A Nodal Pricing Analysis of the Future German Electricity Market

Özge Özdemir, J. Sebastiaan Hers, Emily Bartholomew Fisher, Gert Brunekreeft, Benjamin F. Hobbs

Abstract— **The electricity market in Germany is likely to undergo several significant structural changes over the years to come. Here one may think of Germany's ambitious renewable agenda, the disputed decommissioning of nuclear facilities, but also unbundling of TSO's as enforced by European regulation. This study is a scenario-based analysis of the impact of different realizations of known investment plans for transmission and generation capacity on the future German power market while accounting for internal congestion. For this analysis the static equilibrium model of the European electricity market COMPETES is deployed, including a 10-node representation of the German high-voltage grid. Results for the multi-node analysis indicate that price divergence and congestion are likely to arise in the German market as renewable additions affecting mainly the North of Germany, the debated decommissioning of nuclear facilities in the South, and the expected decommissioning of coal-fired facilities in Western Germany appear to render current investment plans for transmission capacity insufficient. The current system of single-zone pricing for the German market may therewith be compromised. However, transmission additions would not benefit all market parties, with producers in exporting regions and consumers in importing regions being the main beneficiaries. Vertical unbundling of German power companies could increase the incentive for constructing transmission lines if generation capacity would cause Germany to be a net-importing country. In case Germany remains a net-exporting country, the effects of vertical unbundling on cross-border capacity are less clearcut.**

Index Terms— **complementarity problem, electricity market, investment, market power, nodal pricing, partial equilibrium model, transmission system unbundling,**

I. INTRODUCTION

SIGNIFICANT structural changes are expected to take place in the German power market as well as in the other European power markets over the years to come. These changes include developments related to not only environmental concerns (i.e., massive renewable energy installations, further developments in CO_2 trading, and decommissioning of nuclear facilities) but also regulations to improve competitiveness in the EU markets (i.e., unbundling of TSO's, integration of EU markets). In particular, an increase in thermal capacity and renewable electricity production, notably wind energy, is expected, both in Germany and in the neighboring countries. Furthermore, new interconnections between EU countries are planned and market coupling in the Benelux countries, France, Germany, and Denmark will be established. Combined with developments in fuel prices and the price of CO_2-emission allowances, these changes may result in divergence of short run marginal costs of electricity production among the EU electricity markets, in turn driving price differences and exchanges of electricity within Germany and between Germany and its neighbors.

In Germany, among several important developments, one stands out: the planned construction of about 30GW of offshore wind in the North of Germany exhausts network capacity, because load is not in the North. Increased network congestion on the intra-Germany network implies that zonal pricing may be justified. At the same time, offshore wind tends to stress the limits of the cross-border connections, which tend to be congested already. The picture gets more complicated if we realize that Germany may be facing generation capacity scarcity, due to decommissioning of nuclear assets and old coal assets and difficulties and delays in the construction of new assets. This gives rise to the question what would happen if cross-border transmission capacity is expanded and what are the incentives for private firms to invest in cross-border transmission capacity, which should be seen against the debate on TSO unbundling.

This study involves a scenario-based analysis of the impact of expected developments of new transmission and generation capacity in Germany and its neighboring countries on the future German power market. In the analysis, Germany is represented by 10 nodes and the other EU markets are represented as a single node, including a physical transmission network within Germany and between EU countries. Nodal pricing is assumed within Germany whereas a mixed transmission pricing system is applied between EU markets. The mixed transmission system includes both congestion-based pricing of physical transmission constraints and the auction-based transmission pricing of interface capacity between the countries in the EU, with implicit auctioning of capacity between the Benelux countries, France, Germany and Denmark. The main objective is to analyze the effects of the expected future developments in Germany and the neighboring electricity markets on internal congestion, price differences, and producer and consumer benefits within Germany. For this analysis, the static equilibrium model of the European electricity

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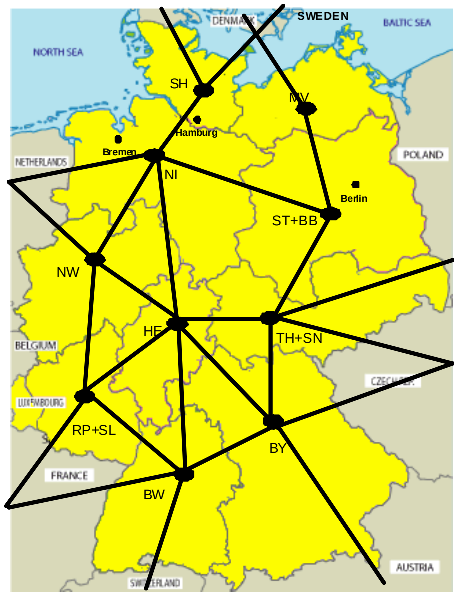


Fig. 1. 10-nodes representation of Germany

market COMPETES [1] is deployed, including a 10-node representation of the German high-voltage grid. The study focuses on the year 2020 and takes into account expected developments between today and 2020.

In the following, a brief description of the COMPETES model is given in Section II. Section III summarizes the scenario assumptions for 2020, whereas the results of the model simulations are presented in Section IV. Finally, Section V covers the incentives for transmission expansion in the light of unbundling.

II. The Model

The COMPETES model solves for price equilibria in European electricity markets under different market structures varying from perfect competition to oligopolistic market conditions (Cournot competition). In the version of COMPETES used for this study, each of the 20 EU countries is modeled as a single node except Germany, which is represented by 10 nodes (see Fig. 1). The model includes the physical transmission network within Germany and between EU countries.

The model is formulated as a mixed complementarity problem and is derived from models of generator, TSO, and arbitrageur behavior. Generators are assumed to be profit maximizers who sign bilateral contracts with consumers in their own countries or elsewhere. Each of the larger generating companies maximizes its short-run (fixed generating capacity) profit assuming that it cannot affect the cost of transmission services (Bertrand assumption), given either the local prices of power (Bertrand/Competitive assumption) or local sales by its rivals (Nash Cournot assumption). Smaller generators (the competitive fringe) are price-taking for both transmission services and power sales. Meanwhile, the TSO sets transmission prices to clear the market for transmission services, such that congested transmission lines and interfaces are priced so that flows do not exceed capacity. Both path-based and linearized DC load flow constraints are imposed. Path-based restrictions reflect the contractually allowed flows among EU countries; in addition transmission of electricity within Germany and among EU countries is constrained by utilizing power transmission distribution factors (PTDF), which is a linearised 'DC load flow' representation of the physical transmission network. Arbitragers buy power in one location and sell in others; their price-taking behavior ensures that price differences between locations equal the cost of transmission service between the points; as shown by [2], this is equivalent to a nodal pricing system. With regard to consumer behavior, the present version of the model considers 12 different levels of demand, based on the typical demand during three seasons (winter, summer and autumn/spring) and four time periods (super peak, peak, shoulder and off-peak). Finally, market-clearing conditions are imposed to ensure that supply matches demand at all locations.

The mathematical representation of COMPETES is described in [3]. The input data involves detailed generation type, capacity and the location for all the generation companies in EU countries based on WEPPS database. The physical transmission capacity limits are based on the NTC values given by ETSO [4]. The electricity demand in each country for 12 periods is aggregated from the hourly consumption data given by UCTE [5]. Similar to the electricity demand, the output of wind power is also varied between the 12 periods representing seasonal variations from the average yearly wind production.

The model is validated for the year 2006 based on actual market data for generation and transmission capacity, and consumption levels in 2006. The validation shows that the COMPETES output (average base-load prices in each country and exchange flows between counties) matches quiet well with the actual market realizations in 2006 (See [6] and [7]). The model has been used by ECN in several studies ([6]-[10]) to simulate EU power markets.

III. Scenario Assumptions for Year 2020 Electricity Markets

A. *Baseline scenario*

For the study, a baseline scenario is chosen against which the effects of more generation and transmission capacity in Germany and the corresponding demand response can be measured. The baseline scenario represents Germany as a single node and, hence, disregards internal congestion

The data of the baseline scenario for Germany and the other neighboring countries are set by the recent country baseline scenarios ([11]-[20]) in combination with PRIMES Baseline scenarios that were developed as reference projections for the European commission [21]. The data involve assumed fuel and CO_2 emission allowance prices in 2020, the assumed decommissioned and newly developed production capacity in Germany and the neighboring countries until 2020, and finally the assumed new transmission capacity built within German and the EU electricity grid through 2020. In addition, demand levels are assumed to increase in all the neighboring countries except Germany. Electricity demand in Germany in 2020 is assumed to be close to the current level, in line with [13]. Finally, the fuel prices are taken from the Global Economy, High oil Price scenario (GEHP) as defined in [22]. GEHP is used as a background scenario for recent energy and climate policies in the Netherlands.

The equilibrium prices of the baseline scenario are calibrated at assumed demand levels for each country. For the interested reader, the assumptions and the corresponding data used for the baseline scenario can be found in [6].

B. Scenarios for new generation and transmission capacity in Germany

The scenarios indicated in Table 1 are designed to evaluate the impact of more generation and transmission capacity in Germany on the price divergence and internal congestion among the 10 network nodes of Germany. The scenarios therefore differ in assumptions regarding development of German production and transmission capacity. More detailed information on the nodal decomposition of decommissioning and new generation capacity in Germany assumed for these scenarios is presented in the Appendix (see Table 3 and TABLE 4). All other data, such as supply and demand for the neighboring countries and fuel and CO_2-emission allowance prices are in line with the baseline scenario.

TABLE 1 OVERVIEW OF YEAR 2020 SCENARIOS

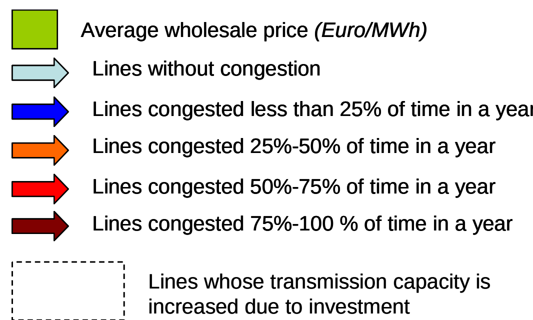
# of nodes in DE	Low generation capacity in DE		High generation capacity in DE	
	No transmission capacity built in DE	Expected transmission capacity built-in DE	No transmission capacity built in DE	Expected transmission capacity built-in DE
10	Scenario 1	Scenario 2	Scenario 3	Scenario 4

Scenario 1 is identical to the baseline scenario but distinguishes 10 German network nodes instead of a single node. This Scenario allows for assessment of the impact of internal German congestion on system costs and prices. Scenario 3 differs from Scenario 1 by assuming significantly more new generation capacity and no decommissioned capacity of nuclear in Germany as given in Appendix. Scenarios 2 and 4 are defined as Scenarios 1 and 3 respectively, apart from assuming expansion of the current transmission capacity in Germany. Data for national German investment plans are based on the report/assessment by the DENA [15], while the investment plans for the German cross-border capacity are adopted from the 'High renewable scenario' of CESI study [24]. These scenarios of new generation and transmission capacity investments are exogenous scenarios and the fixed costs of additional new capacity investments are not taken into account. Hence, the outcomes (e.g. prices and revenues) of the scenarios reflect short-run equilibrium in 2020.

In all the scenarios given in Table 1, the same linear demand curve is assumed for each country or region such that its demand curve passes through the equilibrium price and demand level of that country observed in the baseline scenario.

IV. SIMULATION RESULTS FOR THE FUTURE GERMAN ELECTRICITY MARKET

This section presents the simulated prices and congestion patterns within Germany as observed in the four different scenario evaluations. Figures 2 and 3 indicate the impact of developments in new generation and transmission capacity on the congestion within Germany. All nodal prices are quantity-weighted averages over the 12 demand periods in the scenario year. To represent the frequency of congestion in the German network, the following graphical representation is used in the figures:



The planned construction of massive wind offshore wind power capacity in the North of Germany causes internal congestion within Germany in all the scenarios. In Scenarios 1 and 3, the congestion is more severe and the congested lines correspond to the lines that are expected to be expanded over the years to come. Although the expected future investments in transmission lines in Scenarios 2 and 4 reduce congestion, they seem to be insufficient. Accordingly, price differences can be observed within Germany for all scenarios as well. In all of the scenarios, price differences are observed between the Northern and Southern regions of Germany. The Northern regions are likely to have lower electricity prices whereas the prices in the Southern regions tends be high. This is mainly due to the new wind and coal-fired power plants located in the North and a significant amount of decommissioned coal and nuclear power plants in the South.

Also, Germany is a net importing country in the low generation capacity scenario (Scenarios 1,2) due to scarce domestic capacity and therefore net German imports increase with the increase in transmission capacity in Scenario 2. If there is ample capacity in Germany (Scenario 3 and 4), Germany remains to be a net exporting country and the net exports increase with the increase in transmission capacities in Scenario 4.

It should be noted that the low generation capacity growth scenarios (Scenario 1 and 2) assume decommissioning of nuclear facilities, while the high generation capacity growth scenarios (Scenarios 3 and 4) assume nuclear facilities to remain operational. The BY region, for example, therefore becomes one of the high price regions in Scenario 1.

(a) Scenario 1

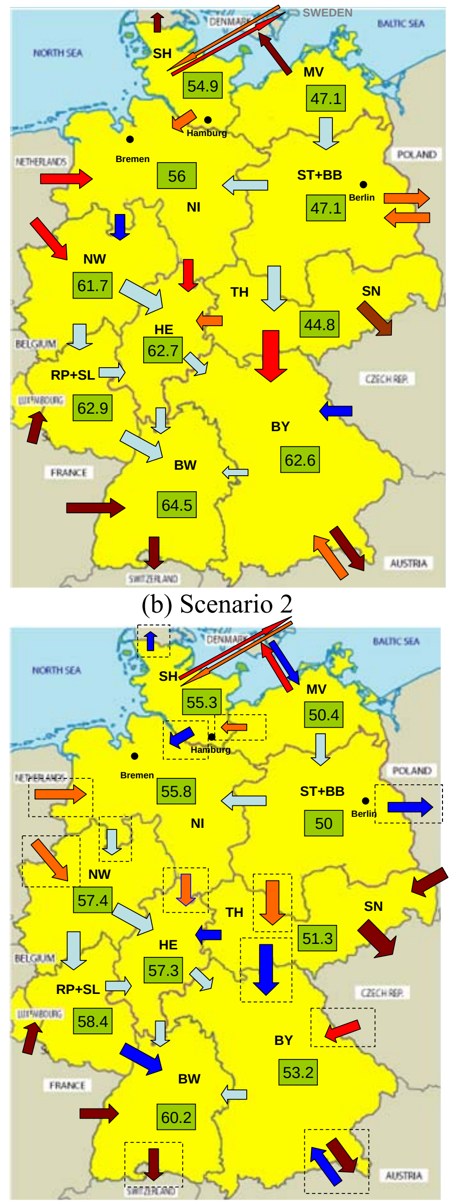
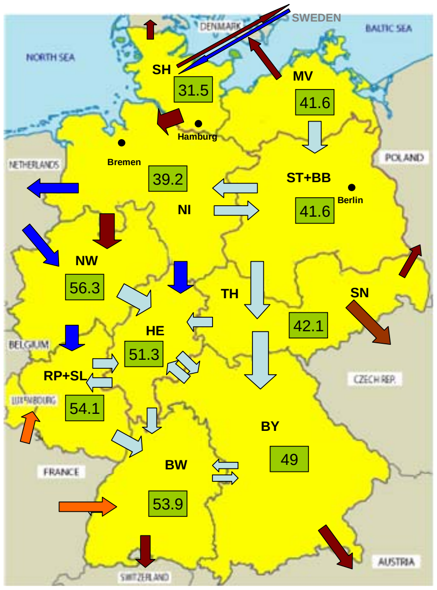


Fig. 2. Low generation capacity growth scenarios in DE

As a significant amount of nuclear capacity is located in the South of Germany, one may observe that the decision to decommission nuclear capacity in the German market may enhance the congestion issues that arise due to the new wind and coal-fired power plants located in the North. The congestion of transmission lines between ST+BB and TH+SN, between TH+SN and BY, and between TH+SN and HE are also result of decommissioning of nuclear capacity in the BY and HE regions. On the other hand, in Scenario 3, which assumes no decommissioning of nuclear capacity, the average base load price in BY gets close to the average prices observed in the Northern regions and the congestion between TH+SN and BY disappears.

(a) Scenario 3



(b) Scenario 4

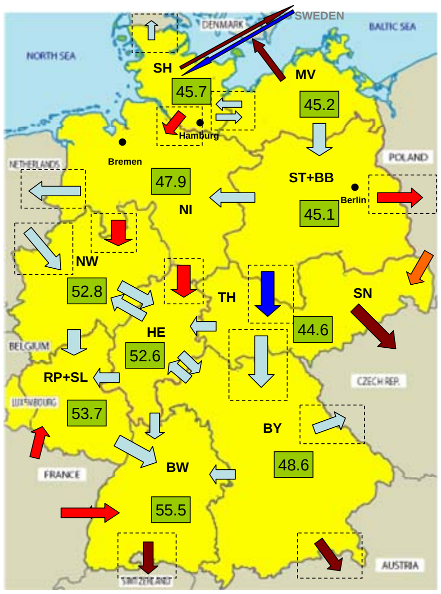
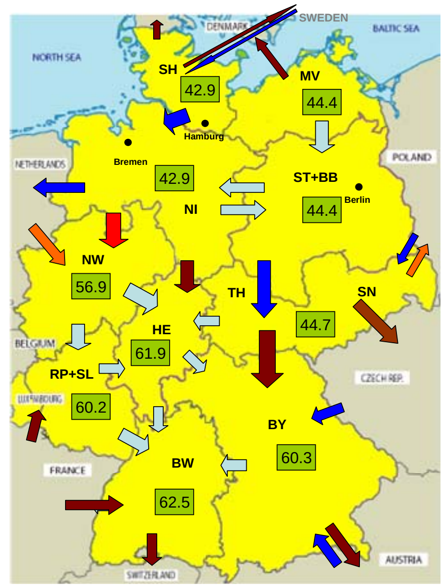


Fig. 3. High generation capacity growth scenarios in DE

In order to isolate the impact of nuclear decommissioning on the observed congestion patterns in Scenarios 3 and 4, a sensitivity analysis is performed. An additional simulation was performed for the high generation Scenarios (Scenarios 3 and 4), assuming decommissioning of nuclear capacity and therewith enhancing the congestion problem. The results are presented in Fig. 4. Comparison of Figures 3 and 4 indicate that nuclear decommissioning may indeed aggravate price divergence and congestion in the German power system.

(a) Scenario 3 nuclear decommissioning variant



(b) Scenario 4 nuclear decommissioning variant

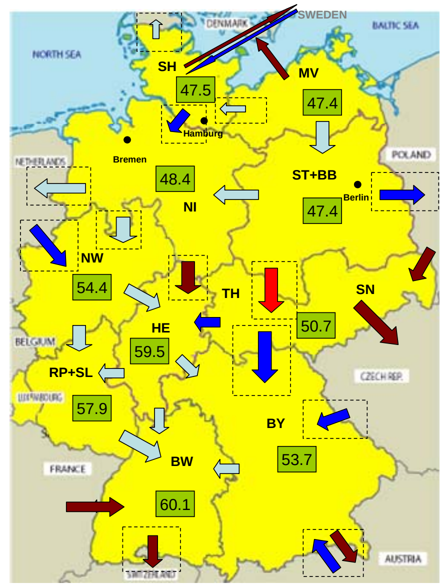


Fig. 4. Impact of nuclear decommissioning in Scenarios 3 and 4

On the basis of the simulation results with respect to pricing and congestion in Germany, one may summarize as follows:

- Congestion between the Northern and Southern German regions is likely to increase if planned generation capacity investments in wind and coal-fired facilities in the North of Germany will be realized.
- Congestion between the Northern and Southern German regions is likely to be aggravated if nuclear capacity is decommissioned.

- As a result of increased congestion, the price differences between the Northern and Southern regions of Germany increase.
- Internal congestion and price deviations in Germany decrease in all the scenarios as a result of inland transmission capacity expansion.
- The net exports of Germany decrease significantly due to decrease in excess competitive capacity caused by the decommissioning of nuclear.

One may note that single zone pricing may not be justifiable anymore. Price differences are observed mainly between the Northern and Southern regions of Germany, but the congestion pattern may change depending on the locations of the new generation capacity and the decommissioned capacity. Therefore a given zonal decomposition may not be robust.

V. Investment incentives of vertically integrated utilities versus unbundled TSOs in German electricity network

Unbundling of TSOs is expected to result in earlier and/or higher investments in transmission capacity. This is one of the more important drivers for the European Commission in the European debate on TSO unbundling. The underlying argument is what we call "strategic investment withholding"[23]; the idea is that higher cross-border capacity increases the potential for competition from other areas. Therefore, a vertically integrated utility (VIU) will have an incentive to protect its generation markets by not expanding cross-border capacity. In contrast, an unbundled TSO would not take the effect of additional cross-border capacity on the generation revenues into account.

This section compares the incentives to build transmission capacity in the German electricity network (both inside Germany and at the border) where TSOs and producers are bundled with the incentives that are in place and where TSOs are unbundled. In both cases, we assume that changes in transmission revenues are "ring-fenced" such that changes in congestion revenues are either devoted to network investment or result in adjustment to fixed network charges to network users. In addition it is assumed that network charges would be regulated such that unbundled TSOs would be incented to make investments that increase overall market efficiency, no matter who benefits. Since the transmission revenues are ring-fenced through adjustments to network charges, changes in net surplus would then be reflected by changes in net consumer and producer surplus. It should be mentioned that this is a strong assumption. [25], for example, states that not only TSO's but also national regulators play a role in the allocation of congestion revenues and that the national regulators show a bias towards adjustment of fixed network charges.

Based on the former, the following factors would affect the incentives of VIUs and unbundled TSOs in building new transmission capacity:

VIUs: In this case, since transmission revenues are "ring-fenced", the objective of a VIU would be to maximize its production surplus only.

TSOs and producers are unbundled: In this case, independent TSOs would have an incentive to invest to decrease congestion and price differences within Germany and to achieve higher net surplus (producer surplus + consumer surplus + transmission surplus) in Germany. The assumption is that network charges would be regulated such that TSOs would be incented to make investments that increase overall market efficiency, no matter who benefits.

TABLE 2: OVERVIEW OF PRODUCER- AND CONSUMERSURPLUS (IN MEUROS)

	Scenario 1			Scenario 2		
	PS	CS	TS	ΔPS	ΔCS	Δ(PS+ CS+TS)
DE	13805	80398	855	-1187	2027	91
EU (excl.DE)	90919	442756	2825	-727	874	357
	Scenario 3			**Scenario 4**		
	PS	CS	TS	ΔPS	ΔCS	Δ(PS+ CS+TS)
DE	14358	86474	1677	1864	-779	1222
EU (excl.DE)	88680	445050	2311	-2251	2545	-475

In **TABLE 2** the assumed incentives for VIUs and unbundled TSOs for the Scenarios are quantified. The incentives to invest in cross-border capacity depend quite critically on the availability of generation capacity. As mentioned above, development of offshore wind, decommissioning of nuclear and old coal plants, and difficulties in constructing new plant makes relative capacity scarcity a real possibility. However, this is uncertain. The extent to which the many investment plans will be realized is unclear. The results based on our assumptions can be summarized as follows:

- In the scenarios (1 and 2) with low generation capacity, where inland prices are high and imports increase ceteris paribus, we find that expansion of cross-border capacity is beneficial for net surplus, but the VIU would not have an incentive to invest, as imports would increase competition on the home market. In this case, unbundling would improve incentives for expansion of cross-border capacity.
- If generation capacity is high (Scenarios 3 and 4), where Germany is likely to remain a net exporting country, the conclusion above no longer holds, and the incentives to invest for VIUs and unbundled TSOs may be in line.
- The expansion of cross-border capacity may not be beneficial for the net surplus of the rest of Europe

if their imports heavily depend on Germany as in Scenarios 3 and 4.

It should be stressed that this analysis on the incentives to build new cross-border capacity is only part of the picture. In practice, siting permission and other legal requirements may be high hurdles and passing of investment costs to consumers or producers may change the picture.

VI. Conclusions

Nodal price differences and congestion patterns may arise in the German electricity network due to the high investments in wind turbines in the North and the decommissioning of nuclear plants in the South. The study shows that the current investment plans within the German electricity grid is not likely to be adequate to diminish internal congestion. A uniform German price zone may therefore be inappropriate in the future. Finally, in the case where future regulation ensures that unbundled TSO's are incented to maximize social welfare for the EU system as a whole, unbundling is likely to stimulate investments in cross-border transmission capacity. However in the case where Germany remains an export country, VUI's may also be incented to invest in cross-border transmission capacity.

Appendix

TABLE 3
DISTRIBUTION OF NEW GENERATION AND DECOMMISSIONED CAPACITY IN SCENARIOS 1 AND 2

	New Generation Capacity (GW)			Decommissioned Capacity (GW)			
German Node	Gas	Coal	Wind	Coal	Gas	Nuclear	Oil
SH+Hamburg		2.5	4.9	-0.4		-3.4	-0.4
NI+Bremen	0.9	1.6	5.9	-1.6		-1.4	
HE	0.4		0.1	-0.6		-2.4	
BY	1.7	1.1	0.1		-0.1	-6.0	-0.5
MV	1.2	1.6	1.2				
BB+Berlin+ST	0.8	0.8	0.8	-0.6	-0.1		-0.2
TH+SN		0.7		-0.1			-0.4
NW	0.4	7.6	1.0	-15.5	-0.1		
RP+SL		2.3		-1.6			
BW	1.0		0.1	-0.9		-3.0	-0.5
Total	6.4	18.2	14.1	-21.3	-0.3	-16.2	-2.0

TABLE 4
DISTRIBUTION OF NEW GENERATION AND DECOMMISSIONED CAPACITY IN SCENARIOS 3 AND 4

	New Generation Capacity (GW)			Decommissioned Capacity (GW)			
German Node	Gas	Coal	Wind	Coal	Gas	Nuclear	Oil
SH+Hamburg		3.3	8.8	-0.4			-0.4
NI+Bremen	0.9	3.2	10.6	-1.6			
HE	0.4		0.3	-0.6			
BY	1.7	1.1	0.1		-0.1		-0.5
MV	1.2	1.6	2.1				
BB+Berlin+ST	0.9	0.8	1.7	-0.6	-0.1		-0.2
TH+SN		0.7		-0.1			-0.4
NW	0.4	8.4	2.2	-15.5	-0.1		
RP+SL		2.3	0.1	-1.6			
BW	1.0		0.1	-0.9			-0.5
Total	6.5	21.4	26.0	-21.3	-0.3	0	-2.0

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