Supply and Demand of Flexibility in European Electricity Systems

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Abstract

In light of the increasing share of intermittent renewable electricity in Europes electricity system, the flexibility of the system to adapt to changes is of utmost importance.

The European Union as a whole, and member states have a direction that they are taking with regards to Energy Policy, like the 2020 renewable energy targets and the Energy Union. Seven European countries (including Switzerland) were considered. In this study, "flexibility as a term was defined, and four aspects of flexibility that were studied here were enumerated. The primary context of this study was the 2020 targets of the share of renewable energy in national energy systems as follows from the European Commission Directive 2009/28/EC. The possible influence of electricity policies on each of the four aspects of flexibility was estimated qualitatively, particularly focusing on infeed of intermittent renewables.

Four aspects of the power system were studied, focusing on the data available from the Day-Ahead markets, and power system data. The demand of some of these aspects of flexibility as well as the corresponding supply, were compared quantifiably.

In two aspects, namely in residual load variations and in the price peak response, there was a difference between certain countries. It was concluded that correlations between certain aspects of flexibility with the share of intermittent renewables do exist. The difference between countries often was the renewable energy support policies that certain countries had and others did not. It was found that some aspects had many influencing factors, and more insight would be useful.

Keywords: flexibility, electricity market, Europe, renewable energy

1. Introduction

Europe's electricity system has been under a constant change in recent years, particularly due to the higher influence of intermittent renewable electricity sources as well as the decline of conventional electricity generation sources such as nuclear power and coal power. To adapt to these changes, there needs to be flexibility in the electricity system.

In addition, the political and economic union that is the European Union (EU) and certain other non-members like Switzerland introduces interesting perspectives into this electricity transition. The EU, generally, has been at the forefront of policies combating climate change and reducing fossil-fuel dependency. In recent times, the most important step for the EU would be the European Commission Directive 2009/28/EC or the 2020 Renewable Energy Directive. This directive introduced renewable energy mix targets for each member state to be reached by 2020, with each member state having to submit a National Renewable Energy Action Plan (NREAP) to blueprint their progress in reaching the renewable energy targets in 2020. Electricity, along with Heating and Cooling, and Transport, was one of the sub-groups which were defined for which sub-targets were also defined.[1]

When the context of a european "electricity system" or a "power system" is to be defined in this study, it refers to this combination of the technical power system (power plants, grids, etc.), the economic system (Energy Union, market integration, etc.) and the political background (common targets, regulations, and directives). When the topic is being studied, it is aimed to look at each aspect of the system in relation to the others, particularly focusing on the generation and the market aspects of the system and the interplay between them.

The first objective of this study is to give a definition and interpretation of "Flexibility" in this context and establish technical parameters and measurements. Then, after collection of the data required, to analyse this data for each country to obtain the indicators of flexibility required.

Then the objective is to compare these indicators across countries, simultaneously considering the state of renewable electricity penetration as well as individual policies of countries to attempt to establish a correlation between these factors.

2. Background

In this study, seven focus regions were chosen in which the analyses were carried out. These regions were chosen mainly due to their diversity in energy mix types. There are big countries such as France, Spain and Germany, as well as smaller ones like Austria, Portugal and Switzerland. There is also diversity in climatic conditions and the predominant generation sources, which would possibly make for interesting comparisons. There was also the aspect of availability of data, due to which, some comparisons were not possible. The following countries were chosen to be a part of the study:

- Germany
- Austria
- France
- Switzerland
- Spain
- Portugal
- Great Britain (data partially available)

The following sections will give a short overview of the electricity mixes in each of the countries considered. Electricity mix data is taken from the European Commission Directorate-General for Energy's Handbook.[2]

2.1. Germany

To give a broad overview of the electricity mix in Germany, the country has seen a strong marked increase in the share of renewable electricity, with a share of up to 26,8 % of total consumption in 2014 as compared to a 17,6 % in 2010. Coal and other solid fuels have remained relatively stable despite the focus on cutting carbon emissions, possibly due to the decreasing share of nuclear energy which in turn was due to the so called *Automausstieg* (nuclear phase-out). Going by the installed capacity, 39 % of the installed capacity consisted of intermittent electricity sources like wind and solar PV.

At the centre of recent energy policy in Germany is the Erneuerbare-Energien-Gesetz (EEG), or the Renewable Energies Act. The first version of the EEG was introduced in 2000, which offered fixed feed-in tariffs to new installations of renewable electricity sources. It was modified several times through the years in 2004, 2009, 2012, 2014 to make several changes including setting market premiums, switching to direct marketing, and in 2016, announcing a shift from feed-in tariffs to auctions for certain sources.[3][4] The shift from fixed tariffs to auctions seems to signal that the government is ready to expose renewables more to market forces.

2.2. Austria

Austria is known for its high share of renewables in its electricity mix, with about 49,2 % of electricity (final) coming from renewable sources. It is known for its high amounts of hydroelectric electricity, consisting 13,1 MW of a total 23,6 MW (56 %)installed capacity. There is also a significant share of wind power in the mix, with 1,6 MW installed, chiefly in the eastern parts of the country.

The neighbouring countries of the Czech Republic, Slovenia and Hungary are coupled with each other, but not with the rest of the PCR (Price Coupling of Regions) regions, and a coupling would be seen as very beneficial. Austria forms a single price zone with Germany, and as such, has the same price on the market as Germany.

2.3. France

The French electricity mix is based heavily on nuclear energy with nearly 74 % of the generated electricity (2013) coming from nuclear energy. Renewable electricity production takes up the next largest share in the electricity mix with 17,7 %. To break it up by installed capacity, it is evident that the three major sources of installed electricity generation are nuclear (49 %), combustible fuel-based (21 %), and hydroelectric (20 %), with a smaller but significant share from wind.

The French company EDF owns a significant share of the French electricity market, exploiting nearly 91,5 % of installed capacity in France (2014), leaving the market highly concentrated. In addition, the market has low liquidity, with nearly 87 % of the trading taking place over-the-counter (OTC). An important concern that has been raised is the lack of interconnection capacity between France and the Iberian peninsula (Spain and Portugal), this has been cited as a key to a more integrated european power system.

2.4. Switzerland

Switzerland, like its alpine neighbour Austria, is heavily reliant on hydroelectric and nuclear power for its electricity needs. Intermittent renewables make up quite insignificant amounts of power generation, with about 0,1 % of the electricity generation in 2013 coming from solar PV, and 0,8 % from wind power (2013). Hydroelectric and nuclear power make up almost all of the generation in Switzerland.

2.5. Spain

Spain is one of the larger countries in Europe which currently has a majority of its electricity share coming from renewables, with up to 39,84 % of the electricity consumption mix composed of renewables (2013). This could largely be attributed to its high installed capacities of wind power and solar PV (23,0 GW and 4,8 GW respectively in 2013).

An important factor to consider is that Spain is one of the countries that was economically most affected by the european sovereign debt crisis in the late 2000s and early 2010s, and as such, the electricity consumption reduced in line with the economic demand. To counter the tariff deficit, the Spanish government has been introducing regulations (often retrospective) that reduce support for renewable sources of electricity production.[5]

2.6. Portugal

In 2013 in Portugal, the share of renewables in gross electricity consumption was about 49,2 %, with the rest of the mix being filled by natural gas, solid fuels and petroleum products. That figure would have been influenced, however, by trading. To give an idea of the generation capabilities of the country, Portugal has nearly 5,7 GW of installed hydroelectricity generation capacity, and 4,6 GW of installed wind power generation capacity, out of a total of 18,9 GW of installed capacity.

While Portugal has also been affected heavily by the european sovereign debt crisis, its renewable policies have not seen such a drastic shift as have Spain's. The only land border the country has is with Spain, and the interconnection capacity has been increasing. EDP S.A. (*Energias de Portugal*), the formerly state-owned energy generation company was privatised in 2013, but still has a 43 % share in the electricity generation market.[5]

2.7. Great Britain

Previously reliant on coal, Great Britain moved towards producing electricity using natural gas from the early 1990s. Since then, coal, natural gas and nuclear energy have each retained significant shares in the electricity mix till the present day. Renewables have been increasing their share in the mix, with about 15,7 % of consumed electricity in 2013 coming from renewable sources. Wind energy is the primary renewable power source, with 11,2 GW of installed capacity, in contrast with 4,4 GW of hydroelectric and 2,8 GW of solar PV installed (2013).

There are two electricity Spot markets operating in parallel in Great Britain – the APX UK Spot Market, and the N2EX, operated by Nordpool Spot (which operates the Spot market primarily in the Nordic countries). Traders may use either market to take part in the auction, with the result being the same in order to facilitate linking to the rest of the european system. The N2EX has a higher share of volumes traded (about 35 % in June 2015), whereas the APX UK had a share of 17 % in the same month (the rest of the exchange happening Over the Counter (OTC)).

3. Analysis

"Flexibility" on its own is a rather vague term as applied to electricity markets. It is important to clearly define what flexibility is, so that clear indicators can be defined. The report by von Roon et al. (2014) gives some pointers to what could be potentially considered as indicators of flexibility in electricity markets, and that definition has been largely used in this study.[6]

In this study, the flexibility studied is as applied to traditional electricity markets in connection with European and national power systems. Other perspectives might include studying the grid parameters for indicators of flexibility, or studying the volatility in the markets in a purely economic study. For the scope of this study, flexibility, as defined by von Roon et al. (2014) could come under four broad categories:

- Flexibility in adjusting to variations in residual load
- Flexibility in recovering from price extremes
- Flexibility to adjust to load gradients
- Short Term availability of power

3.1. Methodology

Residual Load is defined as the total load on the electricity system that remains after discounting the electricity infeed from sources of energy that *must run* due to either feed-in regulations or very low sale price, or other compulsions. Hence these sources are deemed "uncontrollable" because their infeed is, in effect, mandatory (except in exceptional cases where the TSO can decline infeed). In most cases, these must-run sources are wind and solar PV installations. The residual load denotes the amount of power that is needed to be covered by "controllable" sources like conventional power plants whose grid infeed is not guaranteed and whose generation can be controlled, therefore being regulated by the market.[7] So, the residual load is defined as:

$$L_{res} = (L_{total} - I) \quad (1)$$

where:

L_{res}: is the residual load (GW)

L_{total}: is the total load (GW)

I: is the "uncontrollable" infeed, *i.e.* infeed from wind and solar PV

3.2. Aspect 1: Flexibility in Adjusting to Variations in Residual Load

There is a requirement of flexibility to even out variations in residual load. A flexible power system would be better capable of evening out differences. As such, the degree of variation of the residual load can be seen as a measure of the flexibility *demanded*.

The Standard Deviation of the residual load would give a good measure of the demand of this aspect of flexibility in the power system.

A higher value of standard deviation would denote a higher variation in residual load in the given time interval, and therefore an increased demand for flexibility to balance it out. The time interval selected will also be crucial here, since extended intervals of time may be influenced by seasonal variations.

When it comes to the *supply* of this aspect of flexibility, there could be many options that could be studied, including, but not limited to, analysing the amount of storage or storage potential that the country has, and also by analysing the cross-border interconnection capacities. However, data on storage in particular, was not reliably available publicly, and that analysis was not performed.

3.3. Aspect 2: Flexibility in Recovering from Price Extremes

When a merit order curve and the corresponding buy curve is considered, each curve is constructed by plotting the bid price and cumulative bid volume of each order. The bid price here is considered the marginal price of the bidder. The structure of the curves and also the extremeness of the price show a measure of the shortage of flexible power. So, by flexibility of price-dependent power, the capability available in the market to remain within a specified price range is denoted.

To determine the amount of flexible power *demanded*, the curves for each hour and each day are analysed. First, the price limits are to be defined, beyond which it is deemed an extreme price. For this analysis, to maintain uniformity, any price outside of $\pm 2\sigma$ (2 standard deviations) from the mean price of the reference year, is considered an extreme price.

The hourly price is determined by the intersection point of these two curves. In case the price is outside of the defined limits, the buy curve is shifted accordingly to be at an acceptable price level. The volume (X-Axis) by which it needs to be shifted shows the measure of flexibility available. If the curve at the region of intersection in the graph is too flat, then the system would be deemed to have a high demand for flexible power, since it takes a large volume shift in order to attain a non-extreme price. If it is not flat, then a lesser volume would be needed to shift to an acceptable price level and the system is deemed to have low demand for flexible power.

When there is an extreme price detected, the buy curve is shifted along the X-axis to the nearest non-extreme price point. In this case, the price is above the extreme price limit, so it is shifted left. The amount by which the shifting occurs is taken to be representative of the amount of flexibility demanded.

To determine the *supply* of flexibility to avoid price extremes, once again the sell and buy curves are examined. All sell orders below the intersection point of the curves should be deployed as well as all buy orders above the intersection. So, the total available flexible power here is considered to be the amount by which the buy curve can be shifted (or conversely, the sell curve in the opposite direction) till there are no more available sell offers. This translates to the difference between the first point in the buy curve and the last point in the sell curve.

3.4. Aspect 3: Flexibility to Adjust to Load Gradients

The load on the system is a continually changing measurement; within a day there are variations according to to daily routines, among other factors. Intermittent power sources like solar PV installations contribute to another cycle of variations, whereas both solar and wind energy installations are subject to other general weather variations not necessarily related to the daily cycle.

This measure of flexibility measures the existence of high gradients in the residual load and correspondingly, the necessity of flexibility to handle the gradients. Gradients are defined here as the difference between the residual loads of each point in time:

$$\Delta = \frac{L_{res,t+1} - L_{res,t}}{t} \qquad (2)$$

Where:

Δ: is the gradient in residual load (GW/h)

L_{res}: is the residual load at that hour (GW)

t: is the timestep (h)

The load and generation data available from most providers is in 1-hour intervals, and so as far as this study is concerned, gradients are measured with respect to 1 hour. If data in shorter intervals were encountered, they were converted to 1-hour intervals.

The *demand* of this aspect of flexibility can be seen by the frequency and the magnitude of the residual load gradients. The *supply* of this aspect of flexibility can be determined by the bid curves. The amount of available flexible volume is the difference between the volume of the highest sell bid and the lowest buy bid. At any particular hour showing a high gradient, it is checked to see how much available flexible volume is present in the market.

3.5. Aspect 4: Short Term Availability of Power

This aspect of flexibility refers to the availability of tradeable volume of electricity on the markets after the day-ahead markets have closed i.e. on the Intraday market. The *demand* of this aspect of flexibility can be demonstrated when there is a change in the short term situation in availability of power on the market. The actual load and the load as forecasted can often be different. The forecasted load would have likely been used as a basis for the trade on the Day-Ahead market, and in cases of an inaccurate forecast, electricity on shorter-term markets would have been used.

The difference between the forecast and the actual load can be differentiated into the *known* and the *unknown* forecast error. The *known forecast error* would need to be compensated by the volume traded on the Intraday market. The volumes traded as well as the price levels on the Intraday market, and further, the differences in the price levels between the Day-Ahead and Intraday markets would give a measure of the demand of this aspect of flexibility. The unknown error would likely be supplied by the reserve markets.

For the analysis of the *supply* of this aspect of flexibility, further analysis into the Intraday market curves would be needed. Since this data was not available publicly for all the countries, the analysis was not performed.

4. Comparisons

A comparison of how these seven countries stand with respect to the aspects of flexibility studied above was done. Wherever necessary, data was made comparable by normalisation with a suitable base.

4.1. Aspect 1: Flexibility in Adjusting to Variations in Residual Load

When the different countries are compared on the variations in residual load they exhibit through the year, there are two points of discussion that are very clearly visible, as seen from Figure 1. The graph has been normalised to account for each country's relative size (in terms of residual load).

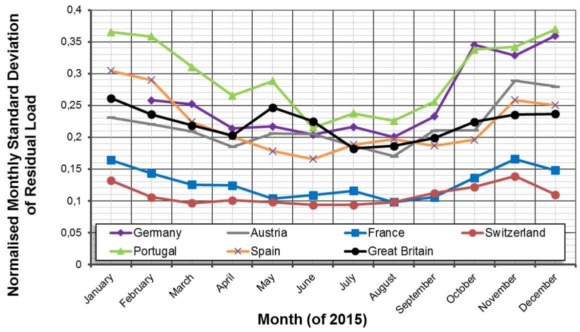

Figure 1: Comparison of the normalised standard deviation of residual load in 2015 for the countries studied

As previously noted, there is a seasonal variation that is readily apparent through the months of the year. Winter months tend to have a higher standard deviation of residual load as compared to summer months, and this is valid for almost all countries. Switzerland is an outlier in this in that it only shows mild increases in its winter months before reverting back to a near constant level.

The chief point notable in this comparison is the striking difference between two groups of countries: France and Switzerland are clearly well apart from the rest of the countries. France, particularly, is famously nuclear-intensive in its electricity mix, with significant shares of hydroelectric and combustible fuel-based power generation. Switzerland, too, has almost its entire electricity generation based on nuclear or hydroelectric power.

When the shares of intermittent renewables (wind and solar PV) in each country is seen alongside the average standard deviation in residual load as in Figure 2, there is a correlation that can be observed.

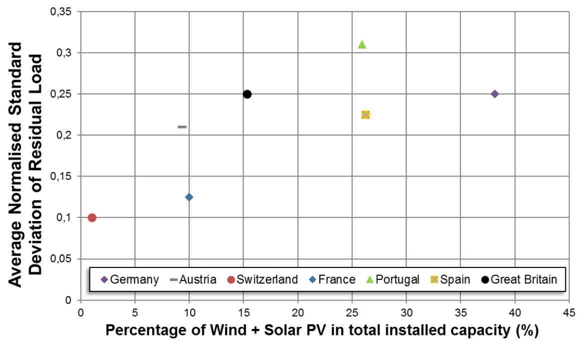

Figure 2: The average normalised standard deviation of residual load in 2015 versus the percentage of wind and solar PV in the share of installed capacity in each country

Countries that have higher shares of intermittent renewables do tend to have a higher standard deviation in residual load, indicating a mild correlation between the two factors. In previously presented cluster analyses, it was also shown that wind power was responsible for a large part of the increase in standard deviation.

However, it must be noted that the infeed of intermittent renewables is only one of the influencing factors, and there are other factors that could be taken into account in order to give a more comprehensive picture of the flexibility required in each of these countries.

4.2. Aspect 2: Flexibility in Recovering from Price Extremes

The central point in the analysis of this aspect of flexibility was the definition of extreme prices and defining the methods used to determine how flexible the market is in recovering from these extremes, by the concept of shifting or offsetting the Day-Ahead market curves. In the development of this aspect of flexibility, the concept of a "flexible volume" of electricity on the market was mentioned.

From the analysis, it can be made clear that the Germany + Austria market had the lowest demand for this aspect of flexibility when compared to the other countries. The French and the Swiss markets demanded more flexibility.

The MIBEL market was unique in that the market did not have too many price peaks to report, due to the fact that whenever there were price peaks, they were very high.

In the interesting case of Great Britain's APX market, in the many cases there was a demand for flexible electricity on the market, it could not be supplied on this market. Great Britain's two markets share a common price, and the required flexible volume might have been supplied by the other market. Nevertheless, the dynamics of two markets working in parallel would be interesting to study further.

Concerning the demand of this aspect of flexibility, a useful measure to compare is the available flexible volume on each market as compared in Figure 3.

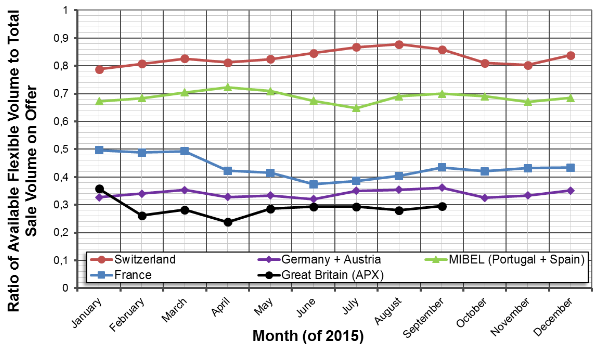

Figure 3: Comparison of monthly averages of the ratio of available flexible volume to total sale volume on offer for each market in 2015

The individually normalised values themselves might not be very useful for comparison, but what is interesting here are the relative positions of the countries. The observation here would be that the Swiss market and the MIBEL market do have a lot more flexible volume of electricity available on average as compared to the Germany + Austria, Great Britain's APX and French markets.

4.3. Aspect 3: Flexibility to Adjust to Load Gradients

Hourly gradients of residual load were calculated for each hour of 2015 for each of the studied countries, in order to determine if large gradients had any effect on the market and available flexible volume.

From the comparison of the gradient frequencies, it can be seen that most countries have residual load gradients that are relatively gradual.

However, when normalised, the graphs look highly similar and overlapping. An interesting aspect to note is that for most countries, there are many more extreme positive gradients than negative gradients. This could possibly be due to the observed fact that gradients in the morning (at about 0500 Hrs - 0600 Hrs) are higher than the gradients in the night, when the loads go down gradually, possibly a characteristic of household loads.

With regard to the availability of this aspect of flexibility, on each of the hours with extreme gradients, there was no significant change in the available flexible volume on the markets of any country, possibly due to reliable forecasting or due to the fact that short term changes are not dealt with on the Day-Ahead markets.

4.4. Aspect 4: Short Term Availability of Power

When the absolute difference in Day-Ahead and Intraday market prices were analysed and compared between countries, the results were such that there seems to be little comparison possible, since the curves are very close to each other, without much to differentiate between them. More insight into the interplay between Day-Ahead and Intraday markets would probably be needed to investigate this aspect of flexibility further.

5. Conclusions

From the studies into the first aspect of flexibility presented in this study, *i.e.* the flexibility to adjust to variations in residual load, a chief conclusion was that there is a mild correlation between the share of intermittent renewable electricity in a country and the standard deviation of residual load. Investigating further, it was found that variations during winter months, possibly due to wind power infeed, was one of the major causes of increased variations in residual load. France and Switzerland in particular, show much lower variations in residual load, and therefore demand lesser flexibility from the system.

In the second aspect studied, *i.e.* the flexibility of the Day-Ahead markets to recover from price peaks, there were some differences in the demand of flexibility from different markets. The Germany + Austria market and the French market demanded the least flexibility, whereas the Swiss market demanded more flexibility. When comparing the supply of flexibility, however, the Swiss and the MIBEL market had the most supply of flexibility on offer. These comparisons did not clearly point to the reason behind this difference, and more information on influencing factors might be necessary.

The third and the fourth aspects, namely the analysis of hourly gradients in residual load and the analysis of the differences in Intraday and Day-Ahead prices yielded many similarities between the studied countries, with little to separate them, and as such, a study into more particular factors might be useful.

The electricity policies of the countries studied does show that there were various ways in which renewable electricity was encouraged by governments. This was dependent not only on the individual geographical positions and geographical or topographical benefits that each country has, but also on the individual histories and political attitudes of policymakers.

Most of the countries considered did make significant progress towards meeting their 2020 renewable electricity targets, but each in different ways. Some of the countries which promoted wind power heavily, for instance, did show increased demand for flexibility. It was seen that the greater impetus given to intermittent renewable energies particularly in countries like Germany, Spain and Great Britain was clearly demonstrated in the increased demand for flexibility, whereas the lesser aggressive promotion of them in countries like France, as well as other historical factors reflected in them having lesser demand for that aspect of flexibility.

While it is not possible to pinpoint specific impacts of specific policies on a macro level, it is useful to differentiate between countries to gain a perspective of the differences between countries on a comparative basis. An alternative or a supplementary approach would be to perform a historical analysis, provided that enough data is made available.

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References

[1] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Luxembourg: Publications Office of the European Union, 2009

[2] EU Energy in Figures Statistical Pocketbook 2015. Brussels: European Commission Directorate-General for Energy, 2015

[3] Act on the Development of Renewable Energy Sources (Renewable Energy Sources Act - RES Act 2014) - Unofficial translation of the RES Act in the version in force as of 1 August 2014. Berlin: Bundesministerium für Wirtschaft und Energie (BMWi), 2014

[4] 2016 Revision amending the Renewable-Energy-Sources-Act. Berlin: Bundesministerium für Wirtschaft und Energie (BMWi), 2015

[5] EU Energy Markets in 2014. Luxembourg: Publications Office of the European Union, 2014

[6] Deutsche Energie-Agentur (dena): Entwicklung der Erlösmöglichkeiten fr Flexibilität auf dem Strommarkt. Berlin: dena, 2014

[7] Höflich, Bernd; Noster, Rafael; Peinl, Hannes; Richard, Phillip; Völker, Jakob; Echternacht, David; Grote, Fabian; Schfer, Andreas; Schuster, Henning: Integration der erneuerbaren Energien in den deutschen/europäischen Strommarkt - Integration EE. Berlin: Deutsche Energie-Agentur GmbH (dena), 2012