripping of large generators • **Malta** reports that in total, 69 supply disruptions have been linked to outages since 2010, with a decreasing tendency in the recent years. The number of disruptions linked to outages was in each of the years since 2010: 13 (2010), 10 (2011), 13 (2012), 12 (2013), 16 (2014), 5 (2015) and 0 (2016). • **Poland** reports that typically, disruptions in the country are not linked to outages, but it does happen irregularly in one of Poland's regions, where there are challenges regarding energy generation by renewable sources and the distribution in the grid. • **Romania** reports that it is rare that disruptions are caused by outages, but it happened in one case in 2016 when a generation plant at TSO level had an outage. • **The UK** reports several cases where failures of supply from an electricity generation company led to disruptions; The number of such disruptions since 2010 was: 25 (2010/11), 45 (2011/12), 14 (2012/13), 7 (2013/14), 8 (2014/15), and 1 (2015/16).
n/a	**9 countries:** Bulgaria, Croatia, Cyprus, Denmark, France, Germany, Greece, Hungary, Sweden

Source: Copenhagen Economics illustration based on survey results

To the question whether any disruptions were caused by malicious attacks, the clear majority reported that this had not been the case. France, Italy and Poland are the exemption and report cases of theft, see Table 6:

Table 6 : Disruptions caused by malicious attacks – the Member States' responses

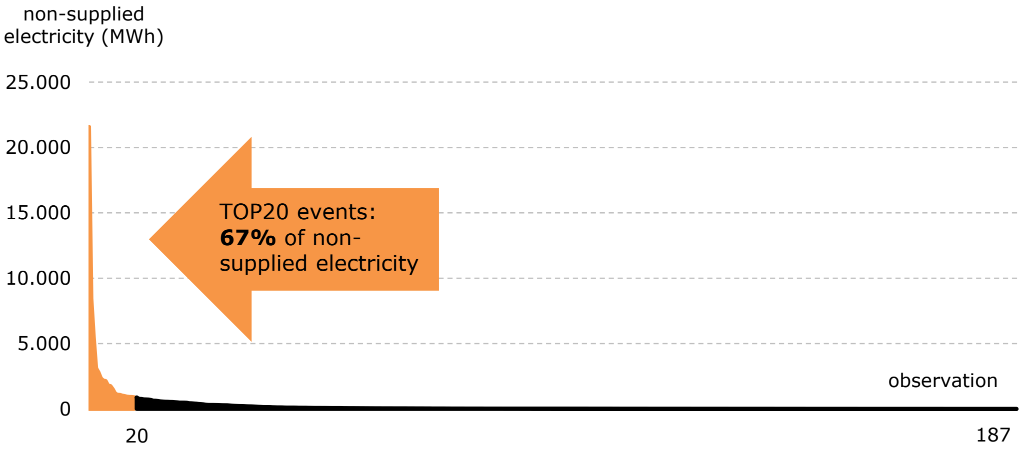
Have any disruptions been caused by outages?	Member States' responses
No	**17 countries:** Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, Ireland, Latvia, Lithuania, Malta, Portugal, Romania, Slovakia, Slovenia, Spain, United Kingdom
Yes	**3 countries:** • **France** reports that the French TSO had only one significant supply disruption in 2016, where a theft of cable/line caused a busbar fault in a VHV/HV transformer station. The disruption had a magnitude of 121 MWh of non-supplied electricity. • **Italy** reports that there have been one or more cases of theft. • **Poland** reports that typically, disruptions in the country are not linked to malicious attacks, but energy infrastructure thefts do happen and can lead to disruption events. That was the case for the following number of events: 2010 (408), 2011 (529), 2012 (553), 2014 (1956), 2015 (840) and 2016 (858).
n/a	**8 countries:** Bulgaria, Cyprus, Germany, Greece, Hungary, Luxembourg, the Netherlands, Sweden

Source: Copenhagen Economics illustration based on survey results

The largest disruptions 2010-2016: TOP20

The reported disruptions in Europe show a wide range in their magnitude in terms of non-supplied electricity to consumers. The disruptions range from less than 1 MWh of non-supplied electricity to more than 21,000 MWh. In fact, the largest 20 disruptions did cause almost 70% of the total non-supplied electricity in 2010-2016, see Figure 50.

Figure 50 : Merit-order-graph of all reported disruptions ranked after market impact (non-supplied electricity, MWh)



Source: ENTSO-E Monthly statistics reports and survey.

A closer look at the 20 largest disruptions in terms of non-supplied electricity to consumers since 2010 supports the conclusion that most disruptions are due to either weather conditions or failure of equipment. None of the largest disruptions has been caused by an outage or by a malicious attack. Further details on the largest events are provided in Table 7.

Table 7 : The 20 largest disruption events in Europe since 2010

Number (1-20)	Country	Year	Month	duration (full hours)	Amount of non-supplied electricity to consumers (MWh)	Cause and details	Source
1	Cyprus	2011	7		**21,575**	Cause: self-detonation of containers of explosives in a naval base resulting in the destruction of the whole Vasilikos Power Station (biggest power station of the country).	ENTSO-E
2	Portugal	2013	1	192	**8,449**	Cause: weather condition (storm). Affected infrastructure element: transformer stations and overhead lines.	survey
3	Germany	2010	11	11	**5,500**	Cause: False operation, failure of equipment or material damage	ENTSO-E
4	Germany	2014	9	4	**3,112**	Cause: tripped generator due to an incident originated in the 380 kV substation Uentrop (failure in the combined instrument transformer Sauerland Nord line)	ENTSO-E
5	Croatia	2012	2		**2,794**	Cause: weather conditions, natural hazards 551,000 consumers where affected.	survey
6	France	2015	6	4	**2,337**	Cause: weather conditions, natural hazards. Series of material failure on measuring transformers on numerous VHV/HV/MV substations, during a heat wave. Brownout of 36 delivery points and load shedding on 21 delivery points. Affected infrastructure element: transformer station.	survey
7	Portugal	2010	2	8	**2,175**	Cause: weather conditions, natural hazards Affected infrastructure element: transformer stations and overhead lines.	survey
8	Germany	2010	3	3	**2,135**	Cause: False operation, failure of equipment or material damage	ENTSO-E
9	Italy	2012	2	24	**1,783**	Cause: weather conditions, natural hazards. Affected infrastructure element: line	survey
10	France	2012	3	96	**1,751**	Cause: weather conditions, natural hazards. Series of incidents on overhead lines during an episode of sticky snow. Brownout of 20 delivery points. Affected infrastructure element: cable/line.	survey
11	Croatia	2014	1		**1,500**	Cause: weather conditions, natural hazards. 15,000 consumers were affected	survey
12	Germany	2011	4	1	**1,167**	Cause: fire in the substation Bürstadt of the transmission system operator.	ENTSO-E

Number (1-20)	Country	Year	Month	duration (full hours)	Amount of non-supplied electricity to consumers (MWh)	Cause and details	Source
13	Slovenia	2014	2	200	**1,088**	Cause: weather conditions (icing of overhead line) Affected infrastructure element: interconnector at transmission level.	survey
14	France	2010	6	72	**1,074**	Cause: weather conditions (storm) Affected infrastructure element: transformer station. Flooding and mudslides in a VHV/HV substation caused brownouts on 12 delivery points and load shedding on 19 delivery points.	survey
15	Portugal	2014	2	48	**1,020**	Cause: weather conditions (snow) Affected infrastructure element: transformer stations and overhead lines.	survey
16	Italy	2015	2		**984**	Cause: weather conditions, natural hazards. Affected infrastructure element: line	survey
17	Germany	2010	6	3	**942**	Cause: weather conditions, natural hazards.	ENTSO-E
18	Portugal	2013	12	48	**919**	Cause: weather conditions (storm) Affected infrastructure element: transformer stations and overhead lines.	survey
19	Germany	2014	9	1	**916**	Cause: tripped generator due to an incident originated in the 380 kV substation Uentrop (failure in the combined instrument transformer Sauerland Nord line)	ENTSO-E
20	Italy	2015	3		**892**	Cause: weather conditions (snow)	survey

Note: Bulgaria, Cyprus and Greece did not answer to the survey.

Source: ENTSO-E Monthly statistics reports, survey, literature research

Disruptions in the transmission grid happen more rarely but with a larger effect

In the above description of the largest disruptions in 2010-2016, it is interesting to see that very few of the disruptions are related to transmission grid failures. History has shown, that while transmission grid failures occurs quite rarely, they have potential to lead to massive disruptions both in terms of length of the duration and number of consumers affected. In this section, we look more closely at a number of different cases of transmission grid failure, and how they affected consumers' access to power in the grid. We will in the following distinguish between two types of disruptions:

1. Cases of an actual disruption, meaning that consumers are out of power due to a problem in the transmission grid, for example a failure in an overhead line. The direct impact on consumers will be large, as there is no access to consume electricity. This will not however necessarily translate into higher electricity prices in the region, as there simply is no infrastructure to facilitate market transactions (prices in neighbouring regions could be affected).

2. Cases of interconnector disruptions, sometimes combined with further problems in the transmission grid, which lead to stress in the grid, but not to an actual disruption in the sense that consumers are out of power. Such cases will typically not cause disruptions, but can increase electricity prices.

The following five case studies illustrate which shapes disruptions or problems in the transmission grid can take. The first three examples from Italy, Germany and Denmark are disruptions of type 1, where consumers were out of power. The latter two examples from Sweden, France and the UK are type 2–cases.

On the night of Sunday 28 **September 2003**, a sequence of events caused a blackout in almost all of Italy as well as parts of Switzerland that affected around 56 million people, see Box 1.

Box 1: Blackout in Italy in 2003 with around 56 million people out of power

The causes
The blackout was caused by a sequence of events triggered by a **trip of the Swiss line Mettlen-Lavorgo caused by a tree catching fire** at 03:01am. The automatic and manual attempts to re-close the line were unsuccessful. Meanwhile, other lines had taken over the load of the tripped line, but **the other Swiss line Sils-Soazza nearby was overloaded**, which is normally acceptable for up to 15 minutes. At 03:11am, the Swiss coordination centre of ETRANS called the control centre of the Italian TSO GRTN (now Terna since 2005) to request countermeasures within the Italian system, namely the **reduction of Italian electricity import**, which was in excess by 300 MW compared to the agreed schedule. This import reduction was effective at 03:21am, but, together with some internal countermeasures taken within the Swiss system, it turned out insufficient to relieve the overloads. At 03:25am, **the line Sils-Soazza also tripped after a tree catching fire**, probably in contact with the line being overheated due to the overload. Having lost two important lines, **the overloads on the remaining lines in the area became intolerable**, and the instability of power and voltage caused an almost simultaneous and automatic trip of the remaining interconnectors towards Italy. As a result, the **Italian system was isolated from the European network** about 12 seconds after the loss of the line Sils-Soazza.
2 minutes and 30 seconds after the separation of the country, **the frequency drop in Italy led to a collapse of the system, causing a blackout**.

The restoration process in Italy started immediately after the blackout. Nearly all of the northern part of Italy was energised before 08:00am, the central part around 12:00am and the remaining parts of mainland Italy at 17:00pm. Sicily was fully energised at 21:40pm. The main reason for the difference in timings was the failure of several hydro plants in southern Italy to black-start.

The impact
The result was an electricity blackout in all of Italy (except the islands of Sardinia and Elba) for approximately 12 hours and a part of Switzerland for 3 hours, affecting a total of around 56 million people for a **total energy not delivered of about 180 GWh** (IEEE 2007).

Source: UCTE (2004) final report of the investigation committee on the 28 September 2003 blackout in Italy; Corsi, S. and Sabelli, C. (2004) General blackout in Italy on Sunday 28 September 2003; IEEE (2007) Blackout experiences and lessons, best practices for system dynamic performance, and the role of new technologies.

In **November 2006**, transmission system disturbances occurred in **Germany, France and Italy.** A high voltage line in Germany had to be switched off to let a ship pass underneath, which led to overloading of lines and eventually a disruption affecting more than 15 million households, see Box 2.

Box 2: Disruptions on the transmission level in Germany, France and Italy in 2006 affecting 15 million households

The causes
On the 4th of November 2006, system disturbances occurred in Germany, France and Italy. The fault originated from Northern Germany, from the control area of the TSO Eon Netz (TenneT since 2009). A high voltage line had to be switched off to let a ship pass underneath. After manual disconnection of the line to let the ship pass, **the N-1 criterion was not fulfilled** in the E.ON Netz grid and on some of its tie-lines to the neighbouring TSOs. The incident demonstrated **insufficient inter-TSO co-ordination**, as a change of time had occurred for switching-off the line but E.ON Netz communicated the change very late to the other involved TSOs (RWE TSO and TenneT). The switching was therefore insufficiently prepared to ensure the secure operation. This led to overloading of lines and finally to splitting of the Union of Co-ordination of Electricity Transmission (UCTE, now ENTSO-E since 2009) network into three zones: West, North-East and South-East. The Western zone lacked power and the Eastern zone had too much power. The power imbalance in the Western area induced a severe frequency drop that caused a disruption in several countries, hitting France and Germany hardest.

In both under-frequency areas (West and South-East), sufficient generation reserves and load shedding allowed to restore the normal frequency within about 20 minutes. In the over-frequency area (North-East), the lack of sufficient control over generation units contributed to the deterioration of system conditions in this area (long lasting over-frequency with severe overloading on high-voltage transmission lines). Generally, the uncontrolled operation of dispersed generation (mainly wind and combined-heat-and-power) during the disturbance complicated the process of re-establishing normal system conditions. Full resynchronization of the UCTE system was completed 38 minutes after the splitting and the TSOs were able to re-establish a normal situation in all European countries in less than 2 hours.

The impact
The result was a blackout affecting **more than 15 million European households**. The most affected area was France where 5 million customers were cut-off. In Germany millions of customers were also affected, while in Belgium, Netherlands, Italy and Spain some hundreds of thousands of customers were without electricity.

Source: UCTE, Final Report - System Disturbance on 4 November 2006.

In the years **2002 and 2003**, there have been two disruptions at the transmission grid in **Denmark** that caused significant blackouts, in the 2002 case for about 20% of the population, see Box 3.

Box 3: Disruptions in the Danish transmission grid in 2002 and 2003 hit millions of consumers

The causes
On **28 December 2002**, **two technical failures** happened independently of each other in the transmission grid in Western Denmark, namely an error in the relay of one of the main cables/lines between Kassø (a town close to the German border) and Tjele (a town further north in Jutland, close to Viborg).

Another large-scale disruption hit Eastern Denmark and Southern Sweden on **23 September 2003** at 12.37 noon. The primary cause was **technical infrastructure failure** at transmission level in Southern Sweden, which caused unavailabilities at several units of a nuclear power plant in the region. Just before, there had been an outage of a unit of the different nuclear power plant. The situation resulted in a voltage breakdown in Southern Sweden as well as Eastern Denmark, which is connected to Southern Sweden through an interconnector.

The impact
On **28 December 2002** in the early morning (6.45am), about one million people in North-Western Denmark – that is about **20% of the country's population – were out of power** for up to three hours. Power supply was up again for the first consumers at 7.35am and the last ones at 9.50am.

On **23 September 2003**, the disruption took **several hours**. In Denmark, power supply was up again after a little more than an hour for the first consumers (1.47pm), and only after more than six hours (7.05pm) for the last ones.

Source: Energinet (2017) Report on power supply security; Danish Energy Agency (2015) Power supply security in Denmark; TV2 News (2003) 10 years of blackouts in Denmark

The following two examples show cases of problems in the transmission grid that did not lead to blackouts.

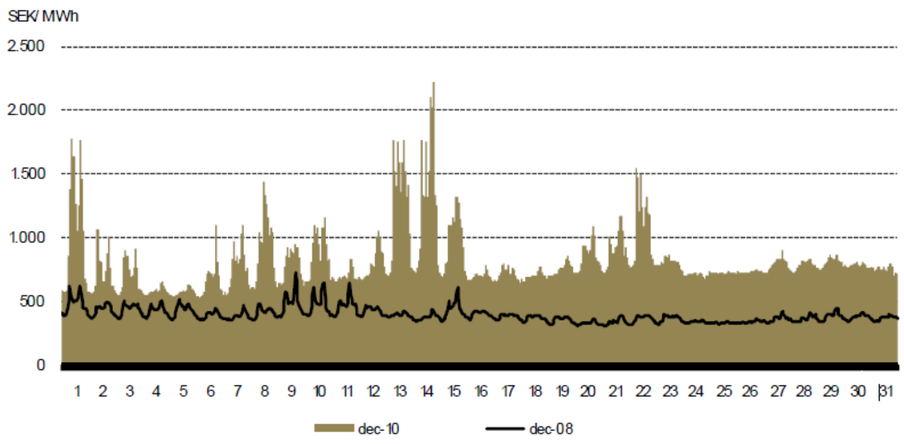
In **December 2010** in **Sweden**, unavailabilities of several interconnectors combined with reduced power supply and high power demand resulted in an extremely tight market situation. Prices increased significantly, and several price peaks with extraordinary high prices occurred, see Box 4. However, disruptions were avoided, and power was delivered reliably to all customers at any time.

Box 4: High prices, but no disruptions as a consequence of a situation resembling a "perfect storm" in Sweden in December 2010

The causes

Several interconnectors were out of order (Swepol Link to Poland of 600 MW capacity, connection to Western Denmark of 740 MW capacity) or had a **reduced capacity** (interconnector from Germany to Eastern Denmark, connection to Southern Norway), which limited Sweden's possibilities to import power.

In addition to those interconnector unavailabilities, three other independent circumstances led to a **reduced power supply**. A series of Swedish **nuclear power plants were running at a 20% reduced capacity** (2,000 MWh less than usual) due to operational problems, while nuclear power accounts for about 40% of the annual Swedish power generation. **The level of Swedish water reservoirs was 30% lower** (7,500 GWh less) compared to the typical level at that time of the year, while hydropower accounts for about 50% of the annual electricity production. **The level of Norwegian water reservoirs was also 30% lower** than the usual level and as the Nordic electricity markets are closely linked, this affects the Swedish power market considerably.



The reduced power supply coincided with **higher-than-usual demand for electricity** due to extremely low temperatures. The December was the coldest in Sweden since 1987, with temperatures 5-15 degrees lower than usually at that time of the year. The increased heating meant that power consumption was 4,000-6,000 MWh higher than usually.

The impact

This combination of events resulted in significantly higher electricity prices at the spot market than usually in December. The figure below illustrates the two main price effects: a **higher general price level** and **more frequent price peaks of an larger magnitude**.

Important to note, only some consumers were actually hit by those high electricity prices. Consumers on fixed price contract paid a similar price per kWh as in 2008, even slightly lower. Consumers on a contract with a flexible price experienced price increases of 50%, from around 63 to 97 Öre per kWh.

Source: Copenhagen Economics for E.ON Sweden (2010) That's how it works in the power market. Analysis of the price peaks in December 2010.

An interconnector failure in **November 2016** between **France and the UK** was expected to have a considerable impact on the British market. However, disruptions were avoided and the British TSO reported "no significant impact on electricity prices" from this event, see Box 5.

Box 5: Interconnector failure between France and the UK in 2016

The causes

The Interconnexion France-Angleterre (IFA) link between Folkestone and Calais is Britain's biggest interconnector, allowing it to import up to 2 gigawatts of power from the continent when UK supplies run low. During a storm (Storm Angus), in the morning of the 20th of November 2016, **four of eight cables have been damaged**, putting 1GW of capacity out of action until the end of February 2017. The cables have been damaged **when a ship dropped urgently an anchor during the storm**. The anchor hit a French pair of cables and then bounced over a British pair before crashing into another French pair.

The faults in the cables were about three miles off the coast in water depths of about 65 ft. The cables were heavily armoured and buried within the seabed, and damage on such a scale was unexpected. The interconnector typically supplies about 5% of the UK's electricity and brings a degree of flexibility to the UK energy system. Moreover, the impact of the outage was complicated by the fact that a series of nuclear reactor safety shutdowns in France had significantly **reduced French power supplies** and increased power prices.

The impact

Analysts at Barclays were forecasting at the time of the incident that the outage was likely to lead to "increased volatility and higher UK power prices over January and February 2017 – especially during peak demand periods". However, the British TSO National Grid reports that **there has not been an impact on prices**, and that the overall impact on the market and their business was very small and almost negligible.

Source: Interview with National Grid; 4coofshore (2017) Presentation of the Interconnection France – UK 2000 (IFA2000) Interconnector; The Telegraph (2016) Winter power crunch fears as UK-France cables severed during storm; The Guardian (2017) All it took was an anchor, how a storm took down half the UK's electricity link to France.

4.2.3 Conclusions

Power supply is very reliable in the EU. For an average EU country, power consumers will on average have access to power in 99.948% of the time (measured in 2014). This means than an average power consumer in Europe will face about 1 to 2 disruption events longer than 3 minutes each year.[46] From 2010 this number has fallen from 1.7 to 1.4 in 2014. Reliability varies across individual Member States with Luxembourg, Denmark, Germany and the Netherlands at the high end with around 20 minutes to half

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[46] "Longer than 3 minutes" is the most commonly used threshold across the EU, with 24 of the 28 Member States using it. The four Member States reporting disruptions in a different way are Denmark and the Netherlands, which report all disruptions of at least 1 minute and 5 seconds respectively, as well as Cyprus and Malta, which do not have a classification.

an hour of disruptions per customer per year, and Romania, Latvia and Croatia in the low end with about 10 to 14 hours of disruptions per customer per year.

By far the majority of disruptions occur at the distribution level. Disruptions at transmission level are rare, but if they happen, they often have a considerable impact – if they lead to a blackout - on hundreds of thousands or even millions of consumers directly, as examples from Italy, Germany, France and Denmark show. For the transmission cables and lines between countries (interconnectors), failure alone very rarely gives rise to significant distress to the power system let alone actual disruptions to consumption. Instead, it leaves the national/regional power market more vulnerable to additional simultaneous failures in e.g. local generation assets, and may increase the power prices in the countries depending on the local supply base. An illustrative example from Sweden in 2010 showed that significant price increases can indeed happen, but it typically requires similar significant events in parallel such as generation assets out for maintenance. Even the combination of multiple significant events in Sweden in 2010 did not give rise to any brownouts.

When a power disruption happens, it is either due to a malfunction in the grid infrastructure either at distribution level or transmission level, or due to a lack of generated power. While the vast majority of the disruptions occur due to problems in the grid such as weather-related breakdown of overhead lines or transformer station malfunctions, there are incidents where a lack of power generation to meet supply has led to disruptions. These incidents are quite rare. When the disruptions are related to infrastructure, it is almost always caused in the distribution grid. All 9 countries answering this particular question stated that disruptions typically happen at DSO level, mostly at electric lines.

About a third of the minutes of disruptions are planned disruptions e.g. for maintenance or construction purposes, and two thirds are unplanned disruptions. The primary reason for the unplanned disruptions are so-called false operation, failure of equipment or material damage (40%) followed by severe weather conditions and natural hazards (30%). We find very little evidence that disruptions have been due to a malicious attack. 17 countries report that no disruption was caused by a malicious attack, only Poland, France and Italy report single cases of thefts of infrastructure elements that have caused disruptions.

We estimate that for EU in total approximately 600 to 850 GWh of electricity have not been supplied to consumers per year in the years 2010-2014. This constitutes both planned and unplanned disruptions.

4.3 Output 5 – The use of voluntary demand curtailment

4.3.1 Objective and approach

Output 5 aims at gathering information on voluntary demand curtailments in case of significant electricity supply disruptions, and to establish estimations of the electricity supply margins thus created. The overall objective of this output is to provide an understanding to which extent voluntary demand curtailment has been used as an effective solution today (and/or could be in the future) in times of severe stress in the energy system.

The information was collected in two steps. First, we carried out desk research through European sources (e.g. ENTSO-E, JRC, Smart Energy Demand Coalition) and national sources (reports and websites of the NRAs, TSOs and DSOs)[47] to identify the voluntary demand curtailment mechanisms in place, the frequency of their activation in cases of significant supply disruptions and the margin supply thus created. To complement the information, we launched a survey with the national TSOs and where relevant, DSOs, and received answers from 14 Member States. Where relevant, we followed up with additional questions by email and phone with the TSOs involved.

4.3.2 Findings

4.3.2.1 Overall findings and conclusions

Traditionally, balancing the power system to ensure the right frequency has been a question of regulating the supply side, that is ramping power generators up or down. However, the demand side is increasingly seen as a potential resource for balancing purposes due to several reasons. *Firstly* due to technological developments making demand response easier to use for balancing purposes, and *secondly* due to the expected increase in large-scale demand assets in individual households such as electrical vehicles and heat pumps.

Demand side flexibility is viewed upon with great potential as it is indeed the current inflexibility that gives rise to the discussions about reserve availability, capacity payments etc. If it could be ensured that consumers were easily and cheaply available to communicate and respond flexibly to price variation, many of the issues related to energy system balancing would be solved.

However, there are still a number of challenges left with respect to utilising the demand side as a balancing asset such as 1) it is not deemed as reliable as supply assets, 2) it cannot typically be available for as long as supply assets, 3) the demand assets are substantially smaller in size and therefore require significant coordination efforts to mobilise sizeable capacity and 4) it is relatively expensive to mobilise especially household assets as it requires investments in e.g. smart metering equipment, new business models and new regulation and market design models.

Nonetheless, the demand side seems to play at least some role in many European Member States. In particular the UK seems to be on the forefront of incentivising demand side response and has by far the most developed market for demand-side aggregators.

Demand response can broadly be categorised in two groups[48]:

- Implicit demand response (or “price-based”) whereby consumers choose to be exposed to time-varying electricity prices that partly reflect the value or cost of

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[47] The full list of literature is available in Annex 8.

[48] JRC, Demand Response Status in EU Member States, 2016. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC101191/ldna27998enn.pdf

electricity and/or transportation in different time periods. These prices are part of their supply contract.

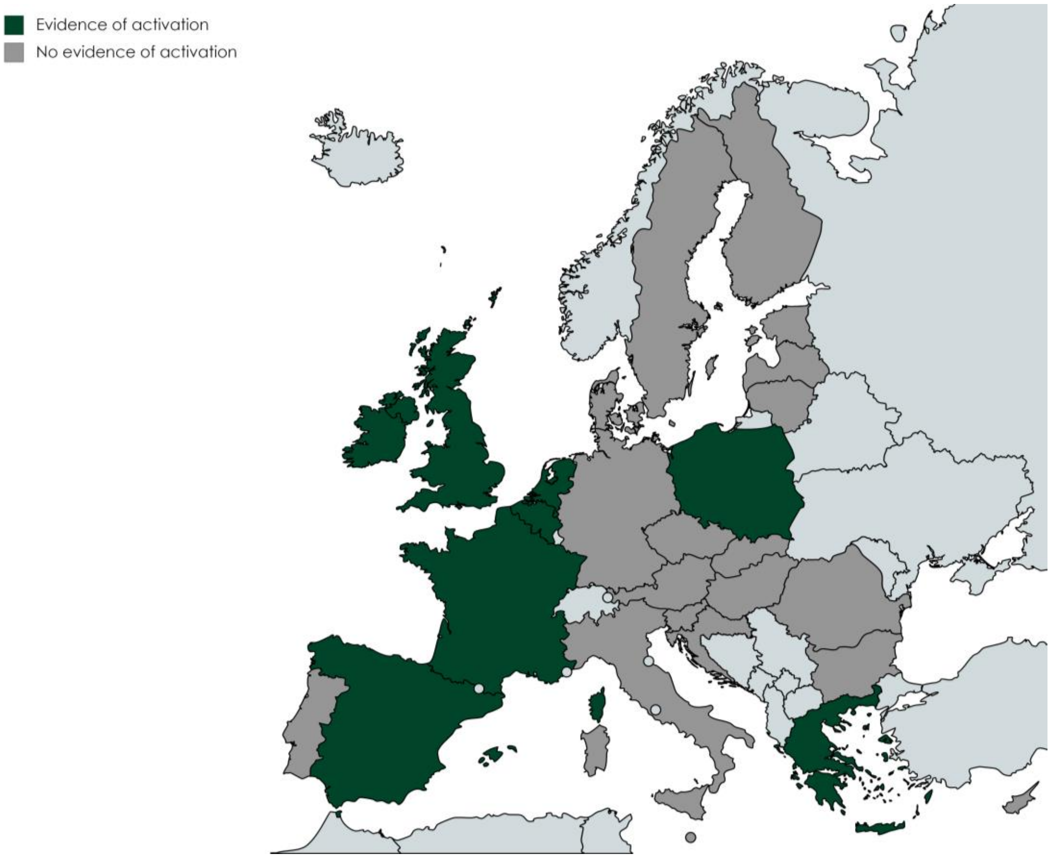
- Explicit demand response whereby demand competes directly with supply in the wholesale, balancing and ancillary services markets through the services of aggregators or single large consumers. Consumers receive direct payments or better conditions to change their consumption upon request, either individually or by contracting with an aggregator which can be either a third-party aggregator or the customer's retailer.

Voluntary demand curtailment mechanisms belong to the category of explicit demand response and consist in medium/long-term agreements where consumers allow TSOs or DSOs to curtail them upon request in cases of impending significant supply disruption events. Voluntary demand curtailment mechanisms are activated in emergency cases where electricity demand exceeds supply and where consumers are inevitably going to be cut out of power.

It has generally been very difficult to find information on the extent to which demand side assets have contributed as an effective tool to avoid brownouts, as this is rarely recorded and/or published by TSOs. To the extent that demand side assets contribute to balancing mechanisms and reserve pools, we expect that these have been called upon in times of severe distress, but that the impact has been quite small compared to the activation of generation assets.

However, some countries also engage in specific demand curtailment programmes used in emergency circumstances. These programmes allow for a more controlled disconnection of consumers before an actual brownout that disconnects an entire geographic area. 12 countries seem to have such voluntary demand curtailment mechanisms in place and in about 8 out of these 12, we have found evidence that these demand side programmes have been activated, see map.

Figure 51 : Activation of voluntary demand curtailment mechanisms 2010-2016



However, the capacity represented by these voluntary demand curtailment mechanisms represents on average only 2% of the total electricity capacity in the respective Member States, while in the country where the volume curtailed was available, this amounted only to 0.0013% of the total electricity consumption in these countries.

4.3.2.2 Detailed findings

The mapping of demand response programmes across the Member States allowed to identify 12 countries where voluntary demand curtailment mechanisms exist. For some of them, the information regarding the frequency of their activation and the supply margin created could also be found, while in some other countries it was not publicly available.

The table below presents the volume contracted under voluntary demand curtailment mechanisms as a share of the total electricity capacity in the respective Member States in 2016. In half of the countries, this share is below 1% while the highest share is recorded in Portugal with such mechanisms representing 10.2% of installed capacity. Information on the volume of demand response curtailed under these mechanisms was only available in Belgium but this volume represented only 0.0013% of the total electricity consumption in 2015.

Table 8: Volume contracted and curtailed compared to total capacity and consumption in 2016

Member State	Voluntary demand curtailment mechanism	Volume contracted (MW)	Share volume contracted/ total electricy capacity (%)	Volume curtailed (MWh)	Share volume curtailed/ total electricity consumption (%)
Belgium	Interruptible contract programme	199	0.9	1,070*	0.0013*
	Strategic reserve	97	0.5	0	0
Finland	Peak load reserves	299	1.9	0	0
France	NEBEF	2,100	1.6	N/A	N/A
	Interruptible contracts	1,600	1.2	N/A	N/A
Germany	Interruptible load programme	1,500	0.8	N/A	N/A
Great Britain	Short-Term Operating Reserve	78	0.1	N/A	N/A
	Demand-Side Balancing Reserve	515	0.7	N/A	N/A
Greece	Demand Side interruptible programs	611	3.7	N/A	N/A
Ireland	Short-Term Active Response	45**	0.6**	N/A***	N/A***
Italy	Interruptible contracts programme	4,061*	3.4*	N/A	N/A
Netherlands	Emergency capacity	350	1.2	N/A	N/A
Poland	Emergency Demand Response Programme	200	0.5	0	0
Portugal	Interruptible contracts programme	2,000	10.2	0	0
Spain	Interruptible load programme	2,890	2.7	N/A	N/A

Note: * 2015 figures as 2016 figures were not available; ** 2014 figures as 2015 and 2016 figures were not available;
*** In Ireland in 2016 a total of 138 MW was curtailed under the STAR programme.

- Belgium

The **Interruptible contract programme (ICH)**, whereby large consumers receive payment from the TSO for the availability of reserve and its activation, offered a capacity of 261MW for 2014 and 2015, 199 MW for 2016, and 200MW for 2017. In 2016, this represented only 0.9% of the total electricity capacity of Belgium.[49] The frequency of the Interruptible contracts activation, and the supply margin thus created is presented in the table below.

Table 9 : Activation of the Interruptible contract programme (ICH)

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[49] FEBEG, Electricity Statistics. Available at: https://www.febeg.be/fr/statistiques-electricite

Year	Number of Interruptions	Volume curtailed (MWh)	Share of total consumption (%)	Total number of hours of interruption	Average number of hours	Average volume curtailed (MWh)
2010	9	4,752	0.0055	42	4.7	113
2011	4	1,884	0.0023	11	2.7	176
2012	2	564	0.0007	4	2.1	135
2013	3	572	0.0007	3	1.0	200
2014	1	1,163	0.0014	5	4.5	258
2015	2	1,070	0.0013	5	2.3	238

Source: CREG, Elia, FEBEG
Note: For one event, several clients may have been interrupted.

The activation of this programme remains limited, as well as the volume of energy curtailed compared to the total consumption (0.002% in average) and the duration of the curtailments. This is due to the fact that this programme is only used in case of severe disruptions and that the contracts only allow few activations per year. It should be noted that the NRA has requested the TSO to activate the contracts minimum once a year to maintain the experience of the service providers.

Demand Response also represents about one tenth of the capacity involved in the **Strategic Reserve**, which represented 0.5% of the total electricity capacity of Belgium in 2016, but to date, the Strategic Reserve has not been activated. The TSO deems the use of demand response as effective as generation participation in the Strategic Reserve mechanism.

- Finland

Consumers can participate in the Strategic Reserve mechanism since 2013, which consists in contracts between the TSO and the largest industrial consumers to provide **peak load reserves**. Demand response in peak load reserve represents 10MW for a total of 299MW in the 2015-2017 period, and 22MW over 729MW for 2017-2020. In 2016, this demand response represented only 1.9% of the total electricity production capacity.[50] The use of peak load reserve capacity is very rare, the last time that the reserve was activated was during the winter 2009- 2010 (when demand response was not participating yet).

- France

Demand response can participate in the **NEBEF** ("*Notification d'Échange de Blocs d'Effacement*") since 2014, whereby curtailed load can bid as energy directly into the wholesale electricity market. In addition, residential consumers can participate in the NEBEF by receiving a premium for the consumption reductions that they provide (so called "*effacement résidentiel diffus*"). This premium is financed through the tax included in the electricity tariffs, however, this premium is under question as a possible subsidy and its future is unclear at this stage. Overall the volume of demand response load contracted under the NEBEF amounted to 850 MW in 2014, 1200 to 1800 MW in 2015, 2100 MW in 2016, 750 to 1400 MW in 2017. In 2016, the demand response share of the NEBEF represented 1.6% of the total electricity production capacity in France.[51] The

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[50] Finland Energy Authority, 2017 National report to ACER. Available at: https://www.ceer.eu/documents/104400/5988265/C17_NR_Finland-EN.pdf/b1048901-ce81-7586-4a9f-5f9fdb4ce5b8

[51] RTE, Bilan Electrique français 2016. Available at: http://www.rte-france.com/sites/default/files/2016_bilan_electrique_synthese.pdf

volume activated under the NEBEF was 310 MWh in 2014, 1522 MWh in 2015 and 10313 MWh in 2016, however the part of demand response in the NEBEF is linked to market prices thus it is hard to link it to specific disruption events. According to the TSO, consumer participation in the NEBEF is effectively contributing to reducing the risk of brownouts and blackouts.

Since 2013, direct **interruptible contracts** exist between the TSO and electricity-intensive consumers. The maximum contracted volume of interruptible contracts was 400MW for 2013, 2014 and 2015, and 1600MW for 2016 and 2017. In 2016, interruptible contracts represented 1.2% of the total electricity production capacity in France. The frequency of their activation and the supply margin created are not publicly available.

- Germany

Large consumption units can participate in the **interruptible load programme** since 2013. Between 2013 and 2015, the TSO had a monthly auction for 1000 MW of immediately interruptible loads and 1.000 MW of quickly interruptible loads (but not even half was tendered due to the entry barriers). Since 2016, there is a weekly auction of 750 MW of immediately interruptible loads, and 750 MW of quickly interruptible loads, which overall represents 0.8% of the total electricity generation capacity in Germany.[52] The frequency of activation of interruptible loads and the supply margin created were not publicly available.

- Great Britain

Consumers can participate in the **Short-Term Operating Reserve (STOR)**, which spurred demand response development in 2011-2012, but now represents a limited part of STOR (less than 10%) and 9-10 aggregators have left, after the requirements have become more and more challenging for consumers (daily weekday participation required with a window of 11-13 hours per day, in order to be paid at a competitive level). Two new variations, STOR Premium Flexible and STOR Runway (auction of 78MW in 2017, which represents 0.1% of GB total electricity generation capacity[53]), have been designed to provide better opportunities for Demand Response aggregation in STOR. In 2012-2013, 3178.3 MW were contracted under STOR and 167.2 GWh were used. In 2013-2014, 3097 MW were contracted under STOR and 292.5GWh were used. In 2014-2015, 3500 MW were contracted under STOR and 233GWh were used. The data do not disentangle the share of demand response and generation. The TSO provided the following example where the use of STOR successfully contributed to preventing a significant supply disruption. In this particular event (see Table 10), the total amount of demand reduction expected under STOR and instructed by the TSO to the DNOS was of 1325 MW, and the total demand reduction achieved is estimated at 765MW equating to approximately 60% of their expected demand reduction.

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[52] Faunhofer ISE Energy Charts, Net installed electricity generation capacity in Germany. Available at: https://www.energy-charts.de/power_inst.htm

[53] UK Government, 2017 Digest of UK Energy Statistics, Electricity. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/633779/Chapter_5.pdf

Table 10 : Example of prevention of supply disruption with STOR

Event Description	**1.** On Saturday 11th February 2012, a number of generation losses occurred during the morning period combined with effects from the under-estimated demand due to the drop in temperatures across GB, resulting in the National Grid Control Room issuing system warnings to the industry and instructing Demand Control to Distribution Network Operators (DNOs). **2.** At 10:10 demand control instructions were issued to reduce demand; Demand control imminent issued to all DNOs and Risk of system disturbance issued to industry participants. **3.** At 12:48 inadequate system margin (NISM) was issued for period 17:30-19:30. The warning of Risk of system disturbance was also extended to cover the darkness peak period. **4.** At 18:30 both inadequate system margin and risk of system disturbance were cancelled.		
STOR Availability / Utilisation during the event	**Time**	**MW**	**Commentary**
	08:30	282MW	Total of 282MW of STOR was instructed
	08:36	407MW	Total of 407MW of STOR was instructed
	08:47	895MW	Total of 895MW of STOR was instructed
	09:00	1207MW	Total of 1207MW of STOR was instructed
	09:30	1243MW	Total of 1243MW of STOR was instructed
	09:47	1423MW	Total of 1423MW of STOR was instructed
	09:47	1610MW	Total of 1610MW of STOR was instructed
	10:05	1760MW	Total of 1760MW of STOR was instructed
	10:06		National Grid Control Room began issuing Demand Control Instructions to DNOs
	10:08	1910MW	Total of 1910MW of STOR was instructed
	10:25		A Demand Control Imminent warning was issued by National Grid Control Room; A Risk of System Disturbance warning was also issued
	10:26	1588MW	Total of 1588MW of STOR was instructed
	11:00	1373MW	Total of 1373MW of STOR was instructed
	11:15		National Grid Control Room started to issue instructions to cancel all Demand Control
	12:00	1271MW	Total of 1271MW of STOR was instructed
	12:15	757MW	Total of 757MW of STOR was instructed
	12:30	357MW	Total of 357MW of STOR was instructed
	12:45		All STOR ceased, The Demand Control Imminent warning was cancelled

Source: National Grid

Note: The amount of STOR at a certain point of time in the above table is the total amount of STOR that were instructed prior to and / or at that particular moment and valid for that particular time.

The **Demand-Side Balancing Reserve (DSBR)**, introduced in the 2015-2016 winter, is targeted at large energy users who volunteer to reduce their demand during winter weekday evenings between 4 and 8 pm in return for a payment. 319MW of DSBR were contracted in 2014-2015, and 515MW in 2015-2016. In 2016, DSBR represented 0.7% of GB total electricity generation capacity. There was no DSBR procurement in 2016-2017 and the service will not be renewed as the recent capacity mechanism includes a similar availability-requirement rendering this programme obsolete. The TSO gave the following example of DSBR activation which successfully contributed to the prevention of a significant supply disruption.

Table 11 : Example of prevention of supply disruption with DSBR

Event Description	**1.** On 4th November 2015 at 13:30, a Notification of Insufficient System Margin (NISM) was issued detailing a shortfall of 500MW from the required system margin over darkness peak of the day (running from 16:30 to 18:30). **2.** Margins were expected tight throughout Monday and Tuesday with the extended low wind. A large amount of generation was on breakdown through to Mon and Tue, plus a few generations delayed return with new breakdowns accounted for additional unavailabilities. **3.** The market warning was cancelled at 17:45.		
STOR / DSBR / SBR Availability / Utilisation during the event	**Time**	**MW**	**Commentary**
	13:30	NISM was issued, stating a 500MW shortfall against margin requirements	
	15:16	43MW	Notification to dispatch Demand Side Balancing Reserve (DSBR) was issued over the peak between 17:00 to 18:00
	16:54	134MW	National Grid Control Room confirmed that Supplemental Balancing Reserve (SBR) were made available (134M for the Darkness Peak (DP around 17:30).
	17:2	400MW	STOR ran over the DP, whilst SBR not instructed.
	17:20	43MW	DSBR ran over the DP.
	17:45	NISM was cancelled	

Source: National Grid

The **Frequency Control by Demand Management** (FCDM) programme consists in bilateral contracts between demand side providers and the TSO to manage large deviations in frequency, such as those caused by the sudden loss of a large generating unit, by interrupting demand consumers. There were nine events in 2013 and nine in 2014, always with a maximum duration of 30 minutes, leading to the use of the FCDM programme. The volume contracted and frequency of activation of the FCDM were not publicly available.

- Greece

Two **Demand Side interruptible programs** have been launched in 2016, each of them capped to a volume of 1000MW. The results of the 7 auctions so far are as follows: 500MW in March 2016, 650MW in April 2016, 750MW in May-September 2016, 550MW in October-December 2016, 750MW in January-March 2017, 500MW in April-June 2017, 580MW for July-September 2017. In average, the volume contracted in 2016 represented

3.7% of the total installed capacity in Greece.[54] Due to the natural gas crisis that affected Greece in December 2006-January 2017, power reduction orders were issued on 23.12.2016 and 10.01.17 respectively, but the amount of supply margin created is not available.

- Ireland

The **interruptible loads programme STAR** (Short-Term Active Response) provides the TSO with 45MW of static reserve from industrial sites used in the event of system frequency falling below 49,3 Hz. In 2014, the volume contracted represented 0.6% of the total electricity capacity in Ireland.[55] 21 events led to the activation of STAR since 2010, offering a supply margin between 17 MW and 89 MW (average of 43 MW). The TSO considers the STAR scheme effective to prevent or reduce electricity supply disruptions, however the programme will be replaced in 2018 by a new programme allowing consumers to participate in ancillary services. Some information on the STAR events can be found below, however the level of supply margin was only available for recent years.

Table 12 : Activations of the STAR programme

Date	31/05/2016 14:29	20/05/2016 21:25	09/04/2016 23:28	07/07/2015	22/06/2015	14/03/2015 16:51	27/04/2014 09:40	22/04/2014 17:30	10/05/2013 11:40	06/05/2013 04:10	06/11/2012 19:30	03/09/2012 04:38	20/08/2012 14:50	29/11/2011 11:28	09/10/2011 12:25	05/09/2011 11:39	25/05/2011 15:50	27/11/2010 10:15	04/07/2010 12:27	01/05/2010 09:08	27/04/2010 15:39
MW (Approx)	44	42	52	64	89	11	17	41													

Source: EirGrid

- Italy

The **interruptible contracts programme** is a dedicated Demand Response programme with a current enrolment of about 4 GW. For the 2015-2017 period, the capacity contracted was 3300 MW in mainland Italy, 389 MW in Sicilia, 372 MW in Sardinia. In 2015, the volume contracted represented 3.4% of the total electricity generation capacity in Italy.[56] It is unclear whether the programme has ever been activated.

- Netherlands

Consumer loads can participate since 2014 in the **emergency capacity** ("*Noodvermogen*"), contracted annually. In 2015, 350 MW were procured for the emergency capacity and 150 MW for its variation called Omgekeerd Noodvermogen. In 2016, 350 MW were procured in total. In 2016, the volume contracted represented 1.2% of the total electricity installed capacity in the Netherlands.[57] The emergency capacity has

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[54] Energypedia, Greece Energy Situation. Available at: https://energypedia.info/wiki/Greece_Energy_Situation#Energy_Supply

[55] Eirgrid, Generation Capacity Statement 2016-2025. Available at: http://www.eirgridgroup.com/site-files/library/EirGrid/Generation_Capacity_Statement_20162025_FINAL.pdf

[56] A2A, Italian Energy Market Overview 2015-2016. Available at: https://s3-eu-west-1.amazonaws.com/a2a-be/a2a/2017-03/Overview-Italian-Energy-Market-2015-2016.pdf

[57] TenneT, Record low electricity prices in first 8 months of 2016. Available at: https://www.tennet.eu/news/detail/record-low-electricity-prices-in-first-8-months-of-2016/

been used 19 times in 2013 and 27 times in 2014. The supply margin thus created was not available.

- Poland

Demand Response can participate in the **Emergency Demand Response Programme** (EDRP). The first contract for EDRP was signed in March 2013 (30 MW of capacity for summer and 25 MW for winter). In total 6 auctions were organised between 2012-2015 and the cumulative power contracted exceeded 200 MW (0.8% of peak demand and 0.5% of total installed capacity[58]) in 2016. However, having only utilisation payments proved to be unattractive to customers and by the seventh tender in mid-end-of 2016 there were no participants. The EDRP was activated 3 times over the 2010-2016 period, all between July and September 2015 during a demand peak, for a supply margin of 1.5 GWh in total. The TSO considers this service effective to contribute to security of supply and is planning to organise more tenders, with a maximum of offers without availability payment, and about 500 MW with both availability and utilisation payments.

- Portugal

The **interruptible contracts programme** is limited to large industrial consumers (contracted power above 4 MW), and represents an available capacity of 2000 MW of demand reduction in peak hours. In 2016, the volume available represents 10.2% of the total installed electricity capacity in Portugal.[59] The TSO Portugal has never activated these contracts in the last 15 years.

- Spain

The **interruptible load programme** for large industrial customers (contracted power above 5 MW) acts as an emergency action in case the system is lacking generation and the balance resources are not enough. It represents an available capacity of 2000 MW of demand reduction in peak hours. The interruptible load capacity was of 3020 MW in 2015 and 2890 MW in 2016. In 2016, the volume contracted represented 2.7% of the total installed electricity capacity in Spain.[60] The lack of activation of the Interruptible Load programme in the last decade raises questions about being a form of subsidy to the national industry. In 2016, some interruptible demand was curtailed due to local problems in the transmission grid, but the margin supply was not available.

4.4 Output 6 – The value of lost load to society from significant disruption events

Output 6 provides information on the value of lost load (VoLL) resulting from the significant electricity supply disruption events. Modern industrialized societies are heavily dependent on electricity. That holds both for commercial and private users of electricity. Electricity is an essential input factor to almost all economic processes, meaning that

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[58] Index Mundi, Poland Electricity - installed generating capacity. Available at: http://www.indexmundi.com/poland/electricity_installed_generating_capacity.html

[59] Global Legal Insights, Portugal Energy 2018. Available at: https://www.globallegalinsights.com/practice-areas/energy-laws-and-regulations/portugal

[60] REE, Red Eléctrica publishes the 'Spanish Electricity System Report 2016. Available at: http://www.ree.es/en/press-office/press-release/2017/06/red-electrica-publishes-spanish-electricity-system-report-2016

most commercial activities will come to a stand-still in case of a disruption. Also, many leisure activities are based on electricity and cannot be carried out during a disruption.

Although being expressed in monetary terms, the VoLL cannot be derived from market interaction, as there is no market for trading disruptions. The VoLL must therefore be found using scientific measuring techniques such as:

- *Stated preferences methods*: obtain the information directly from the consumers. Surveys can be used to ask for the willingness to pay (WTP) for avoiding a disruption, or the willingness to accept (WTA) for experiencing a disruption. The surveys can be hypothetical (ex ante) or refer to an actual blackout or brownout in the past (ex post).
- *Revealed preferences methods*: use data to quantify the consumers loss. Such quantifications can for example be based on the production function of an industry, or the household income as a proxy for the value of leisure for private consumers. Undertaken mitigation measures can also give an indication of how costly it is to the consumer to be out of electricity.

4.4.1 Objective and approach

The objective of this chapter is to get a better understanding of the welfare loss, or in other words the socio-economic impact of the disruptions that occur in Europe.

The methodology applied to obtain a value for the value of lost load (VoLL) per non-supplied kWh of electricity for each of the 28 Member States involved 4 main steps. First, we carried out a literature review to obtain a range of VoLL estimates across countries and across the two categories households and non-households. We identified and removed the outlier estimates and found a mean for the remaining estimates. Then, we extrapolated the mean to the 28 Member States. Finally, we merged the household and non-household VoLL into one estimate per country.

4.4.2 Findings

Commercial and private consumers face different types of costs due to disruptions. Being out of power causes direct and indirect damage costs, and trying to avoid the damage costs causes mitigation costs, see Table 13. The VoLL reflects those costs.

Damage costs and mitigation costs are often exclusive, meaning a consumer faces either the one or the other type. If the consumer spent money on a standby generator or battery, then he or she will not face damage costs. Mixes are however also possible, for example if a disruption is longer than the maximum running time of the generator or battery.

Damage costs are typically higher for commercial consumers than for private individuals, as one can argue that when there is no power, all commercial activity ceases, meaning no production or other forms of value creation is possible. In addition, products, machines and devices can be damaged, and data can be lost. For private individuals, a disruption affects the leisure time, which will be very restricted when there is no power, but will not cease fully. Also damage to goods (e.g. food) and data loss can occur in private households, but the damaged goods are typically of a lower value.

Worth noting is that the cause of the disruption does not have any impact on those costs. That does not imply that knowledge about what drives disruptions is redundant, on the contrary, understanding the causes will help design policies to minimise the occurrence of disruptions.

Table 13 : Damage and mitigation costs related to disruptions

	Damage costs		**Mitigation costs**
	Direct	**Indirect**	
commercial consumers, industry	(a) opportunity costs of idle resources: labour, country, capital, profits (b) production hold-ups and restart times (c) adverse effects and damage to capital goods, data loss (d) health and safety aspects	(a) delayed deliveries along the value chain (b) damage for consumers if the company produces an end product (c) costs/benefits for some manufacturers (d) health and safety aspects	Procurement of standby generators, batteries etc., investment in grid construction via charges (network tariffs)
private consumers, households	(a) Restrictions on activities, lost leisure, stress (b) financial costs due to damage to premises and real estate, food spoilage, or data loss (c) health and safety aspects	Restrictions on acquisition of goods, costs for other private individuals and companies	Procurement of standby generators, batteries etc., Investment in grid construction via charges (network tariffs)

Source: Schröder and Kuckshinrichs (2015) Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review.

Existing studies prove that estimating the VoLL is a difficult exercise. The reported VoLL estimates vary significantly. The estimates for households range from 2 EUR per non-supplied kWh in a study for Austria to 72 EUR per kWh in a study for Ireland, which is more than 30 times larger than the Austrian estimate. For non-households, the range is even larger. Here, the smallest estimate is 0.2 EUR for the gas and water sector in Cyprus, the largest 216 EUR per kWh for non-households in Austria, see Table 14.

The USA has been added to the table, as comparing the EU estimates to US-American estimates will be interesting for two reasons: firstly, several studies have been conducted for the US. Secondly, the USA is a modern, industrialised country and in that regard similar to the EU Member States. The additional estimates for the US will help understand which of the European estimates (if any) should be considered outliers.

Table 14 : Existing estimates for the Value of Lost Load (VoLL), 2010 prices

	Households		Non-households	
country	**EUR/kWh**	Source, details, methodology	**EUR/kWh**	Source, details, methodology
Austria	**2.24**	Fickert (2004)		
	5.61	Bliem (2007), Macroeconomic approach	**216.10**	Bliem (2007), service, Macroeconomic approach
	3.46	Reichl et al. (2007)	**7.80**	Reichl et al. (2007), service
	2.45	Reichl et al. (2013), winter, Macroeconomic approach	**26.80**	Reichl et al. (2013), winter, Macroeconomic approach
Cyprus	**9.22**	Zachariadis and Rey (2012), Macroeconomic approach	**0.20-119.96**	Zachariadis and Rey (2012), lower boundary: Gas and water supply, upper boundary: Construction, Macroeconomic approach
Germany	**18.41**	Praktiknjo et al. (2011), Macroeconomic approach combined with Monte Carlo	**7.04**	Praktiknjo et al. (2011), industrial, Macroeconomic approach combined with Monte Carlo
	13.27	Growitch et al (2013), Macroeconomic approach	**8.32**	Growitch et al (2013), Macroeconomic approach
	15.34	Röpke, L. (2013), Macroeconomic approach	**2.86-15.67**	Röpke, L. (2013), industry, lower boundary: Trade and services, upper boundary: transport, Macroeconomic approach
Ireland	**71.63**	Tol (2007), Macroeconomic approach	**8.43 - 75.85**	Tol (2007), Macroeconomic approach
	10.27	Cer and Niaur (2009), calculation based on estimated peak price of planned electricity capacity		
Italy	**4.1**	Bertrazzi et al. (2005), survey	**129.91**	Bertrazzi et al. (2005), service
Netherlands	**19.13**	De Nooij et al. (2007), Macroeconomic approach	**6.94**	De Nooij et al. (2007), Macroeconomic approach
	3.86	Baarsma and Hop (2009), Survey		
	22.77	Wilks and Bloemhof (2005), Survey		
Spain	**8.27**	Linares et al (2012), Macroeconomic approach	**0.92-34.02**	Linares et al (2012), lower boundary: metal, upper boundary: Construction, Macroeconomic approach
Sweden	**3.76**	Anderson and Taylor (1985), Survey		
United Kingdom			**1.64**	London Economics, 2013, manufacturing
USA	**20.03**	Doane et al. (1988), winter, evening	**20.78**	Fisher (1986), summer, afternoon, trade
	19.93	Doane et al. (1988), summer, afternoon	**71.63**	Woo & Gray (1987), summer, afternoon, production
	0.21	Sanghvi (1983), summer, midday	**10.20**	Woo & Train (1988), summer, afternoon, trade
	3.86	Balducci, Roop et al. (2002), Survey	**26.86**	Carves et al. (1990), service (max value shown)

	Households		Non-households	
country	**EUR/kWh**	Source, details, methodology	**EUR/kWh**	Source, details, methodology
	6.03	Burns and Gross (1990), Survey	**8.03**	Doane et al., (1990), winter, evening, production
	2.59	Krohm (1978), Survey	**45.94**	Sullivan, (1996), service
	8.22	Lawton, Sullivan et al (2003), Survey	**7.62**	Sullivan (1996), production

Note: all estimates have been converted into 2010 prices using the price index of the Euro area 2002-2012.

Source: The studies listed in the table.

The large variation in estimates can at least partly be explained through:

- **Different methodological approaches**. Having different strengths and weaknesses, different approaches (e.g. stated vs. revealed preferences, actual vs. hypothetical disruption, willingness to pay vs. willingness to accept etc) typically leads to different results.
- **Different characteristics of the disruptions assessed**. The magnitude of the damage costs depends significantly on the disruption's time of day, season and duration, as well as the fact of whether the disruption is planned or forced. If a disruption is planned and announced sufficiently in advance, then companies can make arrangements to avoid high damage costs, and private consumers can plan their leisure activities accordingly.
- **Differences between countries**. Different income and price levels as well as differences in the industry structure between countries will entail different levels of damage costs.
- **Different preferences of private consumers**. Also within one country, and private individuals' damage costs will vary for two main reasons: firstly, leisure time is scarcer for some than for other individuals. The scarcer, the higher the damage costs of restricted leisure activities. Secondly, personal preferences regarding the use of their leisure time will vary, also given the same level of scarcity. The damage costs will for example be higher for an individual who spends his/her free time streaming movies, than for an individual going for walks in the forest.
- **Different production functions for industrial consumers**. Different commercial users are, depending on their production function, to a different level dependent on electricity as an input. Also, the extent to which machinery, devices and products can be damaged as a result of a disruption depends on the particular industry or business model.

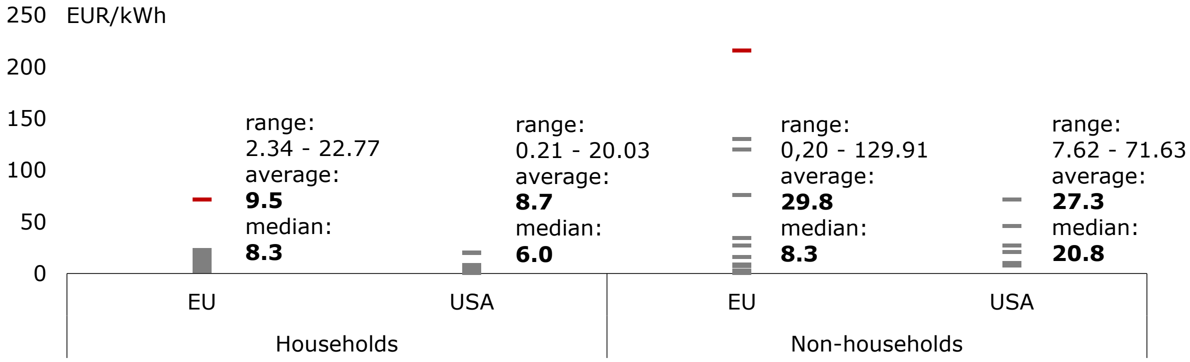
Given this extreme variance in existing estimates, it is impossible to declare a single number as the correct VoLL for Europe. However, looking at the variation in estimates can give an indication of the most likely range of a VoLL for the EU.

15 out of the 16 estimates for the VoLL for households in European Member States lie comparably close to each other, between 2 and 23 EUR per kWh. This range is similar to the US-American estimates, which range between 0.2 and 20 EUR per kWh, see Figure 52. The 16th estimate however is 72 EUR per kWh (marked in red in the figure) and

seems to be a clear outlier. Excluding the outlier results in an average household VoLL of 9 EUR per kWh, and a median of 8 EUR per kWh.

The estimates for non-households show a larger variance, probably partly due to the large differences in different industries' dependency on electricity. Also, the estimates for the USA vary more for commercial than for private consumers. The estimates for European Member States range from 0.2 EUR per kWh to 216 EUR per kWh, the latter value clearly seeming to be an outlier (marked in red in the figure). Removing that outlier results in a range of 0.2 to 130 EUR per kWh, with an average of 30 EUR per kWh and a median of 8 EUR per kWh. This range seems reasonable when comparing to the USA. The lowest value of 0.2 EUR per kWh seems implausibly low, but is a lower boundary of a study for Cyprus, and enters the calculations together with the study's upper boundary of 120 EUR per kWh. The average and median values are therefore not downward-biased from that study.

Figure 52 : Variation in the estimates for the Value of Lost Load (VoLL), 2010 prices



Note: all estimates in 2010 prices. The two outliers marked in red are not included in the range, average and median.

Source: Copenhagen Economics based on Table 14 above.

To get an idea of how much socio-economic harm disruptions do to different countries, the overall estimates can be adjusted for the 28 Member States of the EU.

For households, the GDP per capita is a suitable distribution key for the VoLL. For non-households, we suggest a distribution key based on the value added per consumed unit of electricity, see Table 16.

This indicator itself can be interpreted as a very simplistic macroeconomic estimate for the VoLL for non-households, as it reflects how much value creation will not be possible per non-supplied kWh (assuming that all economic activity ceases without power). The range of this simplistic non-households VoLL is from 2 EUR per kWh for Bulgaria to 14 EUR per kWh for Ireland (2015 prices). This range is in line with the lower part of the variance in Table 15. It does, however, only capture the average costs due to non-production, not the costs due to damaged products or machinery; those estimates should therefore rather be interpreted as the lower boundary.

As the starting point to be adjusted for country differences, one could either use the average or the median of the VoLL estimates. For private consumers, average and median are very close to each other (9 and 8 EUR/kWh). For commercial consumers, the average is significantly higher than the median (30 and 8 EUR/kWh). We will use the average VoLL for two reasons: firstly, a comparison with the US estimates, which have an average of 21 EUR/kWh and a median of 27 EUR/kWh, suggests that the EU-median of non-household VoLL might be too low. Secondly, the VoLL for industrial and commercial consumers tends to be considerably higher than for private users according to the literature (e.g. Schröder 2015), suggesting that the average is more reasonable.

The two VoLL averages are based on studies for 9 different Member States (Austria, Cyprus, Germany, Ireland, Italy, the Netherlands, Spain, Sweden and the UK). To make the averages suitable for taking them as a starting point on EU-level, they are adjusted to 2016 prices and scaled based on the average "key" of the 9 countries, see Table 15.

Table 15 : Scaling the average VoLL estimates toward an EU28 estimate

	VoLL average from studies [EUR/kWh, 2010 prices]	**VoLL average from studies [EUR/kWh, 2016 prices]**	**Average index of countries with studies (EU28=100)**	**VoLL scaled to the EU28 average [EUR/kWh]**
Households	9	10	129	**8**
Non-households	30	32	123	**26**

Note: The conversion from 2010 to 2016 prices has been made based on the average inflation rate of the 9 countries with studies. The average index of countries with studies shows a simple average of the indexes of the 9 countries with studies. The table shows rounded values.

Source: Copenhagen Economics calculation based on Eurostat inflation data.

The scaling results in an EU-level VoLL estimate for households of 8 EUR per non-supplied kWh of electricity, and 26 EUR per kWh for non-households. Those EU28 averages are then adjusted to the 28 Member States using the distribution keys explained above. This adjustment results in a distinct VoLL estimate for households and non-households for each of the Member States, see Table 16.

The Member States' household-VoLL ranges from 2 EUR/kWh (Bulgaria) to 32 EUR/kWh (Luxembourg). The VoLL for commercial consumers ranges from 11 EUR/kWh (Bulgaria) to 67 EUR/kWh (Ireland).

Table 16 : Distribution keys for VoLL estimates across countries

	Households			Non-households		
	GDP per capita (current prices, 2016)	distribution key (EU28=100)	Average VoLL scaled to country (rounded, EUR/kWh)	Value added [EUR] per consumed kWh of electricity	distribution key (EU28=100)	Average VoLL scaled to country (EUR/kWh)
EU-28	29,000	100	**10**	6.79	100	**32**
Austria	40,400	139	**14**	7.01	103	**33**
Belgium	37,400	129	**13**	5.84	86	**28**
Bulgaria	6,800	23	**2**	2.21	33	**11**
Croatia	11,000	38	**4**	4.05	60	**19**
Cyprus	21,300	73	**7**	6.05	89	**28**
Czech Republic	16,700	58	**6**	3.78	56	**18**
Denmark	48,400	167	**17**	11.49	169	**54**
Estonia	16,000	55	**6**	3.44	51	**16**
Finland	39,200	135	**14**	3.14	46	**15**
France	33,300	115	**12**	7.21	106	**34**
Germany	38,100	131	**13**	7.1	105	**34**
Greece	16,300	56	**6**	4.66	69	**22**
Hungary	11,600	40	**4**	3.63	53	**17**
Ireland	58,800	203	**21**	14.15	209	**67**
Italy	27,700	96	**10**	6.71	99	**32**
Latvia	12,700	44	**4**	4.59	68	**22**
Lithuania	13,500	47	**5**	5.02	74	**24**
Luxembourg	90,700	313	**32**	8.87	131	**42**
Malta	22,700	78	**8**	5.59	82	**26**
Netherlands	41,300	142	**14**	7.65	113	**36**
Poland	11,000	38	**4**	3.83	56	**18**
Portugal	17,900	62	**6**	4.63	68	**22**
Romania	8,600	30	**3**	4.54	67	**21**
Slovakia	14,900	51	**5**	3.67	54	**17**
Slovenia	19,600	68	**7**	3.5	52	**17**
Spain	24,100	83	**8**	6.05	89	**28**
Sweden	46,900	162	**16**	4.86	72	**23**
United Kingdom	36,500	126	**13**	11.81	174	**56**

Note: VoLL in 2016 prices. The value added per consumed kWh of electricity for non-households is a weighted average of that indicator for industries and other sectors. The value added per kWh is in 2015 prices.

Source: Copenhagen Economics based on Eurostat data.

An average VoLL per country can be derived from weighting household- and non-household VoLL according to the electricity consumption of those two categories in the respective country, see Table 17.

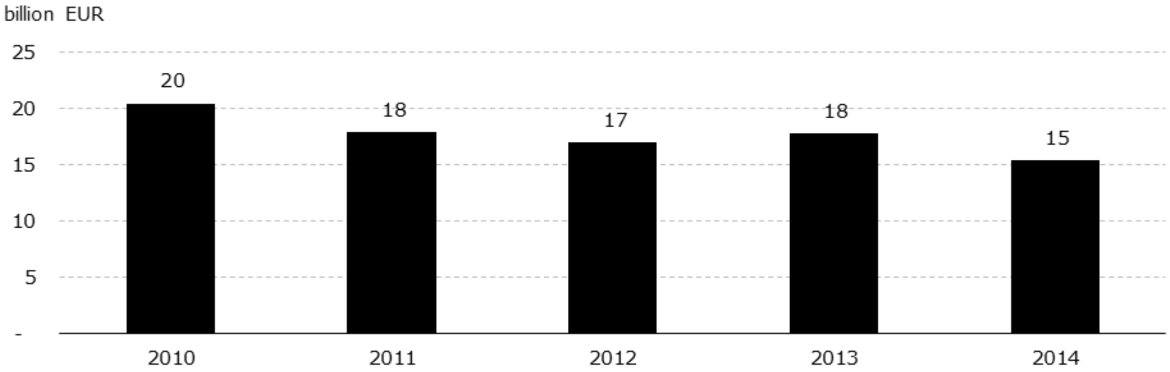
Table 17 : An average VoLL for each of the EU Member States

	Average VoLL scaled to country (EUR/kWh)	Share at total electricity consumption in the country	Average VoLL scaled to country (EUR/kWH)	Share at total electricity consumption in the country	Country-VoLL (weighted average, rounded, 2016 prices)
EU-28	**10**	**29%**	**32**	**71%**	**26**
Austria	14	28%	33	72%	**28**
Belgium	13	23%	28	77%	**24**
Bulgaria	2	38%	11	62%	**7**
Croatia	4	40%	19	60%	**13**
Cyprus	7	37%	28	63%	**21**
Czech Republic	6	26%	18	74%	**15**
Denmark	17	33%	54	67%	**42**
Estonia	6	25%	16	75%	**14**
Finland	14	27%	15	73%	**14**
France	12	36%	34	64%	**26**
Germany	13	25%	34	75%	**29**
Greece	6	35%	22	65%	**16**
Hungary	4	30%	17	70%	**13**
Ireland	21	31%	67	69%	**53**
Italy	10	23%	32	77%	**27**
Latvia	4	27%	22	73%	**17**
Lithuania	5	28%	24	72%	**18**
Luxembourg	32	14%	42	86%	**40**
Malta	8	31%	26	69%	**21**
Netherlands	14	22%	36	78%	**31**
Poland	4	22%	18	78%	**15**
Portugal	6	26%	22	74%	**18**
Romania	3	28%	21	72%	**16**
Slovakia	5	21%	17	79%	**15**
Slovenia	7	25%	17	75%	**14**
Spain	8	30%	28	70%	**22**
Sweden	16	34%	23	66%	**21**
United Kingdom	13	36%	56	64%	**40**

Source: Copenhagen Economics based on Eurostat data.

Combining the average EU VoLL estimate and the rough estimates for electricity non-supplied from output 4 (Figure 42), we can get an overall understanding of how costly disruptions have been to society. Important to note, this analysis combines two very uncertain estimates based on a range of assumptions, and must therefore be interpreted accordingly. The socio-economic cost from disruptions in Europe seems to be around 10 to 25 billion EUR every year, see Figure 53.[61] The true costs to society is the VoLL minus the electricity prices, as consumers do not pay for the electricity they have not been supplied with.

Figure 53 : Rough estimate of the total VoLL in Europe due to disruptions, 2010-2014



Source: Disruptions data based on CEER, VoLL calculations by Copenhagen Economics, based on literature and Eurostat data.

4.4.3 Conclusions

Disruptions are costly to society, as for every disruption, consumers willing to pay the price for electricity do not have the opportunity to consume it. That limits the production of commercial consumers and the use of leisure of private consumers, and can in addition lead to damages of products or machinery. The value of lost load (VoLL) is an estimate for those costs.

The VoLL depends on a wide range of factors. It varies for example depending on the time of day, season and duration of the disruption, as well as with the individual preferences and production functions of the private and commercial consumers affected. The VoLL is moreover typically higher for countries with a high-income level, higher for commercial than for private consumers, and higher for forced than for planned disruptions.

In addition, different methodological methods to measure the VoLL will lead to different results. It is for those reasons very difficult to estimate the VoLL, and existing estimates vary immensely. All estimates, and EU averages in particular, should therefore be considered an approximation rather than the “true” cost to society.

Based on an assessment of existing estimates combined with a well-founded extrapolation, we find that the household-VoLL is around 5-10 EUR/kWh at the European

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[61] Not taking into account potential cost savings from not generating the electricity

average, meaning that a one kWh of non-supplied electricity to an average household in Europe implies costs to that consumer of 5 to 10 EUR. For non-households like industrial or commercial consumers, we find an average VoLL of 20-30 EUR/kWh, which is approximately three times as much as for households.

Those estimates show that the disruptions in Europe in the period 2010 to 2014 gave rise to a socio-economic loss of approximately 10 to 25 billion EUR annually.

5. LIST OF ANNEXES

5.1 Annex 1 – Content of Commission Regulation (EU) 543/2013

Table 18 Content of Regulation 543/2013

Article	Regulation text	Deadline
6.1.A	the total load per market time unit	one hour after the operating period
6.1.B	a day-ahead forecast of the total load per market time unit	two hours before the gate closure
6.1.C	a week-ahead forecast of the total load for every day of the following week, which shall for each day include a maximum and a minimum load value	each Friday no later than two hours before the gate closure of the day-ahead market in the bidding zone
6.1.D	a month-ahead forecast of the total load for every week of the following month, which shall include, for a given week, a maximum and a minimum load value	one week before the delivery month
6.1.E	a year-ahead forecast of the total load for every week of the following year, which shall for a given week include a maximum and a minimum load value	the 15th calendar day of the month before the year to which the data relates
7.1.A	the planned unavailability of 100 MW or more of a consumption unit, including changes of 100 MW or more in the planned unavailability of consumption units, lasting at least one market time unit, specifying: — bidding zone, — available capacity per market time unit during the event, — reason for the unavailability, — the estimated start and end date (day, hour) of the change in availability	one hour after the decision regarding the planned unavailability is made
7.1.B	changes in actual availability of a consumption unit with a power rating of 100 MW or more, specifying: — bidding zone, — available capacity per market time unit during the event, — reason for the unavailability, — the start date and the estimated end date (day, hour) of the change in availability	one hour after the change in actual availability
8.1	the year-ahead forecast margin evaluated at the local market time unit	one week before the yearly capacity allocation but no later than the 15th calendar day of the month before the year to which the data relates.
9.1	information on future changes to network elements and interconnector projects including expansion or dismantling in their transmission grids within the next three years, to the ENTSO for Electricity. This information shall only be given for measures expected to have an impact of at least 100 MW on cross zonal capacity between bidding zones or on profiles at least during one market time unit. The information shall include: (a) the identification of the assets concerned; (b) the location; (c) type of asset; (d) the impact on interconnection capacity per direction between the bidding zones; (e) the estimated date of completion	one week before the yearly capacity allocation but no later than the 15th calendar day of the month before the year to which the allocation relates. The information shall be updated with relevant changes before the end of March, the end of June and the end of September of the year to which the allocation relates.
10.1.A	the planned unavailability, including changes in the planned unavailability of interconnections and in the transmission grid that reduce cross zonal capacities between bidding zones by 100 MW or more during at least one market time unit, specifying: — the identification of the assets concerned, — the location,	one hour after the decision regarding the planned unavailability is made

Article	Regulation text	Deadline
	— the type of asset, — the estimated impact on cross zonal capacity per direction between bidding zones, — reasons for the unavailability, — the estimated start and end date (day, hour) of the change in availability	
10.1.B	changes in the actual availability of interconnections and in the transmission grid that reduce cross zonal capacities between bidding zones by 100 MW or more during at least one market time unit, specifying — the identification of the assets concerned, — the location, — the type of asset, — the estimated impact on cross zonal capacity per direction between bidding zones, — reasons for the unavailability, — the start and estimated end date (day, hour) of the change in availability	one hour after the change in actual availability
10.1.C	changes in the actual availability of off-shore grid infrastructure that reduce wind power feed-in by 100 MW or more during at least one market time unit, specifying — the identification of the assets concerned, — the location, — the type of asset, — the installed wind power generation capacity (MW) connected to the asset, — wind power fed in (MW) at the time of the change in the availability, — reasons for the unavailability, — the start and estimated end date (day, hour) of the change in availability	one hour after the change in actual availability
11.1.A	the forecasted day-ahead transfer capacities per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	-
11.1.A	the forecasted week-ahead transfer capacities per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	each Friday, for all days of the following week
11.1.A	the forecasted month-ahead transfer capacities per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	two working days before the monthly allocation process for all days of the following month
11.1.A	the forecasted year-ahead transfer capacities per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	one week before the yearly allocation process but no later than 15 December, for all months of the following year
11.1.A	the offered intraday transfer capacity per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	one hour before the first intra-day allocation and then real-time, for each market time unit
11.1.A	the offered day-ahead transfer capacity per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	one hour before spot market gate closure, for each market time unit
11.1.A	the offered week-ahead transfer capacity per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	one day before the weekly allocation process
11.1.A	the offered month-ahead transfer capacity per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	two working days before the monthly allocation process
11.1.A	the offered year-ahead transfer capacity per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	one week before the yearly allocation process but no later than 15 December
11.1.A	the offered other transfer capacity per direction between bidding zones in case of coordinated net transmission capacity-based	-

Article	Regulation text	Deadline
	capacity allocation	
11.1.A	the offered day-ahead transfer capacity implicit per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	one hour before spot market gate closure, for each market time unit
11.1.A	the offered intraday transfer capacity implicit per direction between bidding zones in case of coordinated net transmission capacity-based capacity allocation	one hour before the first intra-day allocation and then real-time, for each market time unit
11.1.B	the relevant flow-based parameters in case of flow based capacity allocation	sufficiently in advance of the allocation process
11.3	In relation to direct current links, TSOs shall provide updated information on any restrictions placed on the use of available cross-border capacity including through the application of ramping restrictions or intraday transfer limits	one hour after the information is known to the ENTSO for Electricity
11.4	TSOs or, if applicable, transmission capacity allocators, shall provide a yearly report to the ENTSO for Electricity indicating: (a) the main critical network elements limiting the offered capacity; (b) the control area(s) which the critical network elements belong to; (c) the extent to which relieving the critical network elements would increase the offered capacity; (d) all possible measures that could be implemented to increase the offered capacity, together with their estimated costs. When preparing the report TSOs may choose not to identify the asset concerned and specify its location if it is classified as sensitive critical infrastructure protection related information in their Member States as provided for in point (d) of Article 2 of Directive 2008/114/EC	-
12.1.A	in case of explicit allocations, for every market time unit and per direction between bidding zones: — the capacity (MW) requested by the market — capacity (MW) allocated to the market, — the price of the capacity (Currency/MW), — the auction revenue (in Currency) per border between bidding zones	one hour after each capacity allocation
12.1.B	for every market time unit and per direction between bidding zones the total capacity nominated	two hours after each round of nomination
12.1.C	prior to each capacity allocation the total capacity already allocated through previous allocation procedures per market time unit and per direction	at the latest when publication of offered capacity figures become due as set out in the Annex
12.1.D	for every market time unit the day-ahead prices in each bidding zone (Currency/MWh)	one hour after gate closure
12.1.E	in case of implicit allocations, for every market time unit the net positions of each bidding zone (MW) and the congestion income (in Currency) per border between bidding zones	one hour after each capacity allocation
12.1.F	scheduled day-ahead commercial exchanges in aggregated form between bidding zones per direction and market time unit	one hour after the last cut-off time and, if applicable, shall be updated no later than two hours after each intra-day nomination process
12.1.G	physical flows between bidding zones per market time unit	one hour for each market time unit as closely as possible to real time but no later than one hour after the operational period
12.1.H	cross zonal capacities allocated between bidding zones in Member States and third countries per direction, per allocated product and period.	one hour after the allocation
13.1.A	information relating to redispatching per market time unit,	one hour as soon as possible

Article	Regulation text	Deadline
	specifying: — the action taken (that is to say production increase or decrease, load increase or decrease), — the identification, location and type of network elements concerned by the action, — the reason for the action, — capacity affected by the action taken (MW)	but no later than one hour after the operating period, except for the reasons which shall be published as soon as possible but not later than one day after the operating period
13.1.B	information relating to countertrading per market time unit, specifying: — the action taken (that is to say cross-zonal exchange increase or decrease), — the bidding zones concerned, — the reason for the action, — change in cross-zonal exchange (MW)	one hour as soon as possible but no later than one hour after the operating period, except for the reasons which shall be published as soon as possible but not later than one day after the operating period
13.1.C	the costs incurred in a given month from actions referred to in points (a) and (b) and from any other remedial action	one month after the end of the referred month
14.1.A	the sum of generation capacity (MW) installed for all existing production units equalling to or exceeding 1 MW installed generation capacity, per production type	one week before the end of the year
14.1.B	information about production units (existing and planned) with an installed generation capacity equalling to or exceeding 100 MW. The information shall contain: — the unit name, — the installed generation capacity (MW), — the location, — the voltage connection level, — the bidding zone, — the production type	one week before the end of the year for 3 following years
14.1.C	an estimate of the total scheduled generation (MW) per bidding zone, per each market time unit of the following day	18:00 Brussels time
14.1.D	a forecast of wind and solar power generation (MW) per bidding zone, per each market time unit of the following day	18:00 update at 8:00; The information shall be provided for all bidding zones only in Member States with more than 1% feed-in of wind or solar power generation per year or for bidding zones with more than 5% feed-in of wind or solar power generation per year.
15.1.A	the planned unavailability of 100 MW or more of a generation unit including changes of 100 MW or more in the planned unavailability of that generation unit, expected to last for at least one market time unit up to three years ahead, specifying: — the name of the production unit, — the name of the generation unit, — location, — bidding zone, — installed generation capacity (MW), — the production type, — available capacity during the event, — reason for the unavailability, — start date and estimated end date (day, hour) of the change in availability	one hour after the decision regarding the planned unavailability is made
15.1.B	changes of 100 MW or more in actual availability of a generation unit, expected to last for at least one market time unit, specifying: — the name of the production unit, — the name of the generation unit, — location, — bidding zone,	one hour after the change in actual availability

Article	Regulation text	Deadline
	— installed generation capacity (MW), — the production type, — available capacity during the event, — reason for the unavailability, and — start date and estimated end date (day, hour) of the change in availability	
15.1.C	the planned unavailability of a production unit of 200 MW or more including changes of 100 MW or more in the planned unavailability of that production unit, but not published in accordance with subparagraph (a), expected to last for at least one market time unit up to three years ahead, specifying: — the name of the production unit, — location, — bidding zone, — installed generation capacity (MW), — the production type, — available capacity during the event, — reason for the unavailability, — start date and estimated end date (day, hour) of the change in availability	one hour after the decision regarding the planned unavailability is made
15.1.D	changes of 100 MW or more in actual availability of a production unit with an installed generation capacity of 200 MW or more, but not published in accordance with subparagraph (b), expected to last for at least one market time unit, specifying: — the name of the production unit, — location, — bidding zone, — installed generation capacity (MW), — the production type, — available capacity during the event, — reason for the unavailability, and — start date and estimated end date (day, hour) of the change in availability	one hour after the change in actual availability
16.1.A	actual generation output (MW) per market time unit and per generation unit of 100 MW or more installed generation capacity	five days after the operational period
16.1.B	aggregated generation output per market time unit and per production type	one hour after the operational period
16.1.C	actual or estimated wind and solar power generation (MW) in each bidding zone per market time unit	one hour 16.1.C.: and be updated on the basis of measured values as soon as they become available. The information shall be provided for all bidding zones only in Member States with more than 1% feed-in of wind or solar power generation per year or for bidding zones with more than 5% feed-in of wind or solar power generation per year;
16.1.D	aggregated weekly average filling rate of all water reservoir and hydro storage plants (MWh) per bidding zone including the figure for the same week of the previous year	the third working day following the week to which the information relates. The information shall be provided for all bidding zones only in Member States with more than 10% feed-in of this type of generation per year or for bidding zones with more than 30% feed-in of this type of generation per year.

Article	Regulation text	Deadline
17.1.A	rules on balancing including: — processes for the procurement of different types of balancing reserves and of balancing energy, — the methodology of remuneration for both the provision of reserves and activated energy for balancing, — the methodology for calculating imbalance charges, — if applicable, a description on how cross-border balancing between two or more control areas is carried out and the conditions for generators and load to participate	-
17.1.B	the amount of balancing reserves under contract (MW) by the TSO, specifying: — the source of reserve (generation or load), — the type of reserve (e.g. Frequency Containment Reserve, Frequency Restoration Reserve, Replacement Reserve), — the time period for which the reserves are contracted (e.g. hour, day, week, month, year, etc.)	two hours before the next procurement process takes place
17.1.C	prices paid by the TSO per type of procured balancing reserve and per procurement period (Currency/MW/period)	one hour after the procurement process ends
17.1.D	accepted aggregated offers per balancing time unit, separately for each type of balancing reserve	one hour after the operating period
17.1.E	the amount of activated balancing energy (MW) per balancing time unit and per type of reserve	30 minutes after the operating period. In case the data are preliminary, the figures shall be updated when the data become available
17.1.F	prices paid by the TSO for activated balancing energy per balancing time unit and per type of reserve; price information shall be provided separately for up and down regulation	one hour after the operating period
17.1.G	imbalance prices per balancing time unit	as soon as possible
17.1.H	total imbalance volume per balancing time unit	30 minutes after the operating period. In case the data are preliminary, the figures shall be updated when the data become available
17.1.I	monthly financial balance of the control area, specifying: — the expenses incurred to the TSO for procuring reserves and activating balancing energy, — the net income to the TSO after settling the imbalance accounts with balance responsible parties	three months after the operational month. In case the settlement is preliminary, the figures shall be updated after the final settlement
17.1.J	if applicable, information regarding Cross Control Area Balancing per balancing time unit, specifying: — the volumes of exchanged bids and offers per procurement time unit, — maximum and minimum prices of exchanged bids and offers per procurement time unit, — volume of balancing energy activated in the control areas concerned	one hour after the operating period

5.1 Annex 2 – Overview of data items available on the ENTSO-E TP

Table 19 Overview of data items available on the ENTSO-E TP

Category on TP website	Article in Regulation 543/2013	Data item (49 in total)
Load	6.1.A	Actual Total Load
	6.1.B	Day-ahead Total Load Forecast
	6.1.C	Week-ahead Total Load Forecast
	6.1.D	Month-ahead Total Load Forecast
	6.1.E	Year-ahead Total Load Forecast
	8.1	Year-ahead Forecast Margin
Generation	14.1.A	Installed Generation Capacity Aggregated
	14.1.B	Installed generation capacity per unit
	14.1.C	Day-ahead Aggregated Generation
	14.1.D	Day-ahead Generation Forecasts for Wind and Solar
	16.1.A	Actual Generation per Generation Unit
	16.1.B	Aggregated Generation per Type
	16.1.C	Aggregated Generation per Type
	16.1.D	Aggregate Filling Rate of Water Reservoirs and Hydro Storage Plants
Transmission	9.1	Expansion And Dismantling Projects
	11.1.A	Forecasted/offered Transfer capacities
	11.1.B	Day Ahead Flow Based Allocations
	11.3	Cross-border Capacity for DC Links
	11.4	Yearly Report About Critical Network Elements Limiting Offered Capacities
	12.1.A	Explicit Allocations - Use of the Transfer Capacity
	12.1.B	Total Nominated Capacity
	12.1.C	Total Capacity Already Allocated
	12.1.D	Day-ahead Prices
	12.1.E	Implicit Allocations - Net Positions
	12.1.F	Scheduled Commercial Exchanges
	12.1.G	Physical Flows
	12.1.H	Transfer Capacities Allocated with Third Countries
Balancing	17.1.A	Rules on Balancing
	17.1.B	Amount of Balancing Reserves Under Contract
	17.1.C	Price of Reserved Balancing Reserves
	17.1.D	Accepted Aggregated Offers
	17.1.E	Activated Balancing Energy
	17.1.F	Prices of Activated Balancing Energy
	17.1.G	Imbalance Prices
	17.1.H	Total Imbalance Volumes

Category on TP website	Article in Regulation 543/2013	Data item (49 in total)
	17.1.I	Financial Expenses and Income for Balancing
	17.1.J	Volumes of Exchanged Bids and Offers
Outages	7.1.A	Planned Unavailability of Consumption Units
	7.1.B	Changes in Actual Availability of Consumption Units
	10.1.A	Planned Unavailability in the Transmission Grid
	10.1.B	Changes in Actual Availability in the Transmission Grid
	10.1.C	Changes in Actual Availability of Off-shore Grid Infrastructure
	15.1.A	Planned Unavailability of Generation Units
	15.1.B	Changes in Actual Availability of Generation Units
	15.1.C	Planned Unavailability of Production Units
	15.1.D	Changes in Actual Availability of Production Units
Congestion management	13.1.A	Redispatching
	13.1.B	Countertrading
	13.1.C	Costs of Congestion Management

5.2 Annex 3 – Questionnaire for online user survey (Output 1)

Part I: Introduction

- Which datasets from the Transparency Platform have you used?
- Do you rely on Transparency data to make business decisions?
- What do you use Transparency data for? [Fundamental power system modelling/Econometric analysis/Statistical analysis/Other (write-in)]
- Approximately how frequently do you download data from the Transparency Platform? [Rarely—I do so a couple of times each year/Regularly—I do so a couple of times each month/Frequently—I do so several times each day/Other (write-in)]
- How experienced are you with analysing (downloaded) Transparency Platform data? [Not very—I use the data rarely/Somewhat—I use the data on a monthly basis/Very—I use the data everyday/Other (write-in)]

Part II: Completeness

- Are there missing observations or gaps in the data? [There are many gaps/There are some gaps/There are no gaps/I’m not sure]
- Please specify any incompleteness issues regarding gaps in the data by time series and/or geographic area.
- Are there any types of data not currently available that you would like to see provided on the Transparency Platform?

Part III: Accuracy

- Do you find data on the platform to be accurate (correct)? [Most values seem implausible/Some values seem implausible/Data seems correct/I’m not sure]
- Please specify any inaccuracies and to which data they are related.
- Do you find Transparency Platform data to be inconsistent with other sources? If so, which data and which other sources?

Part IV: Timeliness

- Within what timeframe do you need electricity market data? [Intraday/Within one week/Within one month/Other (write-in)]
- Do you find data on the platform to be available when you need it? [Data is rarely available when I need it/Data is usually available when I need it/Data is always available when I need it/I’m not sure]
- Please specify any timeliness issues and to which data they are related.
- Are historical data being updated with more recent data?
- Are data updated in a way such that useful legacy data are overwritten?
- Please specify any issues with updates and to which data they are related.

Part V: User friendliness

- Is finding data on the Platform unintuitive or intuitive [scale of 1–5]?
- Do you have any suggestions for making the Platform more user friendly?
- Do you find server response waiting times to be slow or fast [scale of 1–5]?
- Are you aware of the following options for accessing data (Website GUI, FTP server, Restful API, Data repository, Subscriptions, Web services, ECP)? [Not aware of/Aware of but have not used/Have used]
- Why did you choose your current method of accessing the data? [Only option I was aware of/Other (write-in)]
- Please rate the usefulness of the following methods for accessing data: website GUI, FTP server, Restful API [scale of 1–5].
- Linked here is the data documentation. Were you already aware of this documentation?
- Do you find the documentation to be of sufficient quality?
- Is there something missing from the data documentation?
- Are you aware of the data licence for information obtained from the Platform?
- Has data licensing prevented you from using the data for any purpose?

Part VI: Wrapping up

- What suggestions do you have for Neon regarding improving the Platform?
- Any additional comments or concerns?
- How experienced would you consider yourself in using the Transparency Platform? Limited experience or expert [scale of 1–5]?
- Do you have any suggestions of other Platform users who might be interested in joining us for an interview?
- Type of institution [Research/Consulting/Industry/NGO or journalism/Other (write-in)]

5.3 Annex 4 - Survey questionnaire for Output 3 (with electricity producers and TSOs)

Dear Sir or Madam,

The Directorate-General for Energy of the European Commission has mandated VVA Consulting, Copenhagen Economics and Deloitte Consulting to carry out a study on the quality of electricity market data of transmission system operators, electricity supply disruptions, and their impact on the European electricity markets. As part of the study, the evaluation team seeks to gather **data on outages of generation units** by Member State and generation technology **for the period 2010-2016**.

We have downloaded all the data available on the unavailability of production and generation units on the **ENTSO-E Transparency Platform**, where we have identified a number of data gaps. For the purposes of the study, we would like to know if you have stored historical data and are in a position to provide detailed data on the most relevant variables for each outage, namely:

- Information on plants (name, location);
- Nature (planned or unplanned);
- Cause(s)
- Length in time;
- Reduction of the availability capacity (in MW);
- Amount of non-generated electricity (in MWh).

If you do not have such data, we would greatly appreciate it if you could answer the following four high-level questions:

1) What is the share of planned outages in total outages in your Member State? (in %, 2010-2016 on a yearly basis)
2) What is the share of unplanned outages in total outages in your Member State? (in %, 2010-2016 on a yearly basis)
3) Did any of these outages lead to supply disruption events? If yes, could you please provide further information on their date, length, the reduction of available capacity and the amount of non-generated electricity?
4) Are you aware of any case where a malicious attack caused an outage in a generation unit?

5.4 Annex 5 – Survey questionnaire for Output 4 (with national regulators and TSOs)

Dear Sir or Madam,

The European Commission mandated VVA Consulting, Copenhagen Economics and Deloitte to carry out a study on the quality of electricity market data of transmission system operators, electricity supply disruptions, and their impact on the European electricity markets. As part of the study, this survey aims at gathering data on electricity supply disruptions in each Member State on a monthly basis for the period 2010-2016.

We have downloaded all the electricity supply disruption data available in the ENTSO-E Monthly Reports and from the CEER Benchmarking reports. We would like to ask you to take part in the following survey to close the relevant data gaps identified on the extent and sources of electricity supply disruptions in Europe.

Survey questions

The first part of the survey questions will focus on the macro-level with questions on the overall number of supply disruptions and the causes for these disruptions. We would be very grateful if you could answer those questions in priority.

The second part of the survey will ask questions at the micro-level to have more information on the specific supply disruption events.

Part 1: Macro-level questions

Introduction:

Disruptions are the focus of this survey. A "disruption" of power supply can occur at the level of a line, a transformer station or a substation. In the case of a disruption, a certain amount of energy will be unavailable during a period. A disruption can lead in some cases to a brownout and impact the amount of energy supplied to consumers.

In some questions, we will ask about outages. An "outage" can occur at the level of the electricity generation or the production plants. The outage can be either planned (e.g. maintenance) or unplanned (e.g. weather conditions) and will cause a loss of power, leading in some cases to disruptions.

- Country / area of operation
- Over the period of 2010 to 2016, what was the System Average Interruption Duration Index (SAIDI) (monthly figures, if possible)?
- Over the period of 2010 to 2016, what was the System Average Interruption Frequency Index (SAIFI) (monthly figures, if possible)?
- Over the period of 2010 to 2016, what were the most frequent reasons for supply disruptions?
- Over the period of 2010 to 2016, were any significant supply disruption events caused by malicious attacks?
- Over the period of 2010 to 2016, at which infrastructure level did significant disruptions events occur more frequently: TSO- or DSO-level?

  - At TSO-level, most frequently in (a) electric cables/lines, (b) transformer stations or (c) interconnectors?
  - At DSO-level, most frequently in (a) electric cables/lines or (b) transformer stations?
- Over the period of 2010 to 2016, were some of the significant supply disruption events linked to outages in the electricity generation/production plants (i.e. lack of power)? If yes, how often did that happen?

Part 2: Questions on specific disruption events

- Over the period of 2010 to 2016, what where the 10 most significant supply disruptions in your area of operation? For each of the disruptions, please provide:
  - start and end date (dd/mm/yyyy, hh:mm)
  - duration
  - infrastructure elements (cable/line, interconnector, transformer station)
  - cause (natural hazard, lack of power, …)
  - reduction in available capacity (MW)
  - non-transferred electricity (MWh)
  - did the disruption lead to a brownout, i.e. were consumers out of power? (yes/no)
  - electricity non-supplied to consumers (MWh)

5.5 Annex 6 –Survey questionnaire for Output 5 (with TSOs)

Dear Sir or Madam

The European Commission mandated VVA Consulting, Copenhagen Economics and Deloitte to carry out a study on the quality of electricity market data of transmission system operators, electricity supply disruptions, and their impact on the European electricity markets. As part of the study, this survey aims to gather data on voluntary demand curtailment mechanisms and their use in case of significant electricity supply disruptions in the 28 Member State during the period 2010-2016.

Survey:

We would like to know whether voluntary demand curtailment mechanisms are in place in your country, and in particular whether they have been used in cases of significant supply disruptions, meaning when electricity demand exceeded supply and when consumers were inevitably going to be cut out of power. We are therefore focusing on voluntary demand curtailment agreements but not on price-based demand response in the balancing market.

Questionnaire A: Questions for the TSOs of Belgium, Ireland, Finland, France, Germany, Great Britain, Greece, Italy, Netherlands, Poland, Portugal, Spain (where we have pre-identified voluntary demand curtailment mechanisms)

During our initial desk research, we have found that such voluntary demand curtailment mechanisms exist in your country.

1. Which are the main types of electricity consumers involved in these voluntary demand curtailment agreements?
2. How often and when have such voluntary demand curtailment mechanisms been activated during significant electricity supply disruptions since 2010?
3. Do you consider that such voluntary demand curtailments are effective to prevent or reduce electricity supply disruptions? How much energy has been delivered to other consumers as a result of voluntary demand curtailment avoiding a brownout?
4. Do you plan to increase the part of voluntary demand curtailment mechanisms in the future as part of your business plan, or if not in place yet, do you plan to introduce such mechanisms?

Questionnaire B: Questions for all other TSOs

1. Have such voluntary demand curtailment mechanisms been in place in your country in the 2010-2016 period to deal with significant supply disruptions where consumers would need to be curtailed anyway?
2. If yes, which are the main types of electricity consumers involved in these voluntary demand curtailment agreements?
3. How often and when have such voluntary demand curtailment mechanisms been activated during significant electricity supply disruptions since 2010?

4. Do you consider that such voluntary demand curtailments are effective to prevent or reduce electricity supply disruptions? How much energy has been delivered to other consumers as a result of voluntary demand curtailment avoiding a brownout?
5. Do you plan to increase the part of voluntary demand curtailment mechanisms in the future as part of your business plan, or if not in place yet, do you plan to introduce such mechanisms?

5.6 Annex 7 - List of stakeholders

Table 20 : List of stakeholders interviewed for Output 1

Name	Institution	Sector
Jan Abrell	ETH Zürich	Academia
Lissy Langer	TU Berlin	Academia
Jens Weibezahn	TU Berlin	Academia
Florian Ziel	University Duisburg-Essen	Academia
Lothar Rausch	Öko-Institut	Consulting
Paul-Frederik Bach	Freelance consultant	Consulting
Philip Hewitt	EnAppSys	Data service provider
Olivier Corradi	Tomorrow	Data service provider
Talia Parisi	Genscape	Data service provider
Ralf Uttich	RWE	Industry
Christian Bärwolf	LEAG	Industry
Jens Wimschulte	Vattenfall	Industry
Chris Münster	Vattenfall	Industry
Tobias Schulz	Vattenfall	Industry
Sigurd Pedersen	DONG Energy	Industry
Dave Jones	Sandbag	NGO
Antonella Battaglini	Renewables Grid Initiative	NGO
Thorsten Lenck	Agora Energiewende	NGO
Mara Marthe Kleiner	Agora Energiewende	NGO
Rafael Muruais-Garcia	ACER	Policy
Marcus Mittendorf	EEX	Power exchange & data service provider
Katrin Petri	EEX	Power exchange & data service provider
Filippo Pirovano	EDF Trading	Trading

Table 21 : List of stakeholders responding to the survey of Output 1 who provided biographical information

Country	Institution	Type of Institution	Number of stakeholders
BE Belgium	ENGIE	Industry	2
CH Switzerland	Universität Basel	Academic	1
DE Germany	50Hertz	Industry	1
	Agora Energiewende	NGO	1
	Frankfurt Institute for Advanced Studies	Research	2
	Fraunhofer IWES	Research	1
	Hochschule Niederrhein	Academic	1
	Öko-Institut	Consulting	1
	Technische Universität Berlin	Academic	3
	Technische Universität Dresden	Academic	1
	Universität Duisburg-Essen	Academic	2
	Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg	Research	1
	ZNES Flensburg	Research	1
DK Denmark	Danmarks Tekniske Universitet	Academic	1
	Dansk Energi	Interest organisation	1
	Ea Energianalyse	Consulting	1
	Independent consultant	Consulting	1
FI Finland	UPM Energy	Industry	1
FR France	EDF Energy	Industry	3
IE Ireland	The Economic and Social Research Institute	Research	1
	University College Cork	Academic	1
IT Italy	University of Rome	Academic	1
NL Netherlands	Delft University of Technology	Academic	1
Other	European Commission	Government	1
	TrailStone Group	Industry	1

Table 22 : List of stakeholders contacted for the survey of Outputs 3, 4, 5

Country	Main electricity producers	National regulators	TSOs	Main DSOs
AT Austria	Verbund AG	Energie Control Austria (E-Control)	Austrian Power Grid AG (APG) Vorarlberger Übertragungsnetz GmbH (VUEN)	Energienetze Steiermark GmbH (Energienetze Steiermark) Netz Niederösterreich GmbH (NÖ Netz)
BE Belgium	Electrabel	Commission de Régulation de l'Electricité et du Gaz (CREG)	Elia System Operator SA (Elia)	ORES, Tecteo (Resa), Régie de Wavre, AIESH and AIEG in Wallonia Sibelga in the Brussels-Capital Region Eandis and Infrax in Flanders
BG Bulgaria	Natsionalna Elektricheska Kompania EAD (NEK)	State Energy & Water Regulatory Commission (SEWRC)	Electroenergien Sistemen Operator EAD (ESO)	CEZ EVN Energo-Pro
CY Cyprus	Electricity Authority of Cyprus	Cyprus Energy Regulatory Authority (CERA)	Cyprus Transmission System Operator (Cyprus TSO)	Electricity Authority of Cyprus (EAC)
CZ Czech Republic	CEZ.a.s	Energetický Regulační Úřad (ERÚ) / Energy Regulatory Office (ERO)	ČEPS a.s. (ČEPS)	CEZ.a.s PRE.a.s
DE Germany	EnBW, E.On	Federal Network Agency for Electricity, Gas, Telecommunications, Posts and Railway (Bundesnetzagentur - BNetzA)	TransnetBW GmbH (TransnetBW) TenneT TSO GmbH (TenneT DE) Amprion GmbH (Amprion)	RWE E. ON SE

Country	Main electricity producers	National regulators	TSOs	Main DSOs
			50Hertz Transmission GmbH (50Hertz)	
DK Denmark	DONG Energy	Energitilsynet - Danish Energy Regulatory Authority (DERA)	Energinet.dk (Energinet.dk)	Dansk Energi
EE Estonia	Eesti Energia AS		Elering AS (Elering AS)	Elektrilevi OÜ
EL Greece	Public Power Corporation S.A.	Ρυθμιστική Αρχή Ενέργειας / Regulatory Authority for Energy (PAE / RAE)	Independent Power Transmission Operator S.A. (IPTO)	DEDDIE Hedno.s.a
ES Spain	Endesa	Agencija za energijo / Energy Agency	Red Eléctrica de España S.A. (REE)	Iberdola
FI Finland	Fortum, Pohjolan Voima	Energiavirasto - Energy Authority	Fingrid Oyj (Fingrid)	Energia
FR France	EDF	Commission de Régulation de l'Énergie (CRE)	Réseau de Transport d'Electricité (RTE)	Enedis
GB United Kingdom	EDF Energy, Scottish and Southern Energy plc	Office of Gas and Electricity Markets (Ofgem)	National Grid Electricity Transmission plc (National Grid) System Operator for Northern Ireland Ltd (SONI) Scottish Hydro Electric Transmission plc (SHE Transmission) Scottish Power Transmission plc (SPTransmission)	Energy Networks
HR Croatia	HEP Group	Hrvatska energetska regulatorna agencija (HERA)	HOPS d.o.o. (HOPS)	HEP ODS
HU Hungary	MVM Hungarian Electricity Ltd.	Magyar Energetikai és Közmű-szabályozási Hivatal (MEKH)	MAVIR Magyar Villamosenergia-ipari Átviteli Rendszerirányító Zártkörűen	ELMU Net Ltd EMASZ Net Ltd

Country	Main electricity producers	National regulators	TSOs	Main DSOs
			Működő Részvénytársaság (MAVIR ZRt.)	
IE Ireland	ESB Group	Commission for Energy Regulation (CER)	EirGrid plc (EirGrid)	ESB Networks
IT Italy	Enel	Autorità per l'Energia Elettrica e il Gas (AEEG)	Terna - Rete Elettrica Nazionale SpA (Terna)	ENEL Distribuzione
LT Lithuania	Lietuvos Energijos Gamyba	Valstybinė kainų ir energetikos kontrolės komisija / National Control Commission for Prices and Energy (NCC)	Litgrid AB (Litgrid)	AB LESTO
LU Luxembourg	Enovos	Institut Luxembourgeois de Régulation (ILR)	Creos Luxembourg S.A. (Creos Luxembourg)	Creos Luxembourg
LV Latvia	Latvenergo AS	Sabiedrisko pakalpojumu regulēšanas komisija/ Public Utilities Commission (PUC)	AS Augstsprieguma tīkls (Augstsprieguma tīkls)	Sadales tīkls AS
NL Netherlands	Essent NV	Autoriteit Consument & Markt (ACM)	TenneT TSO B.V. (TenneT NL)	Enexis
PL Poland	Polska Grupa Energetyczna	Urząd Regulacji Energetyki / Energy Regulatory Office (URE / ERO)	Polskie Sieci Elektroenergetyczne S.A. (PSE S.A.)	GKPGE
PT Portugal	EDP - Energias de Portugal, S.A.	Entidade Reguladora dos Serviços Energéticos / Energy Services Regulatory Authority (ERSE)	Rede Eléctrica Nacional, S.A. (REN)	EDP Distribuiçao,Energia S.A
RO Romania	Electrocentrale Bucharest	Antoritatea Naţională de Reglementare în domeniul Energiei / Romanian Energy Regulatory Authority (ANRE)	C.N. Transelectrica S.A. (Transelectrica)	ENEL Romania
SE Sweden	Vattenfall AB	Energimarknadsinspektionen / Swedish Energy Markets Inspectorate (EI)	Svenska kraftnät (SVENSKA KRAFTNÄT)	Vattenfall AB
SI Slovenia	Holding Slovenske Elektrarne (HSE)	Agencija za energijo / Energy Agency	ELES, d.o.o. (ELES)	SODO d.o.o
SK Slovak Republic	Slovenské elektrárne	Úrad pre reguláciu sieťových odvetví (URSO) /	Slovenská elektrizačná prenosová sústava, a.s.	ZSE (West)

Country	Main electricity producers	National regulators	TSOs	Main DSOs
		Regulatory Office for Network Industries (RONI)	(SEPS)	SSE (Central) VSE (East)

5.7 Annex 8 – List of literature

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