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DOES ONE DESIGN FIT ALL?

ON THE TRANSFERABILITY OF THE PJM MARKET DESIGN TO THE GERMAN ELECTRICITY MARKET

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Abstract

Germany's nuclear phase out and an increasing share of fluctuating RES production amplifies the North-South congestion problem in the German electricity grid. But congestion management becomes a serious issue not only in the German but in the whole European electricity system as German wind production does not only affect the German grid. In theory it is well established that nodal pricing is the most efficient congestion management method. In literature the PJM well-established nodal market design often serves as a reference and is viewed as benchmark. To benefit from experiences made in the U.S. the transfer of the PJM market design to Germany could be advantageous. This article compares key elements of the generation mix, the network structure, the cross-border interconnection as well as the congestion situation of both electricity markets to assess potentials and impediments for an implementation of the PJM nodal market design in Germany. We show that both markets are less different in structure than expected but that large differences in performance respectively in congestion frequency lead probably to much lower welfare gains. Transfer of the PJM market design to Germany is possible in principle, but adjustments to RES would be advantageous.

Keywords : Nodal Pricing, Market Design, Electricity Markets

JEL-Classification : Q40

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1. Introduction

In the past, redispatch in Germany was rather exceptional. While the amount of redispatch measures needed to keep up system reliability decreased constantly between 2007 and 2010, the amount of redispatch increased by 90% in 2011 (cf. Bundesnetzagentur 2012). Mainly the moratorium on nuclear power and the corresponding shutdown of the 8 oldest nuclear power plants in Germany is responsible for the huge increase of redispatch seen in 2011. Increasing renewable production and massive delays in grid extension[1] make congestion management a major issue for the future. While production (and especially wind production) is mainly located in northern Germany, main consumption centers are located in the south. The integration of huge offshore wind parks in the German North Sea will additionally amplify the North-South congestion problem unless the grid extension is accelerated massively. Moreover additional German offshore wind capacities do not only affect the German electricity grid but also the grid of neighbouring countries such as Poland and the Czech Republic.

Besides zonal pricing and enhanced market coupling, nodal pricing is discussed in the literature and proposed as first-best answer to deal with upcoming congestion management issues in Germany and Europe (e.g. Neuhoff et al. 2011, Weigt et al. 2006). In the current German market design, one wholesale electricity market price is determined for Germany without regional differentiation. Congestion is dealt with through redispatch done by the grid operators. By contrast, nodal prices take congestion from the outset into account by differentiating power prices between nodes on both sides of a congested line. Nodal prices are thus expected to provide adequate signals not only for the operation of power plants but also for the usage of transmission capacities. The American PJM interconnection is one of the most well-known and long-lasting examples of a well-functioning nodal market and serves therefore often as a reference case for nodal market design.

But the transferability of the PJM nodal market design to an electricity market like Germany and potential welfare gains strongly depend on the characteristics of the system considered. Therefore a detailed comparison of the system characteristics is an important first step to identify crucial issues to be solved ahead of an implementation and to assess the potential benefits of the implementation of a nodal market design in Germany.

[1] 15 of the 24 so-called Enlag-grid extension projects are currently facing delays of 1-5 years. For more details see Bundesnetzagentur and Bundeskartellamt (2012)

Within this article we analyze key elements of the generation mix, the network structure, the cross-border interconnection as well as the congestion situation of both markets to assess potentials and impediments for an implementation of PJM's nodal pricing in Germany. We therefore define and compare structural and performance indicators for each of the four fields mentioned and analyze their importance for the transferability of the PJM market design and the potential gains in efficiency. As the largest market within Europe our focus is on Germany, but many results may also be transferable to the broader European realm.

The paper is organized as follows. After a brief recapitulation of the issues surrounding market design in the context of congestion management (cf. section 2), the paper focuses in section 3 on the differences and similarities between PJM and the German electricity market. In the field of generation (section 3.1), a particular focus will thereby be on the share of renewables. Especially decentralized renewables are expected to lead to important implications for an adequate market design, notably to cope additionally with congestion on distribution network level. For the description of the network structure (section 3.2), key indicators are developed and quantified to characterize the density of the existing network and the density of the underlying electricity consumption. As loop flows can have negative impacts on the efficiency of LMP markets (cf. PJM 2011a), we compare the deviations between scheduled and physical cross-border flows for both markets as an indicator for loop flows (section 3.3). The congestion frequency mainly influences the potential benefits of a nodal market design and is therefore compared for both markets in section 3.4. Section 4 concludes with the major findings about the transferability of the PJM market design to Germany and about the potential benefits of the implementation of LMPs in Germany in general.

2. Market design in the context of congestion management

Congestion occurs when transmission facilities are not sufficient to transport available, least-cost energy to all loads for a period. In case of congestion, higher cost units must be dispatched in the transmission-constrained area to meet the local load as bottlenecks in transmission avoid the import of least-cost energy. The combination of congestion and higher costs of local generation consequently leads to a higher price of energy in the transmission-constrained area than in the unconstrained area (PJM 2010b).
"Congestion is neither good nor bad but is a direct measure of the extent to which there are differences in the cost of generation that cannot be equalized because of transmission constraints" (PJM 2010b, p. 403). In line with this general statement, several approaches for an efficient management of transmission constraints have been described in the literature (cf. e.g. Hogan 1992, Schweppe et al. 2000, Wu et al. 1996). There is an

ongoing discussion which market design is best suited to assure adequate price signals including scarcity signals and locational investment incentives. Different congestion schemes such as nodal, zonal and uniform pricing but also market coupling as currently pursued by the European Commission are proposed in academic literature and politics to deal with upcoming national and international congestion.

In theory, nodal pricing (also: locational marginal pricing) is the most efficient congestion management method as shown by Hogan (1992). PJM (2011a) p.471 defines locational marginal prices as prices that "reflect the price of the lowest-cost resources available to meet loads, taking into account actual delivery constraints imposed by the transmission system. Thus LMP is an efficient way to price energy when transmission constraints exist."

With regard to increasing congestion in Germany it is therefore reasonable to discuss the shift to a nodal market design, which is obviously the most efficient way to deal with the upcoming congestion. In this context Germany could learn from the experience made in PJM while implementing a more efficient market design. PJM is a well-established and long-lasting example for a good-working nodal market. It might be advantageous to transfer the PJM market design to Germany to benefit from the broad base of experience made.

Thus our key research questions are:

- How different are both electricity markets?
- How do differences identified affect the transferability of the PJM nodal market design to Germany?
- How great are the potential benefits for Germany?

Or in other words: could one market design fit all?

To answer these questions we define several indicators to compare market structure and performance within the following four categories. Beside the **generation** mix we take a closer look on the **network** structure and its performance with a particular view on **congestion**. When disregarding transmission losses, nodal pricing is more efficient than zonal or uniform pricing only in hours with transmission congestion. Thus gains in efficiency are higher in a highly congested transmission network than in a network with low congestion. But not only congestion frequency is relevant for the appropriate design of electricity markets. There are several further aspects to be considered carefully.

While a high degree of intermeshing of a transmission grid increases the complexity of a nodal market design, the generation mix of an electricity market can raise further challenges. A high share of fluctuating RES feed-in is likely to increase congestion (as seen in Germany) and emphasize therefore the need for implementing an efficient congestion management. But especially in case of Germany decentralized RES production leads mainly to higher congestion in distribution networks and has therefore also to be considered.

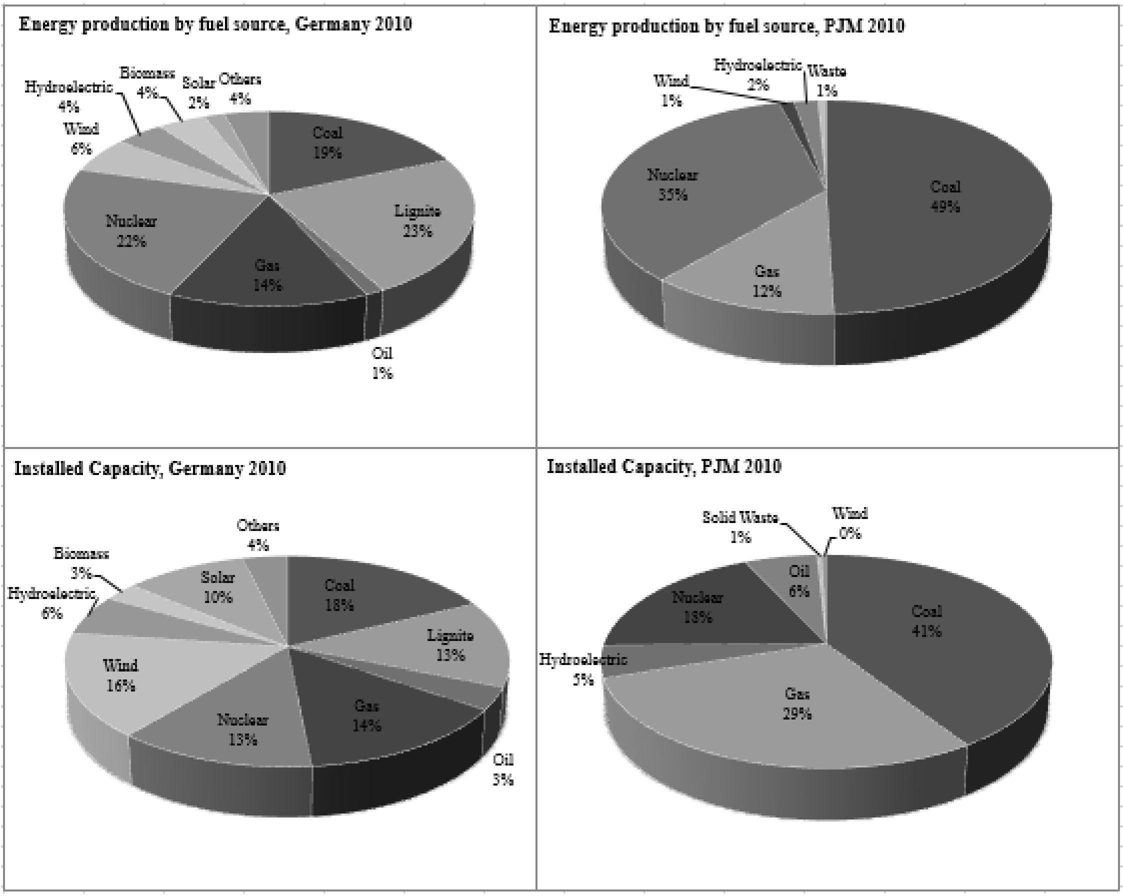
Also the interconnection with other countries is of high relevance for the electricity market design especially in Europe since physical flows do not correspond to scheduled flows. Analyzing the effects of **cross-border loop flows** is however difficult due to data access limitations. The implementation of nodal pricing only in Germany seems to be questionable, given the multiple interconnections with the neighbouring countries.

3. Differences and similarities between PJM and Germany

In the following we define and compare several indicators to highlight differences and similarities between the PJM and the German electricity market. As mentioned before we therefore focus on four main areas for comparison: **generation**, **network**, **cross-border flows** and **congestion**. While the first three aspects relate to the structure of the markets and the grids, the last category describes the performance of networks.

3.1 Generation indicators

Structural differences in the generation mix of both markets may obviously be compared by using the energy production and the installed capacity by fuel source as indicators. Figure 1 therefore shows both indicators and reveals some similarities at first sight. The generation mix of both markets is dominated by fossil fuels – 57% in Germany and 61% in PJM.



Sources: BMWi (2011), PJM (2011a)

Figure 1: Comparison of generation indicators for PJM and Germany (2010)

While remaining demand is mainly served by nuclear power in PJM, nuclear production in Germany served less than the half of remaining demand in 2010 and – needless to say - will decrease further in the future due to the German nuclear phase-out. 16% of German demand are served by RES production, which is about four times the share of RES production in PJM. Due to high subsidies for solar power in Germany, installed PV capacity was 17 GW in 2010 while only serving 2% of energy production (cf. BMWi 2011). Germany's main RES source is wind which is like PV also produced mainly in decentralized installations. Only a few onshore wind parks like Wilster and Putlitz are connected directly to the transmission grid. Installed wind capacity in 2010 was 27.2 GW for Germany (cf. BMWi 2011). But offshore wind farms with about 16 GW capacity are currently planned and approved in the German North and Baltic Sea (cf. IWR 2012).

What are the implications of a higher RES share in energy production for the implementation of nodal pricing in Germany? On the one hand an increasing share of fluctuating renewable feed-in will challenge dispatch processes.[2] Updating day-ahead planning in order to adjust for new information (forecasts) becomes increasingly important (cf. Weber 2010).

On the other hand rising decentralized RES production causes already problems in the distribution network. Therefore the renewable energy law allows curtailing a wind plant's output in situations in which the network is constrained. In 2010 curtailment of RES production in Germany was ca. 127 GWh (almost all wind-shedding), which is only 0.16% of the whole amount of electricity produced by RES (respectively 0.34% of wind energy production). Yet this number will increase significantly in future if grid extension progresses at the current low pace (cf. Bundesnetzagentur 2011).

In most cases, wind curtailment is caused by bottlenecks in the network to which the wind parks are directly connected (cf. Bundesnetzagentur 2011). With an increasing share of distributed RES, DSOs will have to deal with more congestion in distribution networks, especially in hours with high wind penetration or high solar production.

PJM operates a network in which historically most congestion takes place in high-voltage grid levels (see section 3.4). Thus the focus of the PJM market design is mainly on the efficient management of congestion in high-voltage transmission grid, not on congestion at distribution voltage levels. A shift in Germany's congestion management towards the PJM nodal market design should therefore also take congestion in distribution networks into account. LMPs can in principle be used also to manage congestion in distribution networks. Yet the implementation of LMPs not only on transmission but also on distribution network level will lead to a huge increase in complexity due to the larger network and the higher number of buses (which is also a computational issue). In addition to that the resulting smaller market areas probably increase the possible abuse of market power. Further discussion of different options to deal with congestion in distribution networks by locational price signals can be found in Brandstätt et al. (2011).

Also the share of hydro production with (seasonal) storage is of high relevance for the transferability of market design. In 2009, only 2% of PJM's demand has been served by hydro power. In Germany the share is about 4%, yet this percentage is far higher in Europe as a whole. Especially in the Alps and in Scandinavia large hydro reservoirs exist. The valuation of stored hydro resources is an entrepreneurial decision and it is questionable whether it should be transferred to a centralized dispatch.[3]

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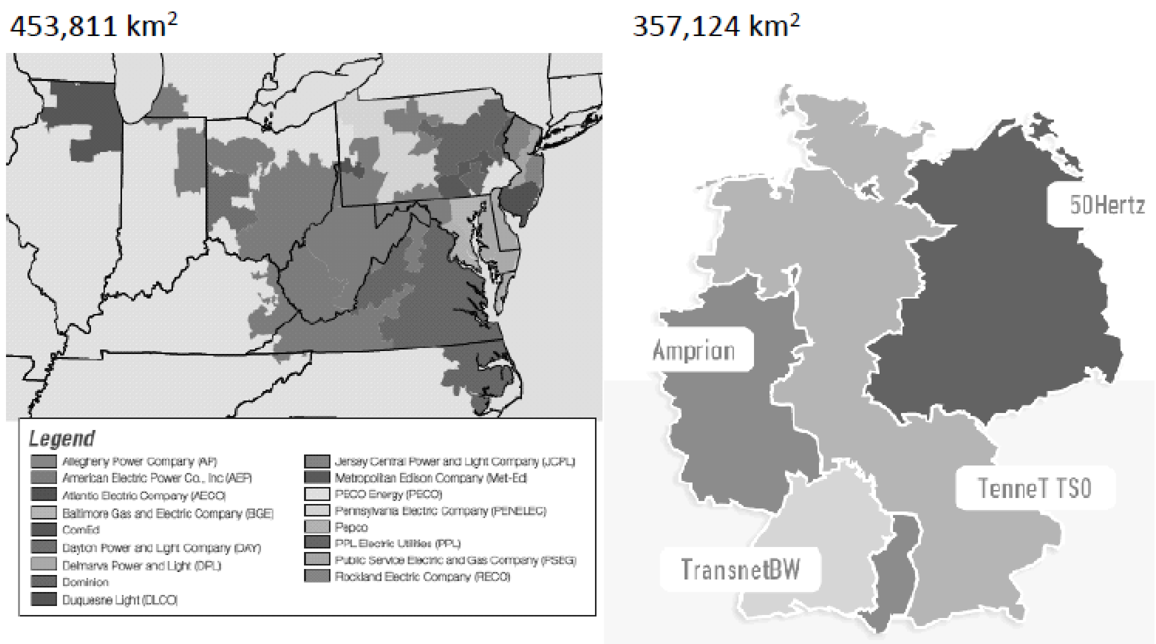
[2] E.g. increasing importance of reliable RES forecasts over short periods not only for TSOs to keep up system reliability but also for market participants to react on lacks of wind power and the associated impacts on (intraday) prices.

[3] PJM currently allows hydro units to use a forward option value method to calculate their value of energy stored by using forward energy price curves from exchanges. But PJM also requires each plant operator to submit a cost-based bid to be used in case of congestion.

With respect to our research questions, we note that there are significant structural differences in the generation mix of both markets. The much higher and still increasing RES share in the German electricity market requires a market design that considers congestion management both on transmission and distribution network level. Furthermore a higher RES share will probably cause more loop flows, which in turn have negative impacts on market efficiency (cf. PJM 2011b). We will analyze loop flow problems within section 3.3 in context of cross-border flows. Hence, we conclude that the generation structure is not a general impediment to the transferability of the nodal PJM market design to the German electricity market but further adjustments are needed regarding congestion in distribution network due to a high share of decentralized RES.

3.2 Network indicators

As a first and rough indicator for the network structure the shape of market areas may be used. Beside the fact that the PJM market area is 27% larger than Germany, the very different shape of both market areas is also shown in figure 2. While Germany looks very compact, PJM is divided in many territories. Especially the Western part of PJM is fragmented.



Sources: PJM (2011a), www.netzentwicklungsplan.de

Figure 2: Comparison of the PJM and German network areas

In general it is believed that European electricity grids are much more intermeshed than the historically more fragmented U.S.-networks (cf. e.g. Brunekreeft and Balmert 2008).

At first glance, the PJM network system seems to be more widespread and therefore less intermeshed than the German electricity grid.

Based on the key figures shown in table 1, network indicators of both transmission networks are computed in order to check that common opinion (cf. table 2). Yet two problems arise. First the available data for both markets are different. While PJM provides information about all monitored network facilities and buses, information about the German network are publicly only partly available. The second problem is that basic concepts (especially the term 'high-voltage transmission grid') are defined differently. In Germany, the electricity transmission grid consists of lines with voltage levels of 220 kV and 380 kV. Lines with lower voltage levels (110 kV and less) are part of the distribution grid. In the U.S. only lines with voltage levels of 345 kV and above are considered as part of the transmission grid. To cope with these problems, we therefore compare the German transmission grid both to the PJM transmission grid and to all lines in PJM with a voltage level of 230 kV and more.

Table 1: Key figures of the electricity grids of PJM and Germany

Key figures	**Unit**	**PJM *(incl. 230 kV)***	**PJM *(transmission grid)***	**Germany *(transmission grid)***
Surface	*km²*	453,811		357,124
Generation (2010)	*GWh*	734,678		628,101
Number of transmission lines [a]	*circuits*	1,270 [b]	397 [b]	1,338 [d]
Transmission line circuit kilometers	*circuit km*	42,269	31,957	35,129
Number of buses	*buses*	408 [c]	162 [c]	351 [d]

Notes: [a] counted in circuits [b] based on PJM transmission providers facilities list [c] based on PJM LMP Bus model: substations, no double counting, including hubs and interconnectors [d] based on ENTSO-E grid map

Sources: BMWi (2011), Bundesnetzagentur (2010), ENTSO-E (2011a), PJM (2010a, 2010b, 2011c), www.pjm.com, Statistische Ämter des Bundes und der Länder (2011), own calculations

Several indicators are defined to analyze whether the first impression based on the geographic surface holds also for the (transmission) grid. First of all, a useful indicator to measure the transportation requirement is the **generation density**, computed as follows:

$$generation\ density = \frac{generation^{4}}{surface} \quad (1)$$

As shown in table 2, our calculation indicates a slightly higher transportation requirement in the German transmission grid.

Table 2: Comparison of network indicators for the electricity grids of PJM and Germany

Network indicators	**Unit**	**PJM *(incl. 230 kV)***	**PJM *(transmission grid)***	**Germany *(transmission grid)***
Indicator of transportation requirement: Generation density per km²	*GWh/km²*	1.53	1.53	1.67
Indicator of transportation capacity: Density of network	*1/km*	0.093	**0.070**	**0.098**
Adjusted indicator of transportation capacity I: Performance of network	*GVA*	1,441	**869**	**1,745**
Adjusted indicator of transportation capacity II: Length-weighted performance of network	*GVA* circuit km*	86,430	**79,727**	**43,541**
Indicator of intermeshing of network I: Ratio transmission lines to buses	*lines per bus*	3.113	**2.451**	**3.812**
Indicator of intermeshing of network II: Average length of transmission line	*circuit km*	104	**197**	**100**

Sources: BMWi 2011, Bundesnetzagentur (2010), ENTSO-E (2011a), PJM (2010a, 2010b, 2011c), www.pjm.com, Statistische Ämter des Bundes und der Länder (2011), own calculations

In contrast, the second indicator measures the size of the actual transportation capacity of the grid. We calculate the **density of the network** as

$$density\ of\ network = \frac{transmission\ line\ circuit\ km}{surface} \quad (2)$$

When the comparison is done solely based on the transmission grid, the German network is nearly 40% more dense than the PJM transmission grid. But the comparison based on similar voltage levels indicates a nearly same level of density.

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[4] The vertical system load would be a better reference basis but is not available for PJM.

But the density of network as defined above does not take into account its performance. Thus we consider two adjusted indicators for measuring the transportation capacity of the grid taking into account the voltage level of the lines. As information about transmittable power in Germany is not available we estimate the performance of both networks in an approximate way. The **first indicator of transportation capacity** measures the performance of the network and is calculated by multiplying average thermal limits th_cap_k (cf. table 3) with the number of circuits with rated voltage level k as described in (3):

$$performance\ of\ network = \sum_k th\_cap_k * numb\_of\_circuits_k$$

$$for\ U_k = \{220, 230, 345, 380, 500, 765\} \quad (3)$$

Table 3: Typical thermal limits of overhead lines as a function of rated voltage

Rated voltage	220 kV	380 kV	500 kV	700 kV
Medium thermal limit (MVA) [a]	650	2050	2400	4000

Note: [a] one circuit Source: Kiessling et al. (2003)

This indicator neglects the distribution of load and generation and the corresponding length of interconnecting lines, yet still it is an adequate indicator to give a first impression of differences in the transportation capacities of both markets. As only the number of circuits is taken into account the PJM network performance however tends to be underestimated: while the number of lines is much higher for Germany, transmission lines circuit kilometers are higher for the PJM market area (cf. table 1). Therefore the **second adjusted indicator of transportation capacity** considers this aspect by weighting the transmission line circuit kilometers with the corresponding voltage levels as described in (4):

$$length - weighted\ performance\ of\ network = \sum_k th\_cap_k * sum\_of\_circuit\ km_k$$

$$for\ U_k = \{220, 230, 345, 380, 500, 765\} \quad (4)$$

While the first indicator indicates a 26% higher (respectively 54%) performance of the German transmission grid, the second adjusted indicator estimates a 50% higher performance for PJM (respectively 45%) higher. The estimated performance of PJM is still higher when lines with lower voltage levels are not taken into account.

Furthermore, two additional indicators are considered for comparing the intermeshing of both networks as a high degree of intermeshing increases the complexity of a nodal market design. Quite obvious is the **ratio of transmission lines to buses** as it indicates how many lines are connected to a bus: A network with three buses and only two lines is less intermeshed than a network consisting of the same number of buses but three lines. Although the market area operated and monitored by PJM is much bigger than Germany, the German network has more transmission lines and approximately as many 'high-voltage buses' (cf. table 1). This holds especially true when not taking into account the 230kV lines in the PJM grid. On average nearly 4 transmission lines are connected to a bus in Germany while a bus in the PJM transmission network is only connected to 2.5 lines respectively 3.1 lines on average (cf. table 2). From this point of view the German transmission grid seems to be much more intermeshed.

But this indicator does not reflect transportation distances. As second indicator for the intermeshing of the networks we therefore compare the **average length of a transmission line**, calculated as ratio of the transmission line circuit kilometers and the number of buses.
Given the much larger surface of PJM one would expect that the average length of a transmission line between two buses in the PJM market area is much higher than in Germany. But this only holds true when disregarding the 230kV lines. When taking into account also the lower voltage lines in PJM the average length of a transmission line is nearly the same in both markets.

Summing up, our analysis shows that there are less structural differences between the PJM and the German transmission grid when focusing on the comparison of the same voltage levels. Even when regarding the same basic concepts ('transmission grid') the first impression that the German transmission grid is much more intermeshed cannot be fully confirmed. While the German transmission grid is much denser than the PJM transmission grid, it is not clear which grid has the higher level of intermeshing as the indicators show contradictory results. The same applies for the performance of the network.

With respect to our research questions, we note that there are no structural differences in the grid structure of both markets which would suggest the non-transferability of the nodal PJM market design to the German electricity market.

3.3 Cross-border flow indicators

In meshed AC interconnected electrical systems, cross-border flows are highly relevant for the design of LMP markets as deviations between physical and commercial flows have negative impacts on efficiency of markets with LMP (cf. PJM 2011a).
The inevitable differences between commercial and physical flows are often called loop flows or parallel flows. Loop flows occur for different reasons. Physical flows are determined by physical laws and complex system constraints and will therefore in most cases not meet fictitious commercial flows.
As mentioned by PJM (2011a), loop flows reduce the efficiency of markets with explicit locational pricing because they have impacts on LMPs, on FTR revenue adequacy and on system operations and can therefore be used to game the market. But especially their impacts on non-market areas are poorly understood.
Furthermore deviations between actual and scheduled flows cause problems, notably at interconnections between different transmission systems. The main reasons for deviations are fluctuating RES feed-in, load forecast errors, plant outages and intraday-trading. Deviations cause redispatch (cf. PJM 2011a) and are often poorly monitored at interconnections. One of the biggest blackouts in recent history was caused in 2003 by loop flows in the Northeast of the U.S. (cf. ITC Holdings 2003).

To get a first impression of the level of interconnection with neighbouring areas, we set the sum of absolute actual cross-border flows in relation to the generation as **indicator of level of exchange**. With a percentage of 13% of generation in 2010, the interconnection of PJM is rather high (cf. table 4). The level of interconnection of Germany attains 10% of generation and thus is even somewhat smaller than in PJM (cf. table 5).

While in 2009 the difference between the net scheduled interchange and the net actual interchange in PJM was 2.2%, actual and scheduled flows differed by -3.1% in 2010 (cf. PJM 2010c, 2011a). But total differences are not a good measure for loop flows as differences for specific interfaces can be much higher and loop flows still exist when the net interchange is zero (cf. PJM 2011a). Therefore we focus on the absolute differences between the actual and the net scheduled flows as first **indicator of loop flows**. The corresponding values at the PJM interfaces are shown in table 4. A high absolute difference of flows indicates high corresponding loop flows. But as mentioned before, deviations between scheduled and actual flows are also caused by fluctuating RES production, deviations in load forecasts, unplanned outages and intraday trading. Therefore the deviations seen at the PJM interfaces can only be a rough indicator for cross-border loop flows.

To account for the different scales of cross-border flows we set the absolute differences in relation to the sum of the absolute actual flows as **adjusted indicator of loop flows**. With an absolute difference of 15,525 GWh between actual and net scheduled flows the interface PJM/MECS (MISO) is the most imbalanced one in 2010. Even when the magnitude of flows is taken into account a percentage of 109% indicates that actual flows frequently reversed the scheduled flow direction at this interface. As shown in table 4 such high deviations at the PJM interfaces are not exceptional but rather the rule. In total, the absolute actual cross-border flows at PJM interfaces deviate by 90% from the net scheduled ones.

Table 4: Cross-border flow indicators for PJM interfaces in 2010 (in GWh)

			Indicator of level of exchange:	**Indicator of loop flows:**	**Adjusted indicator of loop flows:**
PJM interface	Net scheduled flows (1)	Actual flows (2)	Absolute actual flows (3)	Absolute difference (2) – (1)	Absolute difference as percentage of absolute actual flows
CPLE	-1,275	7,496	7,688	8,815	115%
CPLW [a]	0	-1,907	1,907	-	-
DUK	-48	-2,975	3,187	3,432	108%
EKPC	-133	1,064	1,652	1,487	90%
LGEE	1,754	1,300	1,300	1,361	105%
MEC	-5,172	-2,682	2,990	2,865	96%
MISO	-165	-7,936	51,118	52,411	103%
– ALTE	-591	-5,974	5,974	5,393	90%
– ALTW	-646	-2,279	2,280	2,014	88%
– AMIL	-315	7,256	8,091	8,147	101%
– CIN	3,503	1,923	4,197	4,257	101%
– CWLP	-22	-314	407	413	101%
– FE	-2,297	-268	4,728	5,058	107%
– IPL	-334	2,483	2,630	3,080	117%
– MECS	1,559	-13,556	14,185	15,525	109%
– NIPS	-498	-2,716	2,960	2,712	92%
– WEC	-523	5,509	5,665	6,225	110%
NYISO	-13,590	-12,307	13,002	3,152	24%

– LIND	-1,218	-1,218	1,218	0	0%
– NEPT	-4,767	-4,767	4,767	0	0%
– NYIS	-7,605	-6,322	7,018	3,152	45%
OVEC	11,846	7,381	7,466	4,593	62%
TVA	-703	3,312	3,697	4,350	118%
Total	**-7,484**	**-7,254**	**94,007**	**84,786**	**90%**
As percentage of generation	**-**	**-**	**13%**	**-**	**-**

Note: [a] hourly scheduled flows for the interface PJM/CPLW are not available

Sources: PJM (2010c), own calculations

In awareness of the significant loop flow problem, the NERC Operating Reliability Subcommittee is currently working on a market flow tool, called the Parallel Flow Visualization Interim Solution[5], which should make the impacts of dispatch in loop flows in the Eastern interconnection visible as it indicates the source and the priority of all flows on a flow gate.

Loop flows are also a huge reliability problem in the European ENSTO-E grid. The more intermeshed an AC network, the greater are the problems with loop flows between different market areas.[6] ENTSO-E (2004) mentioned that significant deviations in commercial border exchanges and physical border flows are very common in the European ENSTO-E grid. While commercial flows take one direction, physical flows often take the opposite way across border. Corresponding to the analysis of flow deviations at the PJM interfaces, table 5 shows the absolute differences of scheduled and physical flows seen in 2010 at the German borders.[7]

While the summed absolute flow difference at German borders is much lower, flow deviations at specific interfaces are in several cases comparably high. While the highest relative difference seen 2010 at PJM interfaces was 118% the highest difference in Germany was 137% at the German-French-Border.[8]

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[5] See NAESB WEQ Business Practices Subcommittee (2010) for a detailed description of the Parallel Flow Visualization Interim Solution.

[6] This holds of course only without the consideration of phase shifters that control electricity flows.

[7] In case of missing data we cleanse the data set and eliminate entries in hours in which the physical or the scheduled flow was missing. The production of the pumped-storage hydro plants Vianden and Vorarlberg, which are geographically located in Luxembourg and Austria but are physically connected to the German electricity grid are not considered in the hourly flows provided by ENTSO-E. Therefore table 5 does not include flow deviations for Luxemburg.

[8] Consentec and frontier economics (2011) point out that there are significant loop flows going from Germany through the Netherlands, Belgium and France. For example, only 78% of a trade between the Neth-

Deviations between Germany and Sweden respectively Germany and Denmark are not surprisingly very low due to DC connections. Phase shifters control flows between Germany and the Netherlands and therefore reduce flow deviations. It is particularly noticeable that deviations at the German-Czech-Border were such low in 2010 as there are currently considerations about the implementation of phase shifters to prevent the Czech network from blackouts. As reported by the Czech TSO CEPS (2012), there was a huge increase in unscheduled north-south power flows seen in 2011, mainly caused by excessive wind production in Germany. Like Poland, the Czech Republic has become a transit land for German wind energy. If wind blows, huge amounts of the German electricity flow across the German-Czech-Border respectively German-Polish-Border to transport wind energy from the north of Germany to the load centers in the south. There are also huge loop flows going from Germany over Austria to Poland and the Czech Republic. Relative differences are particularly high at the German-Polish-Border. But as the installation of several phase shifters is planned, flow differences between Germany and Poland will probably decrease in future.[9]

Table 5: Cross-border flow indicators for Germany in 2010 (in GWh)

			Indicator of level of exchange:	**Indicator of Loop-Flows:**	**Adjusted Indicator of Loop Flows:**
Border	Net scheduled flows (1)	Actual flows (2)	Absolute actual flows (3)	Absolute difference (2) – (1)	Absolute difference as percentage of absolute actual flows
DE – AT	1,748	40	5,630	4,525	80%
DE – CH	4,337	12,711	13,505	8,589	64%
DE – CZ	-10,009	-8,687	8,840	2,610	30%
DE – DK1	1,224	1,666	3,036	2,235	74%
DE – DK2 [a]	1,141	1,182	3,498	1,061	30%
DE – F	6,717	-14,240	15,300	20,996	137%
DE – NL	4,398	5,976	8,494	4,021	47%

erlands and Belgium flows directly across the border between both countries. The remaining part of 22% flows as loop flow through Germany and France and reaches Belgium from the south.

[9] In 2010 the Polish TSO PSE Operator S.A announced not only to upgrade the transmission capacity between both countries but to install several phase shifter transformers in the substations Krajnik and Mikulowa in cooperation with the German TSO 50HzT (PSE Operator S.A. 2010).

DE – PL	-441	5,148	5,295	5,695	108%
DE – SE [a]	1,411	1,278	1,877	400	21%
Total	**10,524**	**5,075**	**65,475**	**50,131**	**77%**
As percentage of generation	**-**	**-**	**10%**	**-**	**-**

Note: [a] DC connection Sources: ENTSO-E (2010a), ENTSO-E (2010b), own calculations

Summing up, both markets seem to be strongly interconnected. A high interconnection with other transmission systems is of high relevance for the electricity market design as those neighbouring systems are often not willing to go for some coordinated actions to prevent detrimental effects of loop flows and the corresponding (nodal) effects in the neighbouring network. Overall our analysis of the deviations of scheduled and actual cross-border flows as indicator for loop flows suggests that PJM and Germany have comparable loop flow problems. In both markets not only the total deviation of cross-border flows are high but appear even higher at specific interfaces. In summary, loop flows in PJM and also in Germany seem to be of high relevance especially in regard of system reliability.

With respect to our research question on the transferability of the PJM market design to the German electricity market, we cannot spot major differences in cross-border (loop) flows. Both markets seem to have comparable problems with flow deviations.

3.4 Congestion indicators

The previous analyses mostly focused on structural indicators in order to derive statements about the transferability of the PJM market design to the German electricity market. To derive also statements about the potential benefits from a shift to a nodal market design in Germany, congestion is viewed in the following. We identify congestion frequency as one of the main drivers for potential welfare gains induced by the implementation of LMPs as nodal pricing is only more efficient than zonal or uniform pricing in hours when bottlenecks in transmission occur. Or in other words: in case of a non-congested network nodal, zonal and uniform pricing lead to the same prices and have the same efficiency.[10] The higher the congestion frequency, the higher are the gains to be expected from nodal pricing.

To compare the congestion situation of both markets we define performance indicators as summarized in table 6. Congestion event hours (CEH) are a good **indicator for congestion frequency**, as a congestion event hour occurs when a specific facility is constrained within one hour. But a direct comparison of CEH of both markets is difficult as only redispatch event

[10] At least when losses are disregarded.

hours (REH) are publicly available for Germany.[11] The problem is that redispatch does not only occur due to congestion but also for other reasons e.g. forecast errors or unplanned plant outages. Furthermore redispatch is also done anticipatory to guarantee the system security in any case. On the other hand, it is also possible to deal with congestion not only by redispatch but by modifying the network topology. Therefore REH are only a proxy for the CEH and it is difficult to say whether it is biased upwards or downwards.

Table 6: Comparison of congestion indicators for PJM's and Germany's high voltage transmission grid

Congestion indicators 2010	**Unit**	**PJM** ***(incl. 230kV)***	**PJM** ***(transmission grid)***	**Germany** ***(transmission grid)***
Indicator of congestion frequency: 'Congestion event hours' (CEH)	***h***	**59,822** [b]	**35,383** [b]	**1,776** [a]
Adjusted indicator of congestion frequency I: CEH per transmission line circuit km	*h/ circuit km*	1.42	1.11	0.05
Adjusted indicator of congestion frequency II: CEH per produced GWh	*h/GWhprod*	0.081	0.048	0.003
Financial indicator of congestion I: Total congestion costs (TCC)	*Mio €*	814	639	43 [c]
Financial indicator of congestion II: Percentage TCC of TB	*%*	3.14	2.56	0.17
Total billing (TB)	*Mrd €*	*Total system:*	26	25

Notes: [a] redispatch event hours as sum over redispatch events as published by Tennet and 50HzT [b] sum over day-ahead and real time congestion event hours [c] Germany: costs for redispatch and countertrading measures, PJM: without explicit congestion charges

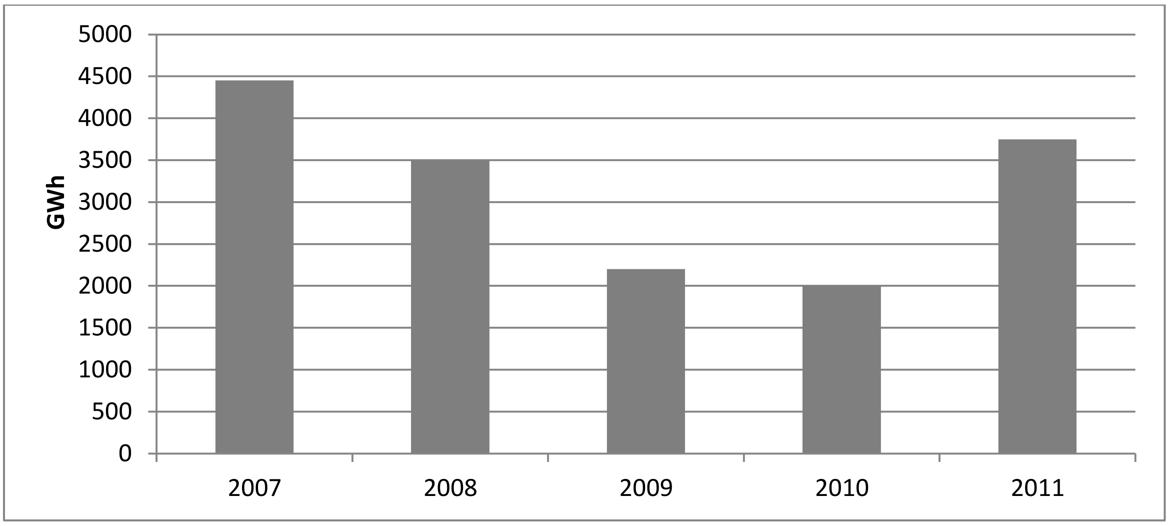
Sources: 50Hertz Transmission GmbH (2011b), BMWi 2011, Bundesnetzagentur (2011, 2012), PJM (2011a), Tennet TSO GmbH (2011a, 2011b), own calculations

Undoubtedly, the transmission network of PJM is much more congested than the German one as shown in table 6. Even if the REH underestimate the 'real' CEH of Germany by a factor of 4, PJM's congestions as measured through CEH would still be significantly higher. In fact congestion is in the PJM network not the exception but the rule – and not just since last year. In 2008 there has been real-time congestion in the total PJM network in 87% of the year (cf. PJM 2010b). The partial upgrading of PJM's backbone network in

[11] Currently only Tennet and 50HzT publish their redispatch events. But as redispatch is mainly done in the control zones of Tennet and 50HzT (cf. Consentec and frontier economics 2011) the disregard of redispatch done in the control zones of Amprion and TransnetBW does not affect the results significantly.

2009 has probably led to the decrease of 12.5% in constrained hours seen in 2009 (cf. PJM 2010b). But congestion in 2010 reached again the level of 2008 (cf. PJM 2011a).

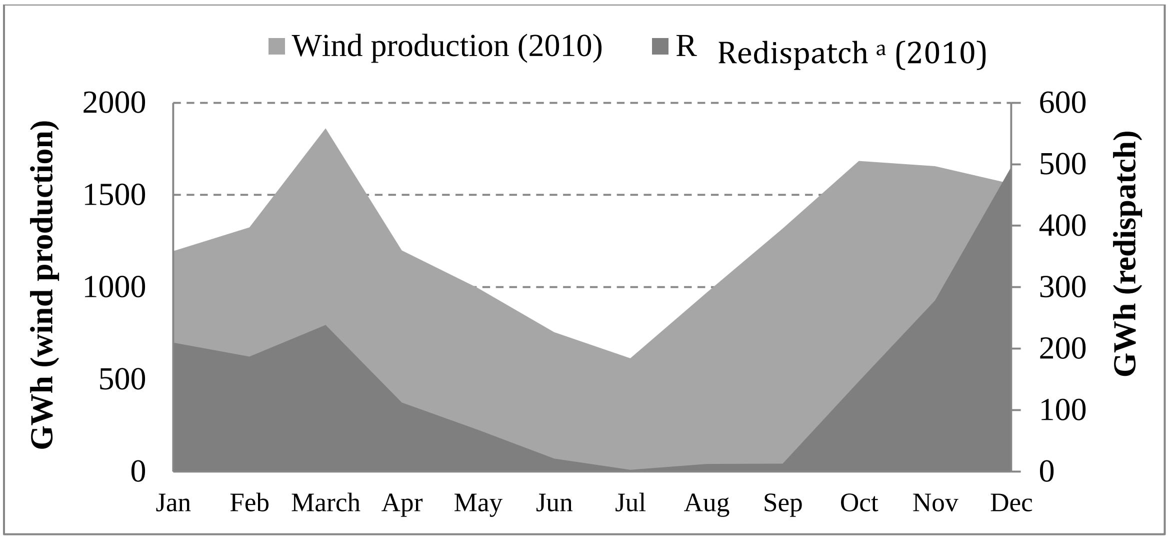
While in recent years redispatch in Germany was still quite rare, the number of redispatch events is expected to increase significantly with increasing RES production. Whereas there was a steady downward trend from 2007 to 2010, figure 3 shows a huge increase of the total volume of redispatch measures in Germany from 2010 to 2011. The moratorium on nuclear power and the corresponding shut-down of Germany's eight oldest nuclear-power plants caused the huge increase in redispatch seen in 2011.



Source: Bundesnetzagentur (2012)

Figure 3: Development of redispatch volume in Germany (2007-2011)

Figure 4 shows the strong correlation between wind feed-in and redispatch events in the TSO control zone of 50HzT (cf. 50Hertz Transmission GmbH 2012). Overall 50HzT had to take market-related measures on each third day in 2010 on average. Only the high PV feed-in 2010 avoided more redispatch needed in summer, when electricity demand in Germany is seasonally lower.



Notes: [a] includes redispatch and countertrading as per §13.1 EnWG and §13.2 EnWG

Sources: 50Hertz Transmission GmbH (2011a, 2012)

Figure 4: Wind production and redispatch measures in 2010 in the TSO control zone of 50HzT

Compared to congestion in PJM, the redispatch volumes in Germany are yet very small. According to Bundesnetzagentur and Bundeskartellamt (2012), only one transmission line (Remptendorf – Redwitz) showed in 2010 a considerable number of hours (10%) in which redispatch measures were needed to keep up system reliability. While the second-most congested transmission line (Vierraden – Krajnik) in Germany was congested in only 3% of 2010, the top 25 constraints of PJM include 11 constraints with congestion in more than 5% of the year - and go up to 17% at the AP South interface (cf. Bundesnetzagentur and Bundeskartellamt 2012, PJM 2011a). But with the shut-down of almost 5,000 MW installed nuclear capacity in southern Germany alone, Germany's congestion situation has worsened in 2011. Thereby the number of congested hours in 2011 increased on the transmission line Remptendorf-Redwitz to a level of 20%, followed by the area Kriegenbrunn with a share of 8% (cf. Bundesnetzagentur and Bundeskartellamt 2012). However, the comparison of the total redispatch volumes seen in 2011 also indicates that congestion in Germany is still considerably lower than in the PJM network.

But as total numbers do not take into account that the PJM grid is considerably larger than the German we define an **adjusted indicator for congestion frequency** and divide the total number of CEH by the transmission line circuit kilometers. As shown in table 6, the CEH per transmission line circuit km are considerably higher in PJM than in Germany in 2010.

A **second adjusted indicator of congestion frequency** takes the produced energy into account, as this is the amount of energy that has to be transported and potentially causes congestion: the more energy has to be transported, the more powerful the grid needs to be. If the grid is not sufficiently large bottlenecks arise. As can be seen in table 6 also the second adjusted indicator suggests a much lower congestion frequency for Germany.

Congestion causes costs. Therefore the financial dimension is taken into account within our last two indicators. As **first financial indicator of congestion** we focus on the comparison of the total congestion costs (TCC). This provides an indication of the overall costs related to congestions[12]. The percentage of TCC in the total billing (**second financial indicator of indicator of congestion**) which is 2.56% for PJM while total redispatch costs for Germany are only 0.17% of the total billing[13] approximately. The general comparability of TCC in a nodal pricing regime with redispatch costs in a uniform pricing market design like in Germany is discussed in the appendix.

The much higher total congestions costs of PJM indicate how much more the transmission network is congested and that it is especially important for PJM to deal with network congestion in an efficient way – to keep overall welfare as high as possible. While the actual congestion costs decreased through the addition of new backbone projects, analyses[14] published by PJM within the yearly regional transmission expansion plan show that PJM remains still below the best possible performance with regard to congestion.

With respect to our research questions, we note that considerable differences in congestion between PJM and Germany exist. Those differences do not influence the transferability of the PJM market design, but show that Germany is still far from having the congestion problems currently experienced in the PJM market. It follows that the potential benefits of nodal pricing are considerably lower in Germany than in PJM. But increasing wind production, especially offshore wind production will relocate generation in Germany deeper to coastal region in future and will probably cause huge bottlenecks when wind penetration is high - if grid extension continues slowly.

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[12] Average congestion costs (ACC) per CEH would be another possible indicator. But as before for Germany only REH are available. Thus ACC could only be calculated based on REH and would therefore be not comparable. Moreover it measures the per unit cost of congestion and not the congestion cost in relation to the overall system size.

[13] The total billing of Germany is approximated by multiplying the hourly net production (= demand minus losses) with the hourly base EEX-price.

[14] PJM publishes each year an updated Regional Transmission Expansion Plan (RTEP) that explains system enhancements needed, discusses system drivers and reliability criteria violations. In this context PJM simulates, among other things, congestion costs using the current system topology respectively a future topology as suggested by RTEP (cf. PJM 2011d).

4. Conclusions

Two simple conclusions can be drawn: 1. Structural differences between PJM and Germany are smaller than expected and 2. The potential benefits of nodal pricing are considerably lower in Germany than in PJM.

Against expectations we found several similarities between PJM and Germany: high fossil-fired production, comparable transportation requirement and capacity of the grid, high interconnection with neighbouring regions and important loop flow problems. There are no structural differences that imply a limited transferability of PJM's market design to Germany in principle. But adjustments are required that allow also congestion management in distribution networks, where in Germany more and more congestion occurs. We summarize our results and implications for the transferability of the PJM market design to Germany and potential benefits in table 7.

Table 7: Comparison of differences between the PJM and German electricity market and implications for the transferability of the PJM market design to Germany

Categories	PJM	Germany	Implications for transferability of market design and potential benefits
Generation	• Dominated by fossil fuels (61%) • But low RES share (3%)	• Dominated by fossil fuels (57%) • High RES share (16%), which will increase in future	• **Transferability is given in principle** • Adjustments required to allow also congestion management in distribution networks
Network	• Much bigger surface than Germany (+ 27%) • Divided in many territories	• Smaller surface than PJM • Surface looks very compact	• **No major structural differences identified that lead to a limited transferability**
	• Comparable number of buses and transmission lines • Comparable transportation requirement and capacity • No clear assessment about degree of intermeshment		

Cross-border connections	• High interconnection with neighbouring areas • High deviations between scheduled and actual cross-border flows indicate comparably huge loop flow problems		• **No considerable structural differences identified that lead to a limited transferability** • Loop flows can have negative impacts on efficiency of LMP markets but are not a contra-argument against LMPs or limit the transferability of the PJM market design to Germany as those problems occur in PJM as well
Congestion	• High congestion frequency (nearly 90% constrained hours in 2010) • Also adjusted indicators suggest very high congestion frequency • Corresponding much higher congestion costs than in Germany (814 Mio €)	• Very low congestion frequency (far less than 20% constrained hours in 2010) • Holds also with regard to 2011 • Also adjusted indicators suggest very low congestion frequency • Very low congestion costs in comparison to PJM (43 Mio €)	• **Differences in congestion do not limit transferability** as congestion is not a structural indicator but can be interpreted as kind of performance measurement • **Low congestion leads to lower potential benefits of nodal pricing** as LMPs are only more efficient than zonal or uniform pricing in hours when bottlenecks in transmission occur

The much higher part of decentralized RES production in Germany requires an adjustment of the PJM market design, which focuses on the efficient management of congestion in the high-voltage transmission grid where congestion historically takes mainly place. But decentralized RES production causes already today congestion in the German distribution network. A shift in Germany's congestion management towards the PJM nodal market design should therefore also take congestion in the distribution network into account. But the implementation of LMPs not only on transmission but also on distribution network level will result in increased complexity due to the larger network and higher number of buses. Additionally the resulting smaller market areas probably increase the possible exercise of market power.

The identified differences in congestion frequency do not limit the transferability of the PJM market design to Germany but show that the potential benefits of the implementation of LMPs are probably much higher in the PJM market than in Germany. While congestion in Germany in recent years was still exceptional (despite significant changes in 2011) problems in PJM's backbone network still cause very high congestion. The much higher congestion frequency leads consequently to much higher congestion costs. The potential of cost reduction through the implementation of LMPs in a highly congested network like PJM is then obviously much higher than in a less congested network. Therefore the potential benefits of nodal pricing in Germany are considerably lower than in PJM.
But increasing RES production in Germany, especially offshore wind production, will increase congestion in transmission and distribution grids in future, if grid extension continues as slowly as today.

Considerable changes in the German (or European) institutional settings are required when nodal prices are to be implemented. Especially the establishment of a German- (or Europe-) wide ISO would be challenging.[15] So far, regional transmission operators are responsible for the operation of the transmission network in their control zones. Hence, the implementation of a nodal market design including an ISO (or any other centralized new system) will be very time-consuming, as it requires additional legislation. This could be an argument for moving ahead to nodal pricing as soon as possible. But further research should address the specific design that fits European rather than national requirements.

In conclusion, we state that the PJM nodal market design is transferable to Germany in principle (with adjustments to allow congestion management in distribution networks) but potential benefits are currently considerably lower than in the highly congested PJM market. Consentec and frontier economics (2008) suspects that the implementation of market splitting in Germany could cause costs in the higher double-digit and even triple-digit millions – an implementation of LMPs should therefore well thought through.

[15] Transferring a considerable part of national decision rights to a supranational institution is seen as a critical aspect in many countries especially given that numerous grid operators are state-owned (e.g. in France or the Netherlands). The fact that Switzerland and Norway are important partners in the European electricity market but not EU-members further complicates the establishment of an European ISO. For a deeper discussion of major concerns surrounding a possible EU transition to a nodal pricing market design see Neuhoff et al. (2011).

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Appendix

The general comparability of TCC in a nodal pricing regime with redispatch costs in a uniform pricing market design like in Germany is shown in figure 5. We used a stylized two country model which is often used in literature in context of showing welfare impacts of increased interconnection capacity (e.g. Kirschen and Strbac 2006, Sauma and Oren 2007).

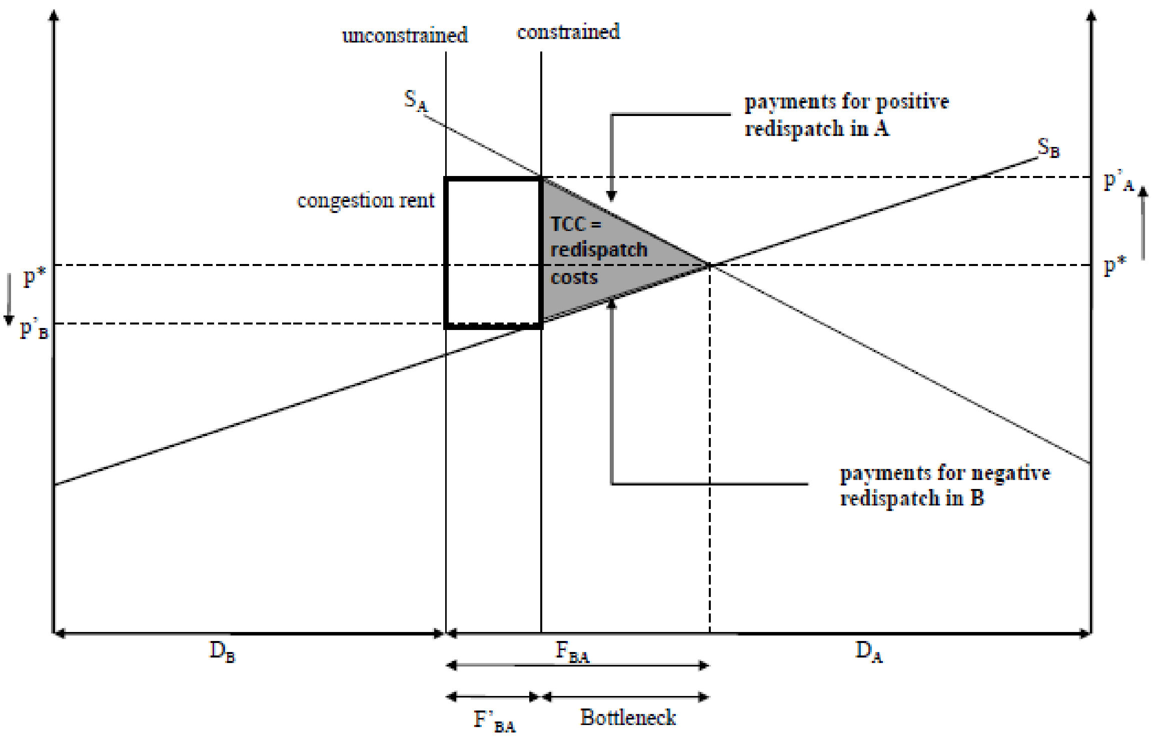

Fig. 5. Comparability of PJM's total congestion costs and Germany's total redispatch costs

S_A and S_B show the supply curves for country A and B while the demand of both countries D_A and D_B is described by the vertical lines 'unconstrained' and 'constrained'. If transmission capacity is not constrained ('unconstrained'), country B exports amount F_{BA} to country A as marginal costs in B are lower than in A. The same price p* results in both countries. In the case of constrained transmission capacity ('constrained') B can only export the lower amount F'_{BA}, leading to the lower price p'_B in B. The price in A increases, as the remaining demand has to be met by more expensive power plants located in A. The TSO earns the occurring congestion rent (black framed box). PJM approximates the remaining congestion costs (grey colored triangle) by correctly summed changes in consumer and producer rent in the whole system. The remaining congestion costs can also be interpreted as a lower limit to redispatch costs. While the upper triangle indicates refunds for up-regulated power plants in A whose marginal costs are above p* ('not in the money'), the lower triangle shows refunds for down-regulated power plants in B, which would otherwise loose the spread (p*-MC).