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How much Electricity do we Consume? A Guide to German and European Electricity Consumption and Generation Data

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Summary

Accurate information about electricity generation and consumption is crucial to power system modelling. Several institutions publish such data: for European countries these include the association of system operators *ENTSO-E*, the EU body *Eurostat*, and the *International Energy Agency;* for Germany they comprise the sector organisation *BDEW*, the federal statistical office *Statistisches Bundesamt*, the working group *AG Energiebilanzen*, and the four transmission system operators. This paper compares the terminology, methodology, and reported data of these sources, finding inconsistencies at all three levels. For example, annual electricity generation from wind and solar power in Germany differs by as much as 10% – 20%, depending on who you ask. ENTSO-E publishes "hourly load", which is widely used among power system modellers. The data documentation provides a (constant) "representativity factor" that should be used to scale the hourly load values. However, we find that the scaling factor, when derived from ENTSO-E's own more comprehensive data sources ("monthly consumption"), is neither the one provided, nor is it constant. The deviation is particularly worrying in Germany, where peak electricity demand might be underestimated by up to a quarter, and so we propose a scaling procedure that avoids such bias.

Keywords: Power system data, Power market modelling

JEL Classification: L94, C63

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How much electricity do we consume?

A guide to German and European electricity consumption and generation data

– August 2015 –

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Highlights

- Power consumption data is crucial to energy system analysis.
- We review various sources of German and European electricity data.
- Inconsistency in terminology, methodology, and data are reported.
- In some case, instantaneous consumption might be underestimated by a quarter.
- We propose a scale procedure to correct for biases.

Abstract – Accurate information about electricity generation and consumption is crucial to power system modelling. Several institutions publish such data: for European countries these include the association of system operators *ENTSO-E*, the EU body *Eurostat*, and the *International Energy Agency;* for Germany they comprise the sector organisation *BDEW*, the federal statistical office *Statistisches Bundesamt*, the working group *AG Energiebilanzen*, and the four transmission system operators. This paper compares the terminology, methodology, and reported data of these sources, finding inconsistencies at all three levels. For example, annual electricity generation from wind and solar power in Germany differs by as much as 10% – 20%, depending on who you ask. ENTSO-E publishes "hourly load", which is widely used among power system modellers. The data documentation provides a (constant) "representativity factor" that should be used to scale the hourly load values. However, we find that the scaling factor, when derived from ENTSO-E's own more comprehensive data sources ("monthly consumption"), is neither the one provided, nor is it constant. The deviation is particularly worrying in Germany, where peak electricity demand might be underestimated by up to a quarter, and so we propose a scaling procedure that avoids such bias.

Key words – power system data, power market modelling

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1 Introduction

Data for electricity consumption and production (e.g., wind and solar power generation) are crucial input parameters for most quantitative analyses of power systems, including power system modelling. Because of the peculiar nature of electricity as an economic good (Hirth et al. 2016), high-frequency data, such as consumption and production hour-by-hour, is as interesting as annual data. This paper assesses and compares datasets from various German and European data sources in order to improve the quality of analyses.

We compare statistical publications from seven institutions:

1. Eurostat
2. International Energy Agency (IEA)
3. European Network of Transmission System Operators for Electricity (ENTSO-E)
4. AG Energiebilanzen
5. Bundesverband der Energie- und Wasserwirtschaft (BDEW)
6. German Federal Statistical Office (Statistisches Bundesamt, StatBA)
7. The four German Transmission System Operators (TSOs)

The first three institutions publish data for most European countries; for the analysis, we focus on Spain, Poland, the Netherlands, and France. The last five institutions publish data for Germany. For this article, we reviewed all public data documentation we could find, and interviewed a number of those experts who prepare the published statistics.

An important source of European hourly electricity consumption data is the "hourly load" published by the European Network of Transmission System Operators for Electricity (ENTSO-E). This dataset is available at no cost, published in machine-readable file formats, and covers most European power system. Many modellers use these data as model inputs, assuming the figures represent electricity consumption.[2] However, from the accompanying documents, it is not clear exactly what these values do represent. For example, it is not clear the extent to which grid losses, industrial auto-generation, small-scale decentralized power production, and electricity consumption in the railway sector are included. ENTSO-E provides a constant, country-specific coverage factor ("representativity factor") in the accompanying documentation. However, when comparing these hourly values with other data sources, including ENTSO-E's own "detailed monthly consumption", we find strong deviations. Take the example of Germany: ENTSO-E states that hourly values cover around 91% of total load, suggesting they should be scaled up by 10%.[3] In fact, we find that they should be scaled up by 22% on average for the period 2006-13, with a minimum of 12% in September 2010 and a maximum of 38% in March 2013. The mismatch is particularly large during the winter, i.e. at peak demand. Consequently, generation adequacy assessments that rely on "hourly load" might dramatically underestimate power demand in critical periods: in March 2013, even after accounting for ENTSO-E's "representativity factor", data should be scaled up by a further 25%.

We also collect and compare wind and solar generation data from four different German sources. This reveals that the data sources vary by about 10% over a year for both technologies. In absolute terms, this corresponds to several terawatt-hours.

Section 2 clarifies terminology and data collect points throughout the power system. Section 3 traces the process of gathering, estimating, processing, and publishing data through various institutions.

[2] In our own research, based on the open-source power market model model EMMA, we have done so (Hirth, 2013; Hirth, 2015; Hirth, et al., 2013; Hirth, et al., 2015).

[3] In ENTSO-E terminology, a "representativity factor" of 0.91 applies, which is the invers of a scaling factor. Hence, the German scaling factor is 1/0.91=1.1.

Section 4 presents a quantitative analysis of the collected data while Section 5 provides a "modeller's guide" with a step-by-step proposal of how to derive hourly data for German consumption, network losses, and solar generation. Section 6 concludes.

2 Power System & Terminology

Determining the annual electricity consumption (or production) of a country is a surprisingly non-trivial task. At least three properties of power systems make this particularly challenging:

- A very large number of physical connection points link consumers to the grid. In Germany, there are more than 45 million[4] connection points. Other energy carriers are less onerous to measure: there are only 14.000[5] gas stations that distribute gasoline and diesel. While large connection points (of power plants and industrial consumers) are measured for each quarter-hour, points that connect households and small services are only measured annually, or even less frequently – simply because the measurement costs of this vast number of connection points would be too great.
- The number of companies that are active in the field is very large, at least in some countries. In Germany, there are four transmission system operators and 880[6] distribution system operators, whereas in Poland, there is only one of each.
- Some actors simultaneously produce and consume within their proprietary sub-grid. This is the case for industrial auto-producers (large industry with its own power plants), but also decentralized households, other services with "plug and play" solar photovoltaics, and for some parts of the railway system. The production and consumption of these auto-producers represent the two major unknown variables in electricity data, since there are only estimates[7], rather than measurements, of this data. This has been especially the case since the EEG feed-in tariff for PV systems dropped below the electricity consumer price; only the electricity in excess of the household's needs is fed into the distribution grid (Weniger, 2015).

Figure 1 shows a schematic structure of the electricity system and its physical flows.

[4] https://www.bdew.de/internet.nsf/id/DE_Energiedaten?open

[5] http://www.mwv.de/index.php/daten/statistikenpreise/?loc=15

[6] The Federal German Grid Authority (Bundesnetzagentur, BNetzA) publishes a complete list of all grid operators on: http://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/DatenaustauschundMonitoring/UnternehmensStammdaten/UebersichtStromUndGasNetzbetreiber/UebersichtStromUndGasnetzbetreiber_node.html

[7] BDEW tries to estimate the magnitude of industrial auto-generation by analysing information that it gets from the "Association of the Industrial Energy- and Power Industry" (Verein der Industriellen Energie- und Kraftwirtschaft, VIK) (BDEW, 2015b).

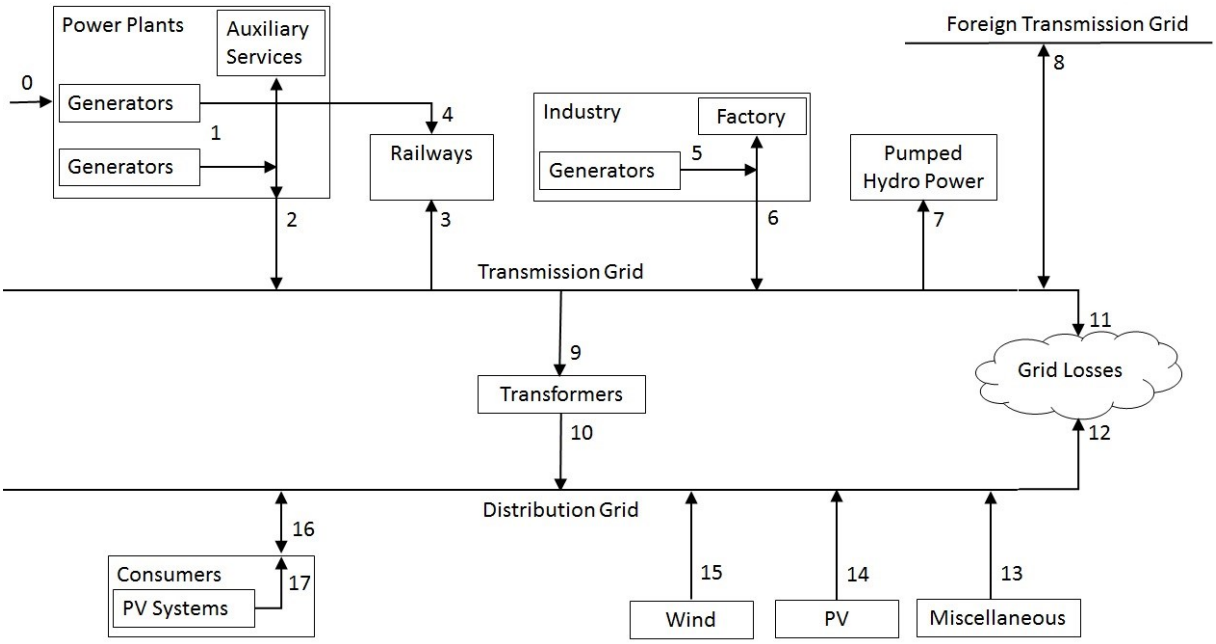

Figure 1: Schematic Structure of the Electricity System *[source: own representation]*

The numbers represent points in the system where measurements can be conducted. It is important to note that this does not mean that measurements are conducted at these points. Table 1 gives a definition of the points in the schematic structure of the electricity system.

Table 1: Definition of Points in Schematic Structure of the Electricity System *source: [own representation]*

Number	Definition
0	Energy of the energy source used to generate electricity
1	Electricity at the connection point of the generator of the power plant
1 – 0	Generator losses
2	Electricity at the bus bar of a power plant
2 – 1	Electricity which is used for auxiliary services
3	Traction power which is supplied by the transmission grid
4	Traction power which is supplied by own generators
5	Electricity at the connection point of a non-electric industry generator
6	Balance of auto-generation and consumption on non-electric industry
5 – 6	Industrial auto-generation
7	Balance of electricity feed-in in out-take of large-scale hydro power plants
8	Balance of electricity imports and exports
9	Electricity before transformation at high voltage level
10	Electricity after transformation at lower voltage level
10 – 9	Transformation losses
11	Grid losses of transmission grid
12	Grid losses of distribution grid
11 + 12	Total grid losses
13	Feed-in of miscellaneous small-scale power generators (hydropower, biomass, etc.)
14	Feed-in of utility scale PV power plants
15	Feed-in of wind power

16	Electricity at the grid connection point of consumers
17	Production of roof-top PV power systems
17 – 16	Household auto-generation

Every physical grid connection point in Germany is assigned to a portfolio of generators and/or loads, which are managed by "Balance Responsible Parties" (BRPs) (Hirth, et al., 2015). Every BRP is assigned to a balancing group, which is coordinated by a "Balancing Group Coordinator" (BGC). In Germany, the TSOs act as BGCs. In order to coordinate the portfolios, the BGC receives the BRPs load forecasts one day in advance and measured load schedules ex post. All processes concerning balancing portfolios and all communication between BRPs and BGCs are regulated by the "Accounting Rules for the German Electricity System" (Marktregeln für die Durchführung der Bilanzkreisabrechnung Strom, MaBiS) (Reuschel, 2013).

Based on Figure 1 and Table 1 one could expect a common terminology to exist for electricity datasets. Indeed, ENTSO-E freely publishes a comprehensive glossary online with definitions and their sources[8]. However, there is no obligation to use these definitions. One might think that "hourly load" and "monthly consumption", both published by ENTSO-E would be identical (in monthly sums, of course), but in fact they are not. "Hourly load" is based on load calculation, while, in contrast, "detailed monthly consumption" is based on generation calculation. Furthermore, data published by StatBA called "Nettostromverbrauch" does not include electricity generation from Wind or PV systems. In contrast, data published by BDEW called "Nettostromverbrauch" includes Wind and PV systems as well industrial auto-generation. A list of synonyms and antonyms can be found in the appendix.

3 Data Collection and Processing

Various institutions publish electricity consumption and production data: German data are published by the sector organisation *BDEW*, the statistical office *Statistisches Bundesamt*, the working group *AG Energiebilanzen*, and the four transmission system operators. Three institutions publish country-level data for Europe: the industry organisation *ENTSO-E*, the EU body *Eurostat*, and the *International Energy Agency*.

Rather than directly gathering data, most of these institutions process information collected or estimated elsewhere. This section traces the process from primary data collection to publication. International organizations usually publish "official" or "national" data. Sometimes however, as in the case of Germany, more than one institution claims this status (StatBA and AG Energiebilanzen) so this does not necessarily mean that data has the same source. Finally, due to revisions and updates, the specific publication data is important.

3.1 Germany

This section traces the winding paths that data take through various German institutions from collection to publication. Given that there are 4 TSOs and 880 DSOs in Germany, it is likely to be the European country with the most complex data reporting process and the largest number of actors involved.

[8] https://emr.entsoe.eu/glossary/bin/view/GlossaryCode/GlossaryIndex

3.1.1 Publications

Table 2 lists various sources with their datasets, the granularity (temporal resolution) of the published data, and the URL of the publication. Some data sources (e.g. AG Energiebilanzen) publish preliminary datasets more frequently than listed in Table 2.

Table 2: Overview of published Electricity Data sources for Germany *source: [own representation]*

Institution	Name of dataset	Granularity	URL
AG Energiebilanzen	Energiebilanz der Bundesrepublik Deutschland	yearly	http://www.ag-energiebilanzen.de/7-0-Bilanzen-1990-2013.html
BDEW	Strom-Kennzahlen	monthly	https://www.bdew.de/internet.nsf/id/strom-de
ENTSO-E	Country Package	hourly	https://www.entsoe.eu/db-query/country-packages/production-consumption-exchange-package
Eurostat	Energy statistics (nrg_10m)	monthly	http://ec.europa.eu/eurostat/data/database
IEA	Monthly Electricity Statistics	monthly	http://www.iea.org/statistics/relatedsurveys/monthlyelectricitysurvey/
StatBA	Monatsbericht über die Elektrizitätsversorgung	monthly	https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/Energie/Erzeugung/Tabellen/TabelleStrom.html
50hertz		hourly	http://www.50hertz.com/de/Kennzahlen
Amprion		hourly	http://amprion.de/netzkennzahlen
Tennet		hourly	http://www.tennettso.de/site/Transparenz/veroeffentlichungen/netzkennzahlen
TransnetBW		hourly	https://www.transnetbw.com/en/key-figures/load-data/total-load

3.1.2 Processing and Reporting of German Data

Only three types of institution collect primary data: power plant operators, DSOs, and TSOs. Besides these measured data sources, there are several sources of simulated (estimated) data: Öko-Institut provides estimates for generation from small-scale combined heat and power plants and Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW) those of auto-generation of small-scale PV.

Figure 2 shows the important paths of the data through the various institutions. The yellow lines are data that are included in ENTSO-E's "monthly consumption", the green lines those that feed into ENTSO-E's "hourly load values", and the blue lines those that contribute to AG Energiebilanzen's "Energiebilanz der Bundesrepublik Deutschland". The core of most German electricity statistics is the monthly data collected by StatBA. These data are used by ENTSO-E, AG Energiebilanzen, BDEW, Eurostat & IEA. Only the data published by TSOs and the "hourly load" published by ENTSO-E are independent of StatBA data. Arrow 18 is double-headed because AG Energiebilanzen supplies BDEW with data modelled by Öko-Institut and ZWS, while BDEW supplies AG Energiebilanzen with data collected from their members.

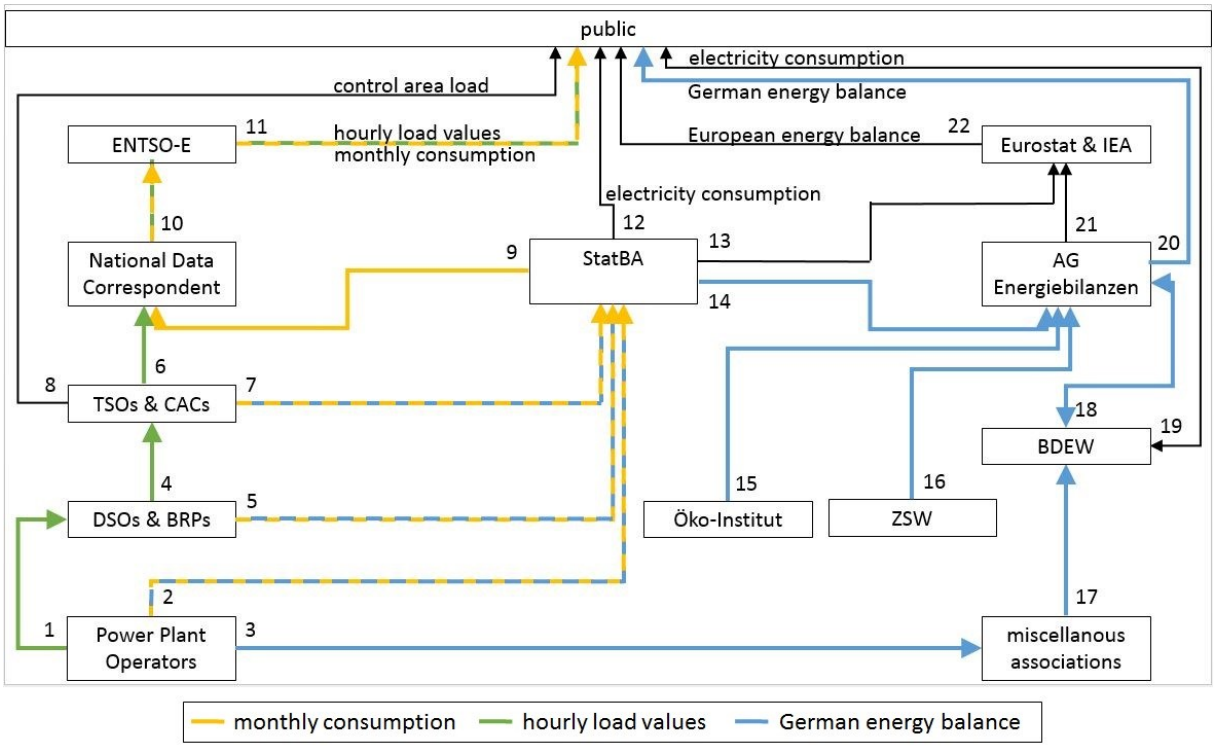

Figure 2: Path of German Electricity Data *source: [own representation]*

Table 3 details the data which are exchanged in Figure 2. "Data" does not represent all exchanged data.

Table 3 Data Exchange among German Data Sources *source: [own representation]*

#	Data	Granularity
1	Generation according to MaBiS	15 min
2	Generation of power plants ≤ 1MW	monthly
3	Generation and fuel consumption	ocassional
4	Generation according to MaBiS	15 min
5	Grid infeed and output, transmission	monthly
6	Hourly load values	hourly
7	Grid infeed and output, transmission	monthly
8	Control area load,PV & wind power feed in	daily
9	Net generation,exchange balance	monthly
10	Hourly load values, detailed monthly consumption	hourly, monthly
11	Hourly load values, detailed monthly consumption	hourly monthly
12	Net generation, grid losses, exchange balance	monthly
13	Net generation, exchange balance, fuel stocks	monthly
14	Electricity consumption, grid losses, exchange balance	monthly
15	BHKW generation	monthly
16	PV auto-generation	monthly
17	Industrial auto-generation, fuel consumption	monthly

18	Estimations, electricity generation	monthly
19	TSO PV & wind data electricity consumption	monthly
20	German energy balance, grid losses, consumption	yearly
21	Gross & net production, fuel consumption	monthly, yearly
22	European energy balance, fuel consumption	monthly, yearly

3.1.3 AG Energiebilanzen and BDEW

The core data of AG Energiebilanzen is the electricity production data supplied by the Federal Statistical Office (StatBA). TSO data of wind feed-in and large-scale PV systems, modelled data of small-scale PV roof-top systems from ZWS and small-scale CHP data estimated by Öko-Institut are added to this (Wernicke, 2015). Table 4 shows the source of data supplied to prepare the balance sheet for the electricity sector.

Table 4: Data sources for Electricity Balance Sheet published by AG Energiebilanzen *source: [own representation]*

Data	Source
Gross and net electricity production without PV and wind	StatBA
Electricity production from wind and PV systems	TSOs
Electricity production from CHP system smaller than 1 MW	Öko-Institut
Electricity production from small scale PV roof-top systems	ZWS
Information about special cases like trial operation etc.	misc. electricity producers

The data published by AG Energiebilanzen is almost the same as the data published by BDEW, since BDEW prepares the electricity data for AG Energiebilanzen. The data is only slightly changed to settle the balance with other energy carriers, for example lignite or oil. AG Energiebilanzen publishes an energy balance sheet once a year for Germany in addition to preliminary reports which are published every three months (AG Energiebilanzen, 2015). BDEW updates its publications more frequently than AG Energiebilanzen (Kiesel, 2015).

Furthermore, BDEW compares the data of the Federal Statistical Office with information collected from its member companies. Consequently, even industrial sub-grid data are included. The geographical area covered by the data prepared by BDEW is equal to the German “infrastructural area”. Thus, functional exclaves such as Kleinwalsertal, which belongs to Austria but is dependent on Germany in terms of infrastructure, are represented in the data published by BDEW.

3.1.4 Statistisches Bundesamt (StatBA)

In contrast to BDEW and AG Energiebilanzen data, the geographical area covered by the data collected by StatBA does not equate to the German infrastructural area. The Federal State Office collects their data via the Statistical State Offices using two questionnaires on the basis of the federal Law about Energy Statistics (Gesetz über Energiestatistik, EnStatG). The first among all electricity producers who operate power plants with 1 MW installed capacity and higher. The second among all grid operators. Due to administrative reasons PV and wind power plant operators are not interviewed for the questionnaire while biomass power plant operators are included[9]. Thus the data does not represent

[9] Only power plant operators which belong to the economic sector “35” are interviewed.

electricity produced by wind and PV systems, although it is published under the terms gross and net production. The data is revised annually (Kaiser, 2015). StatBA publishes data for electricity production and consumption for the entire country once a month.

3.1.5 ENTSO-E – German Data

ENTSO-E does not directly measure electricity data. Instead, data is "regularly provided by member TSO Statistical Data Correspondents (STCs)" (ENTSO-E, 2013). If there is more than one TSO for a member country, the data is aggregated by the various national TSOs and reported as a whole to ENTSO-E (Taccoen, 2013). In Germany this work is done by the NDC.

For the calculation of the "hourly load" the NDC is dependent on data reported by TSOs. Each TSO aggregates the primary data of its operational area. "The hourly load values are uploaded by STCs every month and usually 2 to 3 months afterwards" (Lagarrigue, 2015). However, the data collection process of the German TSOs for the hourly load is not standardised. In general it can be said that hourly load does not include consumption by the power plants themselves. The part of the traction power which is supplied via the transmission grid is represented in the hourly load values. Grid and transmission losses for all voltage levels are part of the load and represented in hourly load (TransnetBW, 2015). Industrial auto-generation is not included in hourly load (Schwaiger, 2015). In order to overcome this lack of information, it is recommended by ENTSO-E that TSOs calculate a "representativity factor" (ENTSO-E, 2014). This factor is the percentage of the data which is accessible for TSOs and it is calculated based on the historical relationship between official national statistical data and TSO data. "The explicit calculation of the representativity factor is the NDCs/STCs own responsibility" (ENTSO-E, 2014). The representativity factor can vary within one published dataset. For example, the data publication "country package" published by ENTSO-E includes "hourly load values" as well "detailed monthly consumption". Within this dataset, the German hourly load has a representativity of 91%[10], while the monthly consumption values have a representativity of 100% (Schwaiger, 2015). Consequently, the "hourly load values" should be around 9% less of the "detailed monthly consumption" data.

The calculation of the "detailed monthly consumption" is standardised for all ENTSO-E member countries and calculated as following:

$$L_{m,y}^{ENTSO} = \frac{G_{net,m,y}^{StatBA} + W_{m,y}^{TSO} + S_{m,y}^{TSO} + I_{m,y}^{TSO} - X_{m,y}^{TSO} - L_{hydro,m,y}^{StatBA}}{r_y} \quad (1)$$

(Schwaiger, 2015)

$m \in 1, \dots, 12$

$y \in 2006, \dots, 2013$

Where $G_{net,m,y}^{StatBA}$ is the net production published by StatBA. $W_{m,y}^{TSO}$ and $S_{m,y}^{TSO}$ is the electricity produced by wind and PV systems as published by TSOs in the EEG balances. $I_{m,y}^{TSO} - X_{m,y}^{TSO}$ is the exchanged balance published by ENTSO-E. $L_{hydro,m,y}^{StatBA}$ is the electricity consumed by hydropower plants and r_y is the representativity factor reported by NDC to ENTSO-E.

3.2 Europe

Eurostat and the IEA publish country-level electricity data for most European countries. ENTSO-E provides two distinct datasets: "monthly consumption" and "hourly load". Eurostat and IEA rely on the same data sources and use aligned terminology and methodology. The two ENTSO-E are different from

[10] For the years 2006-2013 the German representativity factor was 91%, since 2014 it is 97%.

Eurostat/IEA and, in some countries, differ from each other. Due to space constraints, we only report on the data collection process of four countries: Poland, Netherlands, France, and Spain.

3.2.1 ENTSO-E – European Data

The computation of the "detailed monthly consumption" is standardised across all country members, based on "official national statistics" and is computed according equation 1. In contrast, the data collection process of the hourly load values is not consistent across all member countries.

For Poland the hourly load is calculated based on electricity generation measurements: it is the temporary gross production plus import/export balance excluding pumping. This methodology includes all losses. Industrial self-consumption/production is only partially represented in the data. A representativity factor for Poland had not been published until 2014 (Jeżyński, 2015).

The hourly load for the Netherlands is the sum of the average feed-in measured at the bus bar of a power plant and the exchange with the connected control areas over the hour measured at the accounting point[11] between two areas (Tennet-NL, 2015). Network- and -transmission losses as part of the load are included in the hourly load values. Traction power is not considered and included in the hourly load values. Auto-generation of the non-electric industry is included as an estimate. The corresponding representativity factor, until the beginning of 2008, was around 93% (ENTSO-E, 2014). On request Tennet reported an average representativity factor for the years 2008–2013 of 88% (Tennet-NL, 2015).

The French hourly load is calculated based on the net production measured at the bus bar of a power plant (Pharabod, 2015). Electricity generation of power plants, connected to the distribution network, and self-generation, is collected from distributors and industrial sites, sometimes partially estimated through profiles when hourly measurement is not available. Hourly load is deduced by adding imports and deducting exports and pumping consumption. Import, export, and pumping consumption are also measured hourly. Consequently, all network and transmission losses are represented in the hourly load values (Pharabod, 2015). RTE reports a representativity factor of 100% (ENTSO-E, 2014).

In Spain the hourly load data is measured at the bus bar of the power plants, and includes traction power and network and transformation losses. Auto-generation of non-electric industry is taken into account in accordance with the Spanish legislation during the period analysed in this work (2003-2013). This obliged all electricity producers (even non electric-industry) to sell their electricity to the market. The market data was used to prepare the electricity statistics reported to ENTSO-E. Consequently, for Spanish electricity statistics the industrial auto-generation is not an unknown variable and Spain reports a representativity factor of 100% (REE, 2014).

3.2.2 IEA & Eurostat

The energy balances published by Eurostat and IEA differ only in structure but use the same primary data (Eurostat, 2014). These primary data are collected in five joint questionnaires which are monthly and annually conducted within their member countries by the United Nations Economic Commission for Europe (UNECE), in cooperation with IEA and Eurostat. For Germany the data are supplied by StatBA. The questionnaires cover the oil, coal, gas, electricity, and renewables sector. The advantages of these joint questionnaires are the standardised definitions, units, and methodology. Both questionnaires are compiled as excel tables, which can be downloaded from the Eurostat website.

In Cooperation with IEA and the Organisation for Economic Co-operation and Development (OECD), Eurostat have published a very useful "Energy Statistics Manual" (IEA, 2005). This manual gives a detailed comparison between the energy statistics published by Eurostat and the energy statistics

[11] „accounting point" is the term used by Tennet. It can be understood as a connection point between two grid areas.

published by IEA. For specialists who are "prepared to spend more time analysing and using very detailed information and tables" (IEA, 2005), collection methods, nomenclatures, and detailed tables are also provided.

4 Quantitative Data Analysis

This section assesses the reported data themselves. We first compare the two ENTSO-E datasets "hourly load" and "monthly consumption" with each other, and then various German data sources. It turns out that hourly load and monthly consumption is virtually identical in France, but differs in most other countries. The deviation is greatest in Germany at around 12% on average. This difference is only partly explained by the representativity factor. Furthermore, for wind and solar generation data from four different German sources, we find differences between data sources of 10-20%.

4.1 ENTSO-E *Hourly Load Values* and *Monthly Consumption*

We aggregate "hourly load values" by month and compare it to "monthly consumption", both published by ENTSO-E, for France, Poland, Spain, the Netherlands, and Germany. Since the hourly load values, in contrast to the monthly consumption data, do not cover 100% of the real consumption, the deviation between these two datasets should be the (inverse of) the representativity factor. The comparison is done for 2006–2013, since hourly load is not available before that time.

Figure 3 compares the monthly total of "hourly load values" with "monthly consumption" for France, and shows how the values coincide. This is consistent with the data documentation that reports a representativity factor of 100%. However, we will see in the following that France is the only country where this is the case.

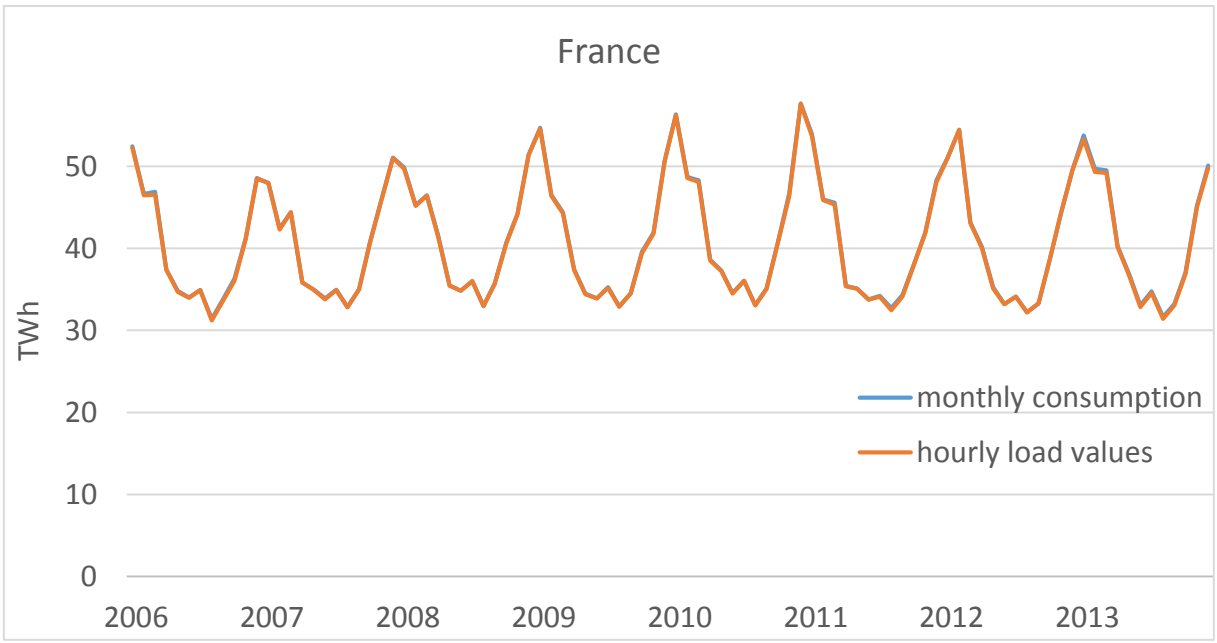

Figure 3: French accumulated hourly load values and monthly consumption data *[Own figure based on ENTSO-E data]*

Figure 4 repeats the exercise for Poland. While in most months the data match well and the reported representativity factor of 100% is appropriate, there is a significant deviation of 5% in May 2009.

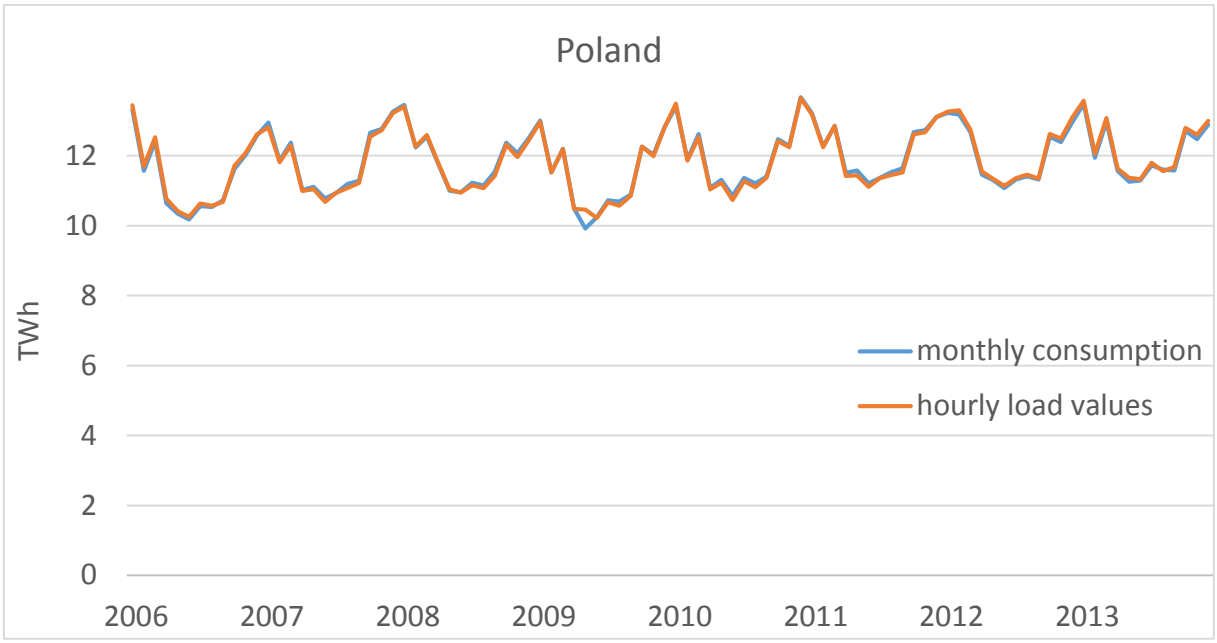

Figure 4: Polish accumulated hourly load values and monthly consumption data *[Own figure based on ENTSO-E data]*

In Spain (Figure 5), the fit is less good. On average, hourly load is 3% below monthly consumption, with individual months of up to 7% deviation which is inconsistent with a reported representativity factor of 100%. The deviation is obviously not homogenous over the total period; three sub-periods can be distinguished as illustrated by Figure 6. The first sub-period lasts until December 2009 during which the average deviation is 3% and in some months even 7%. Surprisingly, from January 2010 until December 2011 the average deviation is almost 0%. In contrast, since January 2011 average deviation has been 6%, with a maximum of 7% and a minimum of 5%. However, although the deviation is significant, it does not seem to increase. The average deviation for January 2012 is 6% which is almost the same as that for December 2013.

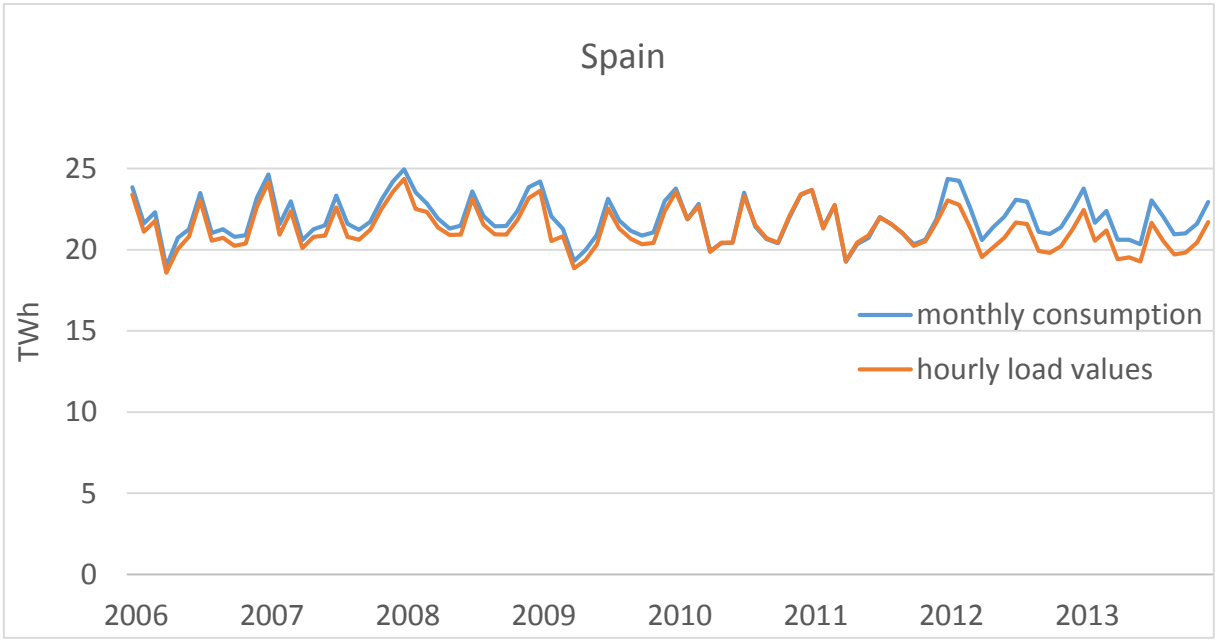

Figure 5: Spanish accumulated hourly load values and monthly consumption data *[Own figure based on ENTSO-E data]*

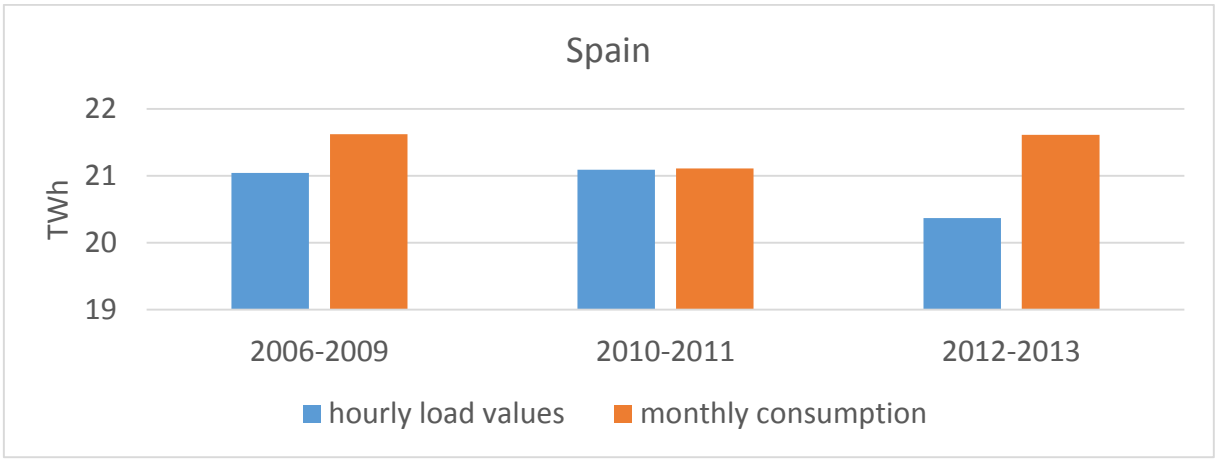

Figure 6: Spanish hourly load values and monthly consumption data by period *[Own figure based on ENTSO-E data]*

There is an even larger mismatch between the two datasets in the Netherlands (Figure 7). The average deviation of 6% in 2006 and 2007 and 5% in the later years cannot be explained by the representativity factors 93% and 88%. The mismatch of almost 39% in January 2013 should be disregarded, because according to the "specific national considerations" published by ENTSO-E "there are some irregularities in TenneT's measurements on which the hourly load data is based" (ENTSO-E, 2014).

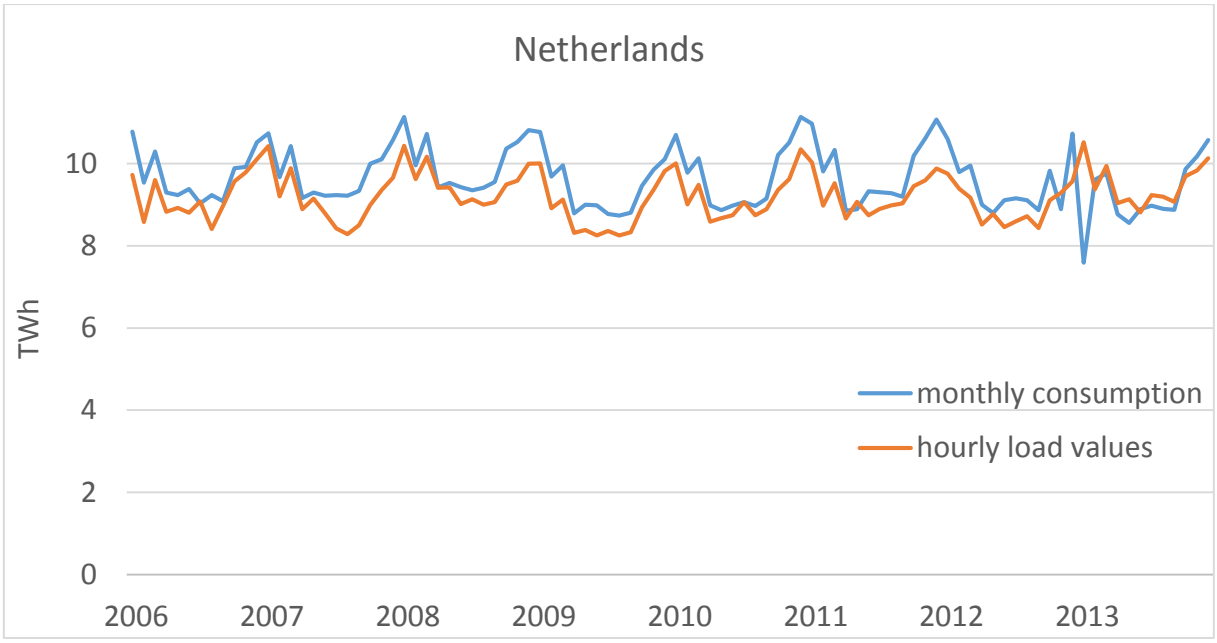

Figure 7: Dutch accumulated hourly load values and monthly consumption data *[Own figure based on ENTSO-E data]*

The comparison of the datasets for Germany (Figure 8) show the largest mismatch. In each individual month, hourly load is less than the monthly consumption. The average deviation is 12%, with a maximum of 4% and a minimum of 20%. The deviation is only partly explained by the representativity factor of 0.91, implying a deviation of 9% (Figure 9). Analysing the seasonal deviation (as illustrated in Figure 10) shows that the deviation is significantly smaller in the last three months of the year than the first three months.

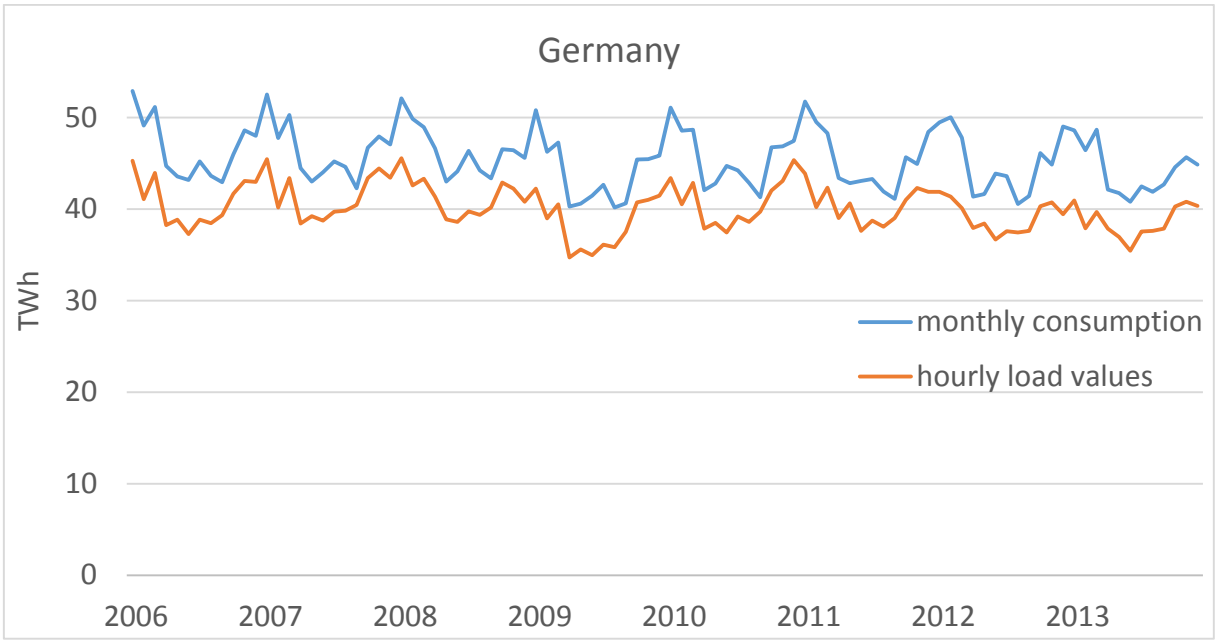

Figure 8: German accumulated hourly load values and monthly consumption data [Own figure based on ENTSO-E data]

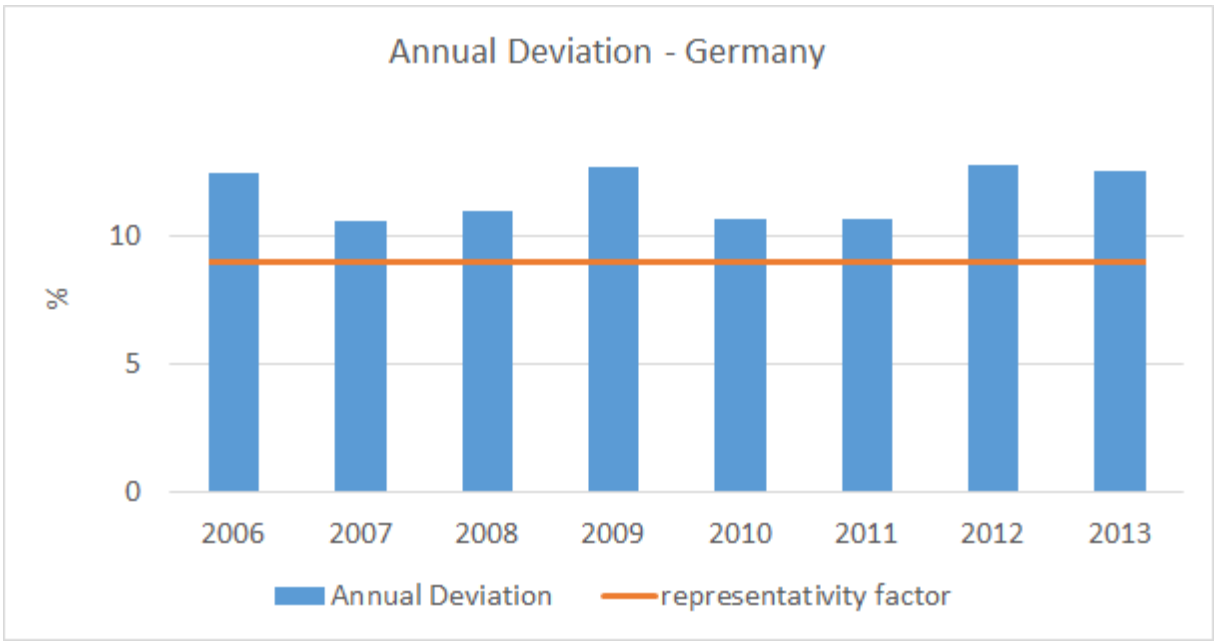

Figure 9: Annual Deviation of German data and representativity published by ENTSO-E [Own figure based on ENTSO-E data]

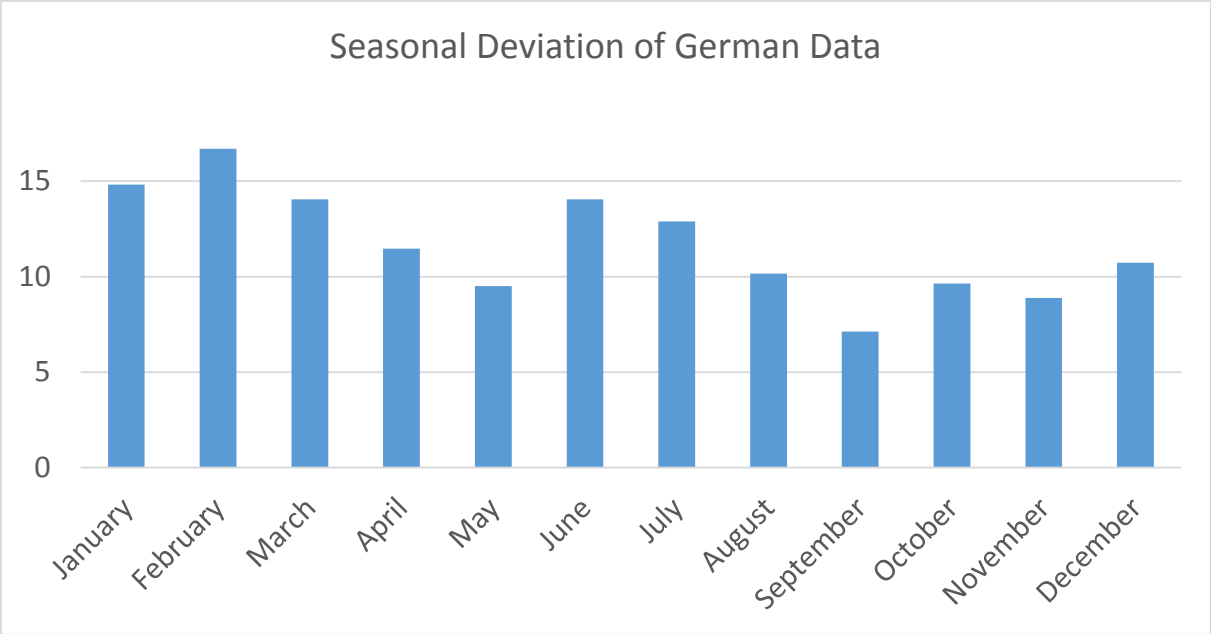

Figure 10: Seasonal Deviation of the German data published by ENTSO-E *[Own figure based on ENTSO-E data]*

Figure 11 visualises the average deviations combined with the maximum and minimum deviations. For Dutch data, we exclude February 2013 as an outlier. The German deviation is largest on average, but the Dutch deviation (even excluding the outlier) shows the largest span.

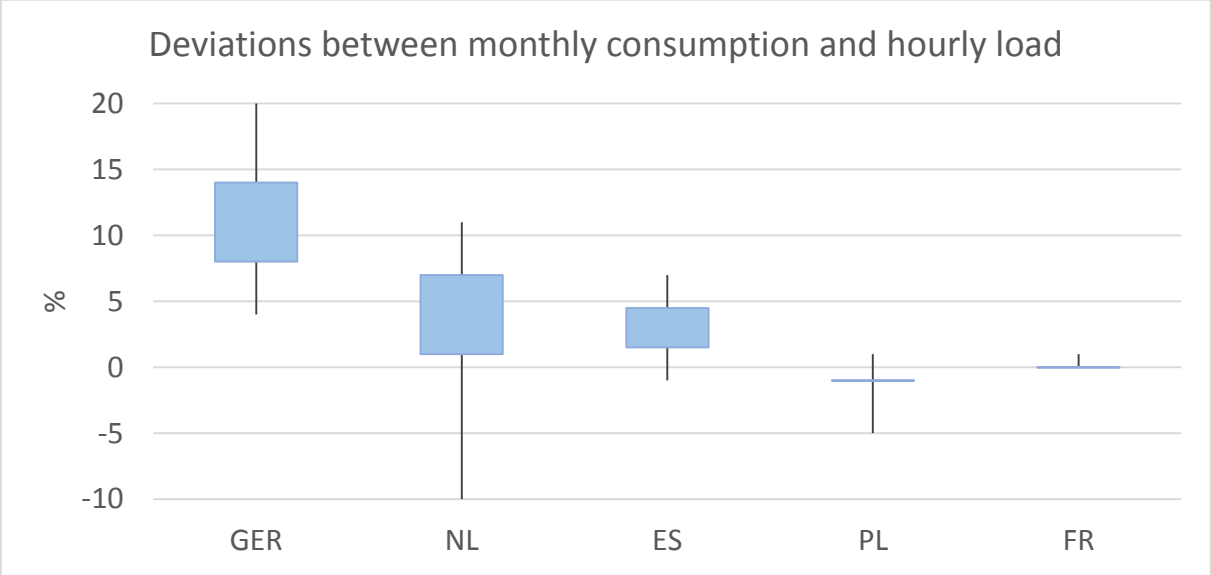

Figure 11: Comparison of Deviation for European countries *[Own figure based on ENTSO-E data]*

Table 5 compares the deviation implied by the reported representativity factor with the one we derived from comparing the two datasets. For example, ENTSO-E reports a representativity factor of 99% for Poland, implying a deviation of 1%. In fact, we observe deviations of -0.7% in 2006 and +0.6% in 2007, and so on. German, Dutch, and Spanish data show (i) a significant difference between reported and calculated factors and (ii) significant year-to-year variation. In individual cases, such as the Netherlands in 2013, the difference is close to 16%.

Table 5: Comparison reported representativity factors and deviations (in percent) *source: [own representation]*

	Poland		France		Germany		Netherlands		Spain	
	reported	calculated	rep	calc	rep	calc	rep	calc	rep	calc
2006		-0.7		0.4		12.5	7	4.9		2.4
2007		0.6		0.1		10.6		6.3		2.7
2008		0.3		0.1		11.0		4.8		2.5
2009	1	-0.2	0	0.2	9	12.7		6.1	0	3.0
2010		0.5		0.3		10.6	12	4.9		0.1
2011		0.5		0.3		10.7		5.7		0.1
2012		-0.6		0.1		12.8		5.1		5.7
2013		-0.7		0.6		12.6		-3.8		5.6

4.2 German data

In our study, we first compare ENTSO-E consumption data for Germany with national data. In this we find significant differences, which seem to increase over time. Then, we compare different national data sources to yearly electricity generation data, reporting that, except for AG Energiebilanzen and BDEW, all sources differ significantly. Even by applying information about reporting and processing as discussed in chapter 3.1.2, a 100% reproduction of German datasets is impossible. Finally, we compare different sources of wind and solar power generation data and find large differences between data sources of around 10% even in recent years.

4.2.1 Reproduction of ENTSO-E monthly consumption data

As described in equation (1), the German monthly consumption data published by ENTSO-E is calculated based on the monthly net generation data and hydro power data produced by StatBA. Wind and solar generation data, as well as electricity exchange data from TSOs, are also included. In order to verify the data published by ENTSO-E, we reproduced the data according to equation (1). The "Nettoerzeugung" published by StatBA is accordingly aggregated to annual values for the years 2003–2013. As explained above, these data include biomass generation, but neither wind nor solar power. The data sets are taken from the EEG balances published by the four German TSOs[12], and the balances are published once for each year without being updated.[13] The exchange balance data is taken from the data published by ENTSO-E and pump hydro consumption data is taken from StatBA. All data is listed in Table 6.

Table 6: Datasets used for reproduction of ENTSO-E monthly consumption for Germany *source: [own representation]*

[TWh]	StatBA	TSOs		ENTSO-E		StatBA	ENTSO-E
	net prod.	PV	Wind	Import	Export	hydro cons.	representativity
2003	498	0.3	19	46	54	7.7	0.91
2004	499	0.6	26	44	52	9.3	0.91
2005	498	1.3	27	53	62	9.5	0.91
2006	505	2.2	31	46	66	9.0	0.91
2007	488	3.1	40	44	63	9.2	0.91
2008	489	4.4	41	40	63	7.9	0.91
2009	446	6.6	39	40	55	7.6	0.91
2010	469	11.7	38	42	60	8.6	0.91

[12] www.netztransparenz.de

[13] Inaccuracies are reported in the EEG balance of the following year.

2011	431	19.3	48	50	56	7.8	0.91
2012	435	25.4	51	44	67	8.1	0.91
2013	431	29.5	55	38	72	7.8	0.91

Since data from the TSOs for the PV and wind feed-in are published as annual data, all other datasets are aggregated to annual granularity. Furthermore, the analysis could only be done up to 2013, since the annual EEG balance for 2014 was not published at the time of writing this paper. The data listed in Table 6 was processed according equation 1 detailed in chapter 3.1.5.

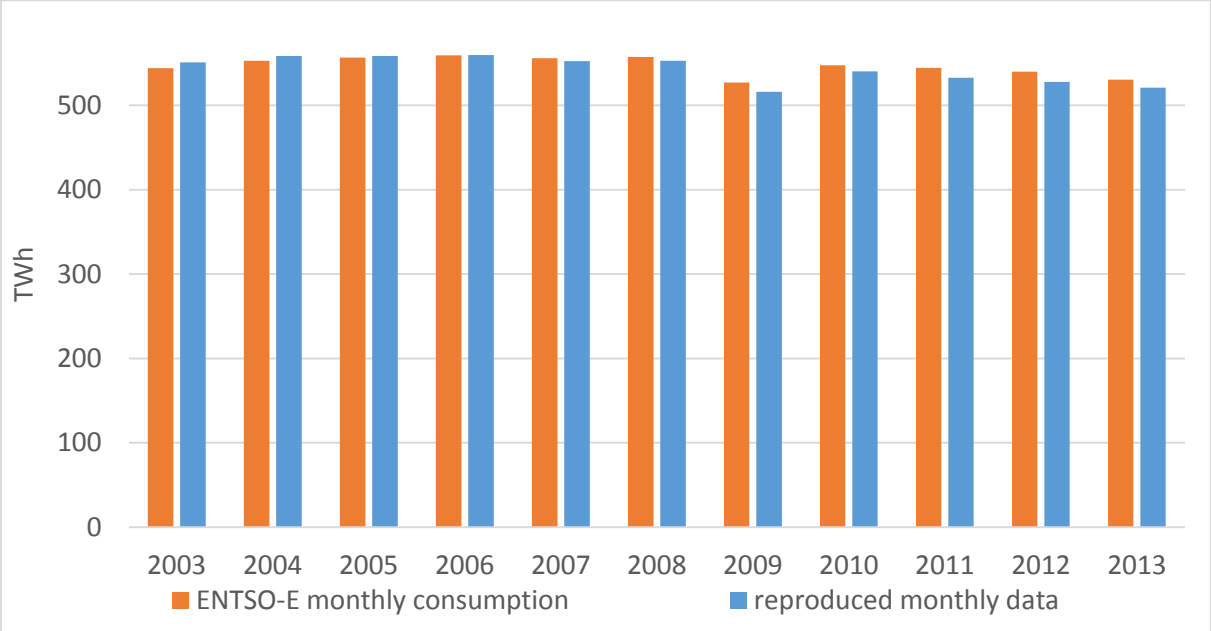

Figure 12: Comparison of reproduced data and ENTSO-E data for Germany *source: [own representation]*

Figure 12 illustrates the comparison based on the data displayed in Table 6 and the above mentioned equation. At first glance, it seems that the reproduced and published data match well. However, a closer look at the differences reveals that they are not insignificant, and they seem to be increasing over time (Figure 13). One possible reason for the displayed deviation is that the reporting method of the four German TSOs is not standardised.

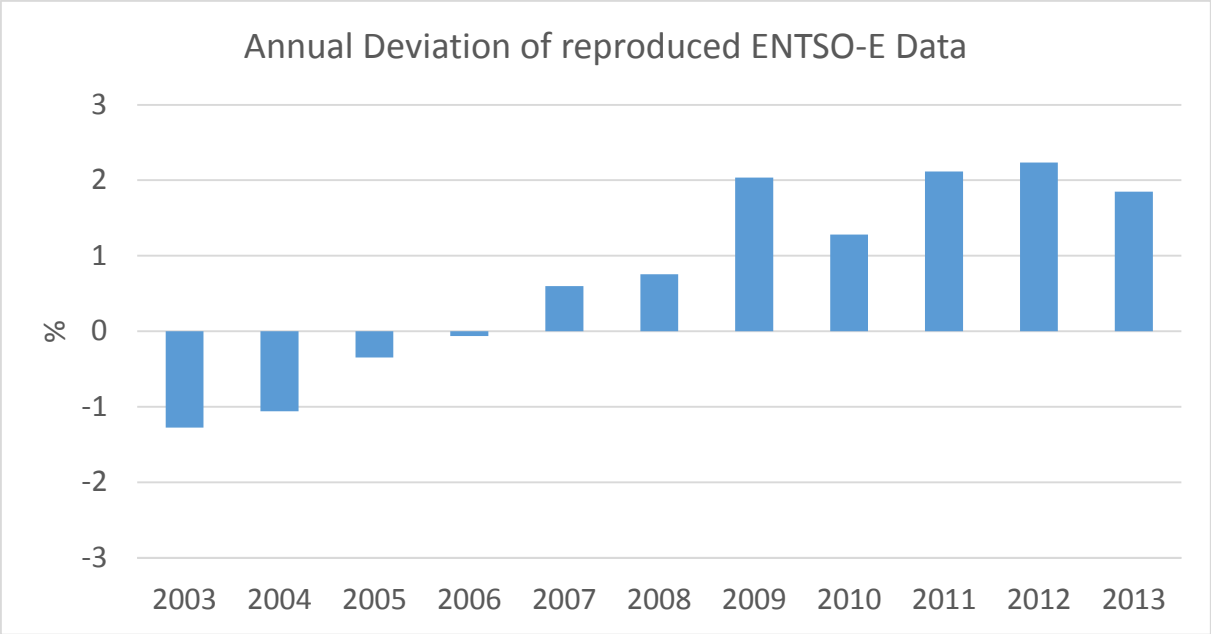

Figure 13: Annual Deviation of reproduced ENTSO-E data for Germany *source: [own representation]*

4.2.2 AG Energiebilanzen Data

As described in chapter 3.1.3, the data prepared by BDEW for AG Energiebilanzen are based on the data collected by StatBA, data simulated by ZWS and Öko-Institut, and information occasionally reported by member institutions. In order to estimate the part of the data which is based on the know-how of BDEW and the other members of AG Energiebilanzen, we reproduce it. This is done by combining the gross production data published by StatBA with the data for PV and wind feed-in published by BDEW. By May 2015 there was still no AG Energiebilanzen energy balance sheet available for 2013; therefore, the analysis is based on the years 2003–2012. Table 7 lists the data used for the reproduction. As it can be seen the wind and solar generation data published by BDEW and by AG Energiebilanzen are almost identical. This confirms the data collection process described in chapter 3.1.3.

Table 7: Datasets used for reproduction of AG Energiebilanzen data

[TWh]	StatBA	BDEW	TSOs	AG Energiebilanzen
	gross prod.	Wind + Solar	Wind + Solar	Wind + Solar
2003	532	19	n.a.	19
2004	533	26	n.a.	26
2005	532	29	n.a.	29
2006	540	33	29	33
2007	523	43	39	43
2008	523	45	40	45
2009	479	45	37	45
2010	501	50	36	50
2011	462	68	63	69
2012	467	77	75	77
2013	463	83	77	83

Figure 14 shows that all average deviations of the various reproduced datasets increase during the period of investigation. Since the dataset published by AG Energiebilanzen is only published annually, a seasonal analysis cannot be done.

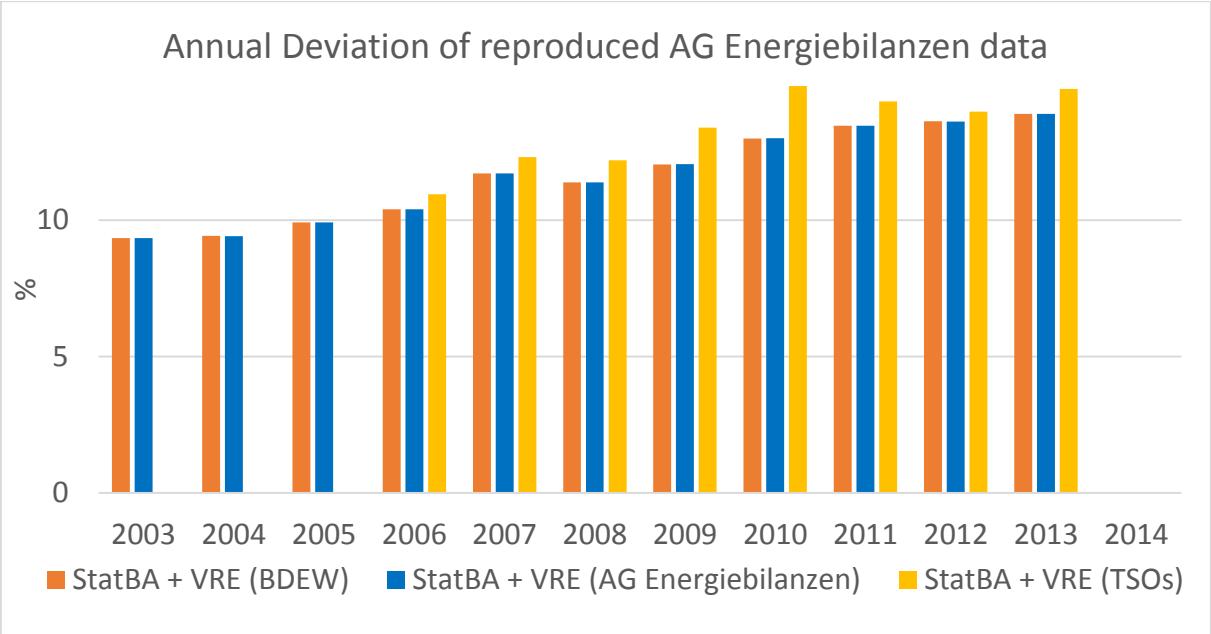

Figure 14: Annual Deviation of reproduced AG Energiebilanzen Data *source: [own representation]*

The larger deviation of the reproduced datasets based on TSO data can be explained by the fact that, based on estimates (as mentioned in chapter 3.1.3) , PV auto-generation of households is included in the AG Energiebilanzen wind and solar data but not in TSO data. Further it can be assumed that the differences between the reproduced datasets based on AG Energiebilanzen and BDEW data occur due to industrial auto-generation which is not reported to StatBA (e.g. in the case of trial operation). AG Energiebilanzen and BDEW datasets include industrial auto-generation information collected from the BDEW members. StatBA datasets do not include such auto-generation.

4.2.3 Wind and solar generation data

Four different sources provide information about yearly wind and solar power generation in Germany: EEG balances, hourly in-feed from TSOs, AG Energiebilanzen, and StatBA, as shown in Figure 15. TSO data only starts in 2011 and is based on the extrapolation of generation from a limited number of solar power plants (Schierenbeck, 2010). BDEW and AG Energiebilanzen data are based on estimates, and are almost identical.[14] EEG balances report the measured values as used for paying the feed-in-tariff. Until 2011 the data derived from the EEG balances is also identical with both BDEW and AG Energiebilanzen. However, in 2012 and 2013 the difference is significant, which is probably due to the EEG law amendment which took effect in 2012. Overall the datasets differ by around 4% although the deviation is around 12% in 2012 due to the peak in the data published by the TSOs. Given that data published by BDEW and AG Energiebilanzen also include auto-generation of PV roof-top systems, it can be said that these datasets for PV generation have the highest accuracy. Consequently, these are the datasets that should be used by modellers.

[14] As mentioned in chapter 3.1.2 BDEW and AG Energiebilanzen respectively use models result from ZSW. More information about the ZSW models: http://www.zsw-bw.de/en/topics/energy-economics/wind-and-solar-power-output-forecasts.html

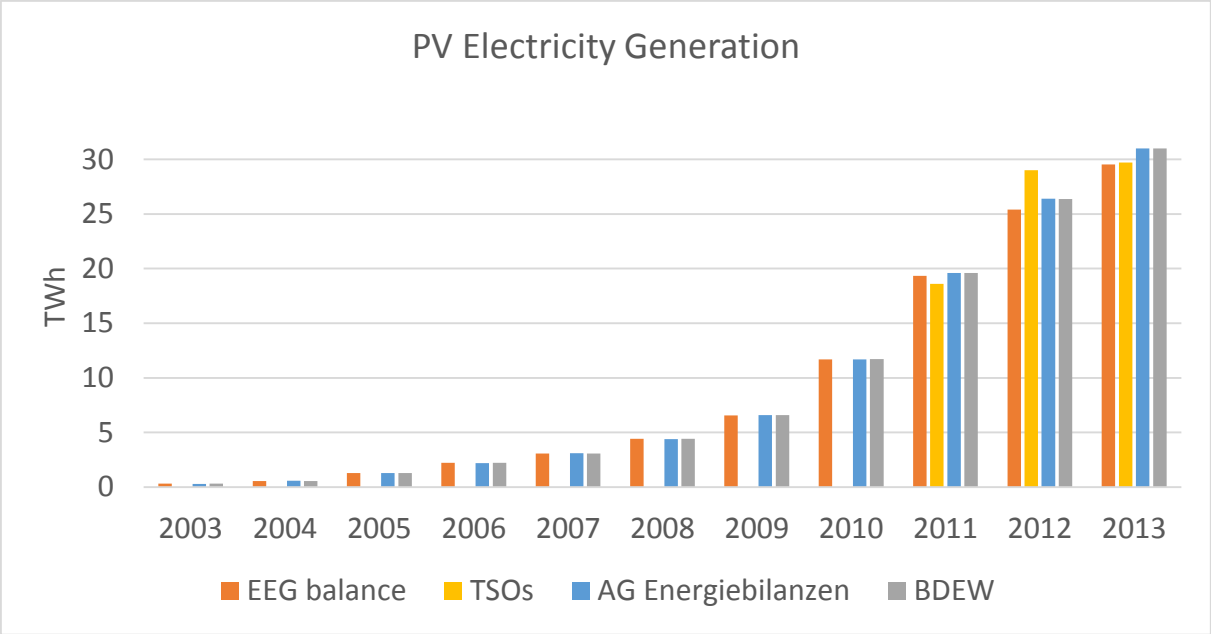

Figure 15: Comparison of various sources for PV electricity generation data in Germany *source: [own representation]*

Figure 16 and Figure 17 show wind generation data in absolute terms and as deviations. It becomes clear that TSOs systematically and substantially underestimate wind power output: even in recent years the deviation is around 9%. Surprisingly, 2013 BDEW data differ greatly to AG Energiebilanzen and EEG balances, given that they had been virtually identical in previous years.

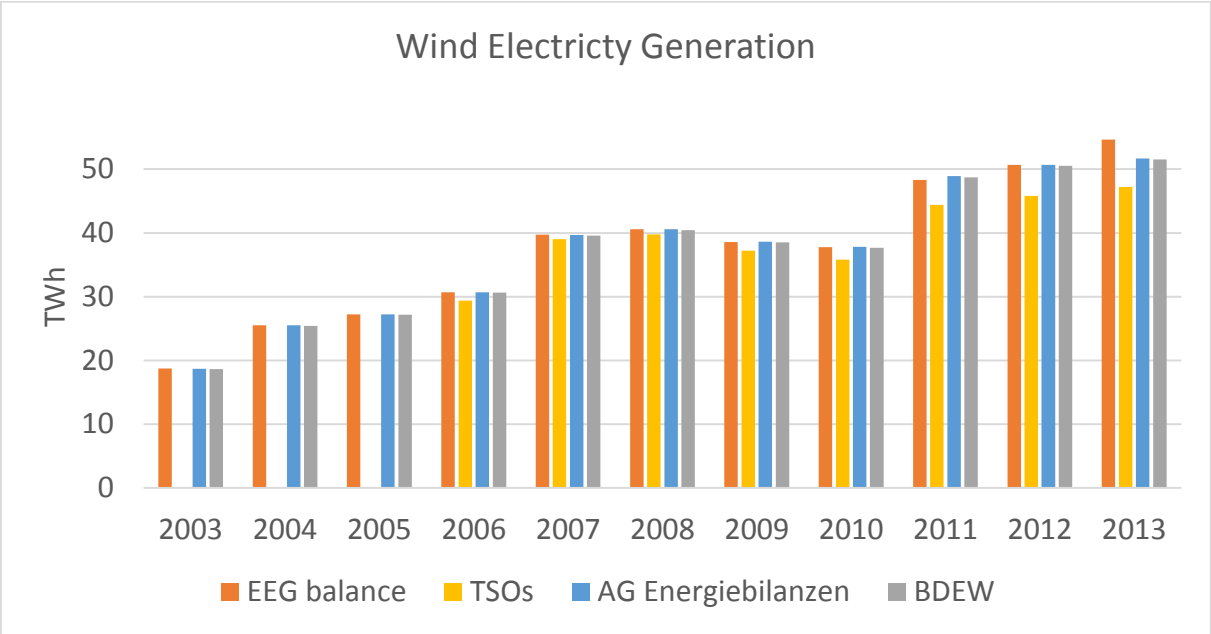

Figure 16: Comparison of various sources for wind electricity generation data in Germany *source: [own representation]*

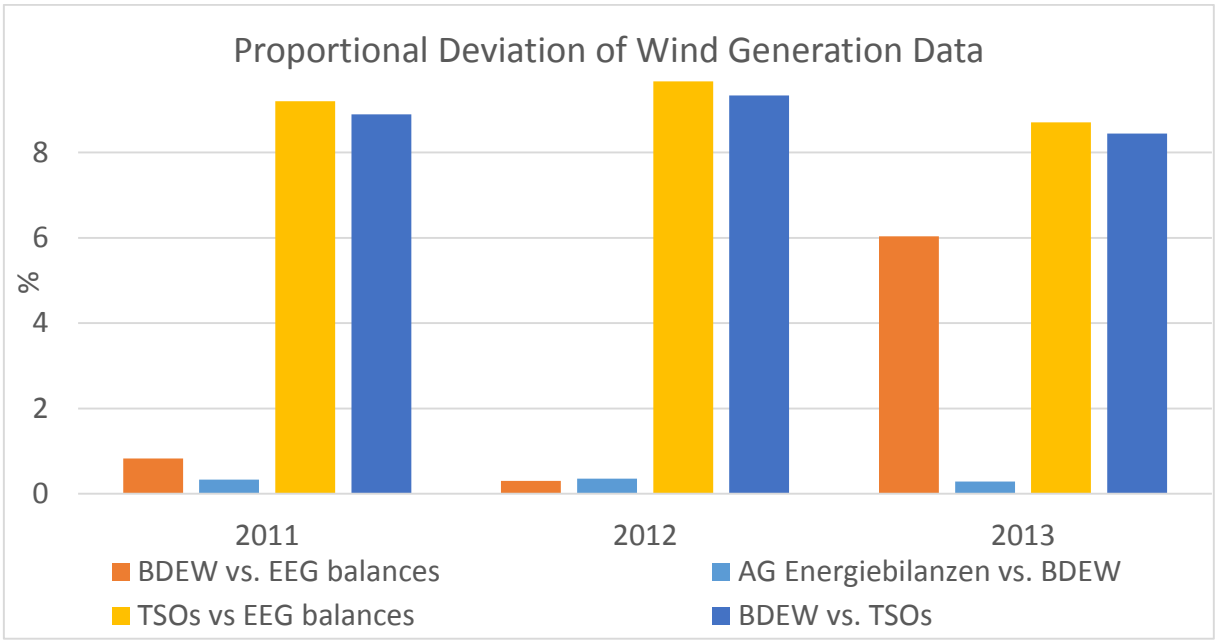

Figure 17: Comparison of Proportional Deviation of Wind Generation Data in Germany *source: [own representation]*

5 Modellers' Guide

The following chapter is focused on German datasets and will suggest a step-by-step guideline for handling officially published datasets for the purpose of power system modelling. In particular, the question is how certain datasets should be processed in order to construct the high-frequency data regularly used for power system modelling. For example: if a model requires as input data the total electricity consumption of all German electricity consumers including grid losses at an hourly granularity – which dataset should be used and (how) should it be scaled?

5.1 Net Electricity Production

BDEW uses the largest number sources to compute their datasets. Compared to other institutions which publish net electricity production data, the data published by BDEW represents almost all producers, including information about industrial auto-generation. Further, the BDEW data is revised and updated more often than the data published by AG Energiebilanzen. Unfortunately, the BDEW data only has an annual granularity; in order to calculate hourly values a profile with a granularity of one hour should be used. Therefore, the ENTSO-E "hourly load values" should be scaled with the ENTSO-E "detailed monthly consumption" data, to take into account seasonality. Furthermore, the computed monthly values should be scaled with BDEW data, since these data are subject to the most extensive data collection process. Consequently, the hourly net generation $G_{net,t}$ should be calculated as follows:

$$G_{t,m,y} = L^{ENTSO}_{t,m,y} \cdot \alpha_m \cdot \beta_y \qquad \begin{matrix} t \in 1,\dots,744 \\ m \in 1,\dots,12 \\ y \in 2006,\dots,2013 \end{matrix} \qquad (3)$$

With α_m as the monthly scaling factor and β_y as the annual scaling factor:

$$\alpha_{m,y} = \frac{L_{m,y}^{ENTSO}}{\sum_{t=1}^{T} L_{t,m,y}^{ENTSO}} \qquad \begin{matrix} t \in 1, \dots, 744 \\ m \in 1, \dots, 12 \\ y \in 2006, \dots, 2013 \end{matrix} \qquad (4)$$

$$\beta_y = \frac{G\_net_y^{BDEW}}{\sum_{m=1}^{M} L_{m,y}^{ENTSO}} \qquad \begin{matrix} m \in 1, \dots, 12 \\ y \in 2006, \dots, 2013 \end{matrix} \qquad (5)$$

$L_{t,m,y}^{ENTSO}$ is the single "hourly load value" published by ENTSO-E and $\sum_{t=1}^{T} L_{t,m,y}^{ENTSO}$ is the sum of the hourly load values. $L_{m,y}^{ENTSO}$ is the "detailed monthly consumption" published by ENTSO-E and, $\sum_{m=1}^{M} L_{m,y}^{ENTSO}$ is the sum of the monthly consumption. $G\_net_y^{BDEW}$ is the annual net consumption data published by BDEW and t is the hour, m the month and y the year.

Table 8: Combined scaling factors according equation 4 and 5 ($\alpha \cdot \beta$)

month \ year	2006	2007	2008	2009	2010	2011	2012	2013
1	1.251	1.248	1.233	1.276	1.280	1.250	1.298	1.335
2	1.281	1.284	1.263	1.258	1.303	1.305	1.328	1.377
3	1.247	1.252	1.219	1.236	1.235	1.209	1.309	1.379
4	1.252	1.251	1.216	1.230	1.208	1.179	1.198	1.252
5	1.201	1.185	1.193	1.209	1.208	1.117	1.191	1.271
6	1.241	1.228	1.233	1.258	1.299	1.214	1.314	1.294
7	1.247	1.230	1.257	1.252	1.227	1.185	1.274	1.272
8	1.215	1.211	1.212	1.189	1.207	1.166	1.190	1.252
9	1.169	1.129	1.164	1.148	1.130	1.117	1.210	1.268
10	1.182	1.163	1.170	1.182	1.209	1.180	1.257	1.245
11	1.209	1.166	1.185	1.175	1.182	1.125	1.210	1.258
12	1.197	1.171	1.205	1.172	1.137	1.226	1.366	1.251

Table 8 displays the combined scaling factors which are the products of the results from (4) and (5). The scaling factors are quite substantial, averaging to 1.22, with a minimum of 1.12 in September 2010 and a maximum of 1.38 in March 2013. Interpreting un-scaled hourly load values as total net generation leads to a quite significant bias. According to the representativity factor published by ENTSO-E, one might think that the scaling factor is constant at $(\frac{1}{0.91})$. In reality, however, it is not.

5.2 Wind and solar generation

In order to calculate the net production of wind and solar power, the profile of the hourly PV and wind electricity production values published by TSOs should be used. Unfortunately these values are estimates. Consequently, they should be scaled to the values derived from the annual EEG balances because these values are measured. Further, it should be taken into account that the PV electricity data published by TSOs as well as the data derived from the EEG balances only represent the feed-in of PV electricity into the grid. Thus, for the PV electricity portion, the data published by BDEW should be used. Consequently, the following formulae should be applied:

$$W_{t,y} = W_{t,y}^{TSOs} \cdot \lambda_y \qquad t \in 1, \dots, 8760;\ y \in 2006, \dots, 2013 \qquad (6)$$

$$S_{t,y} = S_{t,y}^{TSOs} \cdot \sigma_y \qquad t \in 1, \dots, 8760;\ y \in 2006, \dots, 2013 \qquad (6)$$

With λ_y as wind scaling factor and σ_y as PV scaling factor:

$$\lambda_y = \frac{w_y^{EEG}}{\sum_{t=1}^{T} w_{t,y}^{TSOs}} \qquad t \in 1, \dots, 8760;\ y \in 2006, \dots, 2013 \qquad (7)$$

$$\sigma_y = \frac{s_y^{BDEW}}{\sum_{t=1}^{T} s_{t,y}^{TSOs}} \qquad t \in 1, \dots, 8760;\ y \in 2006, \dots, 2013 \qquad (8)$$

Where w_y^{EEG} is the annual wind electricity net production data derived from the EEG balances, $\sum_{t=1}^{T} w_{t,y}^{TSOs}$ is the sum of the hourly wind electricity feed-in values published by TSOs, $w_{t,y}^{TSOs}$ is the single hourly wind electricity feed-in value published by TSOs, s_y^{BDEW} is the annual PV electricity net production data published by BDEW, $\sum_{t=1}^{T} s_{t,y}^{TSOs}$ is the sum of the hourly PV electricity feed-in values published by TSOs and $s_{t,y}^{TSOs}$ is the single hourly PV electricity feed-in value published by TSOs. For the wind scaling factor, data for wind feed-in from the EEG balances are used, because these data are measured. Furthermore, there are no unknown variables in the field of wind electricity which are not accounted for in the EEG balances. Consequently, the wind feed-in data from the EEG balances have the highest accuracy. For the PV scaling factor the PV feed-in data published by BDEW are used, because these data also include PV auto-generation by roof-top systems. Since the EEG balances do not include PV auto-generation, the BDEW PV feed-in data have the higher accuracy. Table 9 displays the PV and wind scaling factors. Scaling factors are quite significant, ranging from 0.88 (solar PV in 2012) to 1.16 (wind power in 2013).

Table 9: PV and wind scaling factors according equation 7 and equation 8

factor \ year	2006	2007	2008	2009	2010	2011	2012	2013

σ_y	n.a.	n.a.	n.a.	n.a.	n.a.	1.040	0.876	0.995
λ_y	1.045	1.018	1.019	1.037	1.056	1.089	1.106	1.158

5.3 Grid Losses and Transformer Losses

Grid losses can be approximated as a quadratic function of the active power flow (Kirschen, et al., 2010). Furthermore, StatBA publishes data of monthly grid losses (which also includes transformer losses) based on questionnaires from all grid operators. Consequently, the hourly net generation calculated by equation 3 should be combined with StatBA data on grid losses in order to calculate hourly values of grid losses. Therefore, following equation can be applied:

$$P\_loss_{t,m,y} = \frac{L_{m,y}^{StatBA}}{\sum_{t=1}^{T} G\_net_{t,m,y}^2} \cdot G\_net_{t,m,y}^2 \qquad \begin{matrix} t \in 1, \dots, 744 \\ m \in 1, \dots, 12 \\ y \in 2006, \dots, 2013 \end{matrix} \qquad (12)$$

Where $L_{m,y}^{StatBA}$ is the monthly data about grid losses published by StatBA, $\sum_{t=1}^{T} G\_net_{t,m,y}^2$ is the sum of the quadratic function of the hourly net production values as calculated in equation 3 and $G\_net_{t,m,y}^2$ is the quadratic function of the single hourly net production value.

6 Conclusion

The objective of this paper was to assess several electricity consumption data sets from various German and European data sources, in order to improve input data for electricity market models. We analysed both the process of data handling from collection to publishing and the published data itself. Based on this analysis we have suggested a guideline how to prepare data for power system modelling.

We find that hourly-resolution data, such as the "hourly load values" published by ENTSO-E or the wind and solar generation estimates published by TSOs should not be used directly. Rather, they should be scaled to match more reliable data sources. The scaling factors we calculate are quite substantial, ranging from 0.88 (German solar PV in 2012) to 1.38 (German load in March 2013). Not for all countries hourly load values require scaling: French and Polish data can be used directly, while German, Dutch, and Spanish data requires scaling. The "representativity factors" provided by ENTSO-E are a poor proxy for proper scaling factors. In one case (Dutch load for 2013), the best estimate for a scaling factor is 16% off the representativity factor.

We recommend the following actions.

- Institutions which publish energy data should provide detailed documentations of the data collection process and their primary data. Eurostat and IEA provide a best-practice example (IEA, 2005).
- Institutions which publish energy statistics should indicate the source of their primary data.
- ENSTO-E should standardise the data collection process of the "hourly load values". At least the German TSOs should agree on one defined data collection process and reporting data format for all data reported to the NDC.
- Data validation and processing would be greatly facilitated in all data was easily accessible, such as CSV files with full-yearly coverage, rather than PDF documents or individual files for days or months.

Appendix

Table 10: Synonyms used for Electricity Statistics *source: [own representation]*

1	gross production	IEA, Eurostat
	Bruttoerzeugung	StatBA
	Umwandlungsausstoß	AG Energiebilanzen
8	Primärenergieverbrauch im Inland[15]	AG Energiebilanzen
	Stromaustauschsaldo Ausland	AG Energiebilanzen
	exchange import - exchange export	ENTSO-E
3 + 6 + 7 + 8 + 11 + 12 + 16	hourly load values	ENTSO-E
	Regelzonenlast	TSOs
11 + 12	Fackel- & Leitungsverluste	AG Energiebilanzen
	Netzverluste	StatBA

Table 11: Antonyms used for Electricity Statistics *source: [own representation]*

Abgabe insgesamt	$3 + 6 + 7 + 8 + 9 + 16$	StatBA
Nettoerzeugung	$2 + 13$	StatBA
Nettostromverbrauch	$2 + 13 + 14 + 15 + 16 - (11 + 12) - (10 - 9) - 7$	BDEW
Nettostromverbrauch	$2 - 7$	StatBA
Bezug insgesamt	$2 + 6 + 7 + 8 + 10 + 13 + 14 + 15 + 16$	StatBA
Energieangebot im Inl. n. Umwandlungsbilanz	$2 - (7 + 8 + 11 + 12 + 13)$	AG Energiebilanzen
hourly load values	3 + 6 + 7 + 8 + 11 + 12 + 16	ENTSO-E
Vertikale Netzlast	10	TSOs
detailed monthly consumption	$2 + 13 + 14 + 15 - 7 - 8$	ENTSO-E

[15] Since primary energy source of electricity imports is beyond the national scope, the electricity import balance is treated as „primary energy source“ in the national energy balance sheet published by AG Energiebilanzen.

References

50hertz. 2015. 10-Punkte Programm der 110-kV Verteilnetzbetreiber und des Übertragungsnetzbetreiber der Regelzone 50hertz. [Online] 05. 05 2015. http://www.50hertz.com/Portals/3/Content/Dokumente/Medien/Positionspapiere/20140915_10-Punkte-Programm_Systemdienstleistungen-Kurzfassung.pdf.

AG Energiebilanzen. 2015. ag-energiebilanzen.de. [Online] 11. 05 2015. http://www.ag-energiebilanzen.de/35-0-Aufgaben-und-Ziele.html.

BDEW. 2015a. bdew.de. [Online] 11. 05 2015a. https://www.bdew.de/internet.nsf/id/8E3FVZ-DE_Ueber-uns.

—. 2015b. *Energie Info - Entwicklung des Stromverbrauchs in Deutschland.* Berlin : BDEW, 2015b.

—. 2012. Gemeinsam Zukunft gestalten - Leistungen des BDEW für seine Mitgliedsunternehmen. [Online] 01. 05 2012. [Zitat vom: 2015. 05 04.] https://www.bdew.de/internet.nsf/res/Gemeinsam%20Zukunft%20gestalten%20-%20Leistungen%20des%20BDEW%20f%C3%BCr%20seine%20Mitgliedsunternehmen/$file/BDEW_Leistungsbroschuere.pdf.

—. 2014. Satzung. *Satzung in der Fassung vom 26. Juni 2014.* Berlin : BDEW, 2014.

BNetzA. 2015. Bundesnetzagentur - Übersicht Strom- und Gasnetzbetreiber. [Online] 30. 04 2015. http://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/DatenaustauschundMonitoring/UnternehmensStammdaten/UebersichtStromUndGasNetzbetreiber/UebersichtStromUndGasnetzbetreiber_node.html.

Boschmann, Viktor. 2015. *Netz- und Systemtechnik.* [Befragte Person] Maximilian Schumacher. 30. 01 2015.

ENTSO-E. 2015. ENTSO-E country packages data sets. [Online] 2015. [Zitat vom: 05. 01 2015.] https://www.entsoe.eu/db-query/country-packages/production-consumption-exchange-package.

—. 2013. *ENTSO-E Yearly Statistics & Adequacy Retrospect 2013.* Brussels, Belgium : Secretariat of ENTSO-E, 2013.

—. 2014. Specific national considerations -Final Draft 2014- Data Expert Group. [Online] 2014. [Zitat vom: 15. 02 2015.] https://www.entsoe.eu/Documents/Publications/Statistics/Specific_national_considerations.pdf.

Eurostat. 2014. Electricity and Heat - annual questionnaire 2013. [Online] 01. 08 2014. [Zitat vom: 15. 03 2015.] http://ec.europa.eu/eurostat/documents/38154/4956296/AQ2013-ELEHEAT-instructions.pdf/fd62e4e2-403c-48ff-aba2-cab4395d9d13.

—. 2015. Eurostat - Overview. [Online] 2015. [Zitat vom: 04. 01 2015.] http://ec.europa.eu/eurostat/about/overview.

Eynck, Martin. 2015. *Amprion GmbH Bilanzkreisführung .* [Befragte Person] Maximilian Schumacher. 23. 04 2015.

Hirth, Lion. 2013. The Market Value of Variable Renewables. *Energy Policy 38.* 2013, S. 218-236.

—. 2015. The Optimal Share of Variable Renewables. *The Energy Journal.* 36, 2015, Bd. 1, S. 127-162.

Hirth, Lion und Ueckerdt, Falko. 2013. Redistribution Effects of Energy and Climate Policy: The Electricity Market. *Energy Policy.* 62, 2013, S. 934-947.

Hirth, Lion und Ziegenhagen, Inka. 2015. Balancing Power and Variable Renewables: Three Links. *Renewable & Sustainable Energy Reviews.* 2015, Bd. 50, S. 1035.

IEA. 2005. Energy Statistics Manual. [Online] 2005. [Zitat vom: 25. 02 2015.] http://www.iea.org/stats/docs/statistics_manual.pdf.

Jeżyński, Łukasz. 2015. *Statistical Correspondent for Poland.* [Befragte Person] Maximilian Schumacher. 05. 05 2015.

Kaiser, Jörg. 2015. *Mitarbeiter des Statistischen Bundesamt.* [Befragte Person] Maximilian. 05. 05 2015.

Kiesel, Florentine. 2015. *Fachgebietsleiterin beim BDEW.* [Befragte Person] Maximilian Schumacher. 28. 05 2015.

Kirschen, Daniel und Strbac, Goran. 2010. *Fundamentals of Power System Economics.* West Sussex : John Wiley & Sons Ltd., 2010.

Lagarrigue, Philippe. 2015. *ENTSO-E Support Desk.* [Befragte Person] Maximilian Schumacher. 22. 4 2015.

Ohlemacher, Frank. 2015. *Elektrische Betriebsführung - Deutsche Bahn.* [Befragte Person] Maximilian Schumacher. 01. 07 2015.

Pharabod, Erik. 2015. *Directeur du Département Information et Transparence.* [Befragte Person] Maximilian Schumacher. 05. 05 2015.

REE. 2014. *Dpto Estadistica e Informacion.* [Befragte Person] Maximilian Schumacher. 15. 04 2014.

Reuschel, Melissa. 2013. Aufgaben des Bilanzkoordinators. [Online] 01. 09 2013. [Zitat vom: 12. 03 2015.] http://www.tennet.eu/de/fileadmin/downloads/uber_uns/marktprozesse/MaBiS-Prozesse.pdf.

Schierenbeck, Dietmar Graeber, Andreas Semmig, Alexander Weber. 2010. Ein distanzbasiertes Hochrechnungsverfahren für die Einspeisung aus Photovoltaik. *Energiewirtschaftliche Tagesfragen.* 60, 12. 01 2010, S. 60-64.

Schwaiger, Florain. 2015. *National Data Correspondent - Germany.* [Befragte Person] Maximilian Schumacher. 04. 05 2015.

Sittaro, Philipp. 2015. *Systemführung - TransnetBW GmbH.* [Befragte Person] Maximilian Schumacher. 15. 4 2015.

Statistsiche Bundesamt. 2015. destatis.de. [Online] 11. 05 2015. https://www.destatis.de/DE/UeberUns/UeberUns.html.

Taccoen, Alain. 2013. REMIT Training. [Online] 10. 4 2013. [Zitat vom: 20. 03 2015.] http://fsr.eui.eu/Documents/Presentations/Energy/2013/130409-12TrainingREMIT/130409-12TrainingREMITENTSO-E.pdf.

Tennet-NL. 2015. *Customers & Markets callnumber: CAL-09044-R9B5L9 ten:0001670.* [Befragte Person] Maximilian Schumacher. 21. 04 2015.

TransnetBW. 2015. TransnetBW - Regelzonenlast. [Online] 23. 4 2015. https://www.transnetbw.de/de/kennzahlen/lastdaten/regelzonenlast.

Weniger, Bergner, Tjaden, Quaschning. 2015. Dezentrale Solarstromspeicher für die Energiewende. s.l. : Hochschule für Technik und Wirtschaft HTW Berlin, Juni 2015.

Wernicke, Ingrid. 2015. *DIW - AG Energiebilanzen.* [Befragte Person] Maximilian Schumacher. 18. 05 2015.

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