E3GRID2012 – European TSO Benchmarking Study

A REPORT FOR EUROPEAN REGULATORS

July 2013

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Executive Summary

Background

Electricity transmission system operators are regulated by national and European directives. Revenue allowances for these companies are set by national regulatory authorities (NRAs). One task typically undertaken by these NRAs is to assess that the regulated revenues are based on efficient costs. Such analysis is often based on cost benchmarking among network companies. Given the limited number of national transmission system operators (TSOs), which limits the ability of NRAs to undertake benchmarking that is national in scope, a number of European NRAs have decided to collaborate in order to develop an international sample of comparator companies.

A larger data set from an international benchmark provides an enhanced ability to identify the drivers of cost that are purely exogenous to the company (i.e. associated with its supply task and operating environment) from those that are endogenous and arise as a consequence of potential differences in underlying managerial efficiency. Benchmarking of this kind can be used to assess the current and past relative cost efficiency, which may inform tariff reviews under both high- and low- powered regulatory regimes.

The overall objective for the e3grid2012 project is to deliver sound estimates for the cost efficiency of European electricity TSOs, using validated data for a relevant sample of structurally comparable operators, which can be used to inform national regulatory proceedings.

Process

The e3grid2012 project was characterised by various interactions between the consortium, NRAs and the TSOs. The process was aimed at the highest degree of transparency while not violating the confidentiality of the data provided by the participating TSOs.

- **Workshops with NRAs and TSOs** – Four workshops were held together with TSOs and NRAs. One kick-off workshop (October, 4th, 2012) at the beginning of the project, one workshop on the status of the data collection (February, 13th, 2013), one workshop presenting the preliminary findings (R1 workshop on April, 26th, 2013) and one workshop presenting the preliminary final results (R2 workshop on June, 21st, 2013). In addition, the consortium held a presentation only with NRAs on June, 13th, 2013 and a presentation of the status of the project at the CEER Taskforce meeting on January, 24th, 2013.

- **Consultation on documents** – Various consultations between the consortium, NRAs and TSOs took place during the project. There were consultations on data collection guides, e.g. on cost guidelines (Call C), on technical assets (Call X), on other parameters (Call Y), on quality indicators (Call Q). There was a consultation on the cost weights used to weight the technical assets from Call X. In addition, TSOs and NRAs had the opportunities to submit comments and remarks to the presentations from the workshop and the R1 report on the preliminary model specification released in April 2013. Finally, a process paper on the Call Z – TSO specific costs was released.

- **Process on Call Z (TSO specific costs)** – After release of the R1 report the Call Z process started where TSOs had the possibility to submit claims on costs not yet included in the preliminary model candidates from R1.

- **Data validation** – After the presentation of the preliminary findings (R1) and the preliminary final results (R2) the full set of data used for the calculations was released to the TSOs. TSOs used this to validate their data and to submit comments if necessary.

- **Ongoing communication** – There was an ongoing communication between the Consortium, NRAs and the TSOs using a dedicated internet platform (so-called "Worksmart platform"). On this platform TSOs could make postings on various issues either using their TSO's helpdesk, which were only accessible by the TSO itself, the Consortium, the respective NRA, or using the common forum accessible to all participants in the project.

Data definition, collection and validation

The quality of the data plays a crucial role in any benchmarking analysis. Given this, the e3grid2012 project placed a strong emphasis on data specification and data collection. NRAs and TSOs were consulted in the data specification process and both groups of stakeholders have provided constructive comments during three project workshops and postings on a dedicated electronic work platform ("Worksmart").

The process has helped support the consistency of data reporting by the companies and the interpretation of the data provided by the companies.

Structure of model specification and efficiency calculation

In principle any efficiency analysis can be described as a sequence of the following steps:

- **Scope of benchmarking** – The benchmarking here relates to Grid construction, Grid maintenance and Administrative support. By contrast excluded from the benchmark are potential TSO functions of Market facilitation, System operations and Grid planning. Offshore activities have also been excluded from the analysis.

- **Benchmarking methodology** – Data Envelopment Analysis (DEA) is used as benchmarking technique. This choice is motivated by the (limited) size of the sample of 21 TSOs. It is also the technique used in previous similar studies. A concern has been raised that a sample of 21 companies may be small for a respective benchmark. However, we point out that a small sample in DEA tends to lead to higher efficiency scores than the same analysis in a larger sample. Therefore, the small size tends to be to the benefit of the efficiency scores of the firms (and is not in itself a detriment).

- **Definition of benchmarked costs** – The benchmarking is based on total expenditures (Totex), which is the sum of operating expenditures (Opex) and capital expenditures (Capex), measured as capital consumption (depreciation and return). The benchmarking only relates to costs associated with the scope of activities listed before.

- **Cost driver analysis and model specification** – Engineering logic and statistical analysis is employed to identify the parameters, which reflect the
  - supply task of the transmission system operator; and
  - other structural and environmental parameter that have an impact on the TSOs' costs.

- **Calculation of efficiency scores and sensitivity analysis** – In the final step the efficiency scores of the TSOs are calculated using the benchmarking methodology, benchmarked costs and identified costs drivers. Sensitivity analysis has been used to explore the robustness of the results, e.g. by identifying and eliminating outliers. Second stage regression analysis has been used whether there would have been other parameters that could have helped explained identified inefficiencies.

Model specification for e3grid2012

The model includes three outputs:

- **NormalisedGrid** – This is a cost-weighted measure of the assets in use. The technical asset base serves as a proxy for the complexity of the operating environment of the firm. The efficiency analysis then no longer questions whether the assets are needed, but questions whether the assets have been procured prudently (at low prices) and whether the company and the assets are operated efficiently.

- **Densely populated area** – The size of the area with a population density more or equal 500 inhabitants/sqkm may require more complex routing of transmission lines (e.g. more corners to pass houses or to cross traffic routes, higher towers to fulfil minimum distance requirements), combining of multiple circuits on one tower in order to save land.

- **Value of weighted angular towers** – This is a weighted measure of the angular towers in use, where the weight is based on the normalised grid for overhead lines per voltage level. This parameter constitutes a correction factor for a "special condition" class of lines. The parameter indicates a complex operating environment where routing of lines is not always straight which leads to higher specific cost of assets. The parameter is technically well-motivated and exhibits the expected sign in the regression model in the log-linear form.

All parameters are statistically significant and have the expected signs in the relevant model specification runs.

Hence, in the following we define the model with the respective outputs:

Table 1. e3grid2012 Model parameters

	Model e3grid2012
Input parameter	Totex (after Call Z adjustments)
Output parameters	NormalisedGrid
	Densely populated area
	Value of weighted angular towers

Source: Frontier, Consentec, Sumicsid

The benchmarking analysis not only considers the above-mentioned cost drivers. Companies have also been invited to claim any company specific cost differences, which are not reflected by other included (or tested and rejected variables). The claims were reflected as an adjustment to the cost base (i.e. such costs were excluded from the benchmark) if they were properly motivated and also quantified by the TSO. In total we received 66 such claims of which 35 were reflected by adjusting the cost base of companies. These reflected claims related to:

- **Structural claims –** These claims allowed the TSOs to specify "special conditions" of power lines and cables. The structural claims comprised three aspects:

- Higher costs due to lines in mountainous regions;
- higher costs due to lines in coastal areas; and
- higher costs for cables in cable tunnels.

- **Individual claims –** These claims were unique for TSOs.

A criticism has been raised that the use of NormalisedGrid as a cost driver is unconventional and that alternative service parameters – such as e.g. peak load – should have been used. We agree that in principle this can be a logical consideration, although in the instance this may on balance be against the interest of the benchmarked companies.

- There are examples of distribution system benchmarking studies that relied mostly or completely on parameters reflecting the supply tasks, such as peak load, number of costumer connections or service area. However, it is a non-trivial task to adopt this principle for benchmarking of TSOs. The reason is that TSOs are facing a supply and transmission task.[1] On the one hand, their networks serve to connect and/or supply customers, be it generators, large consumers or distribution networks. But on the other hand, they also serve for bulk transmission of power, including the exchange of power with neighbouring TSOs. Both functions are realised by the same network assets; it is, therefore, not possible to separate the assets (or, more generally, the costs) into supply and transmission parts, respectively.

  The consequence of this overlapping of functions is that typical exogenous service parameters for distribution networks, e.g. peak load, are not equally sufficient for explaining the costs of transmission networks. For example, two equally efficient transmission networks could have identical peak load, but if only one of them has to transmit significant amounts of transits between neighbouring networks, it is certainly more costly.

  However, simply enlarging the benchmarking model by adding service parameters that reflect the transmission task does not necessarily result in a proper model, for three reasons. Firstly, the number of parameters that can usefully be included in a DEA model with a small sample size is limited. Secondly, separate parameters for supply and transmission tasks fail to account for the repercussions among these tasks. And thirdly, parameters properly reflecting the actual cost impact of the transmission task are hard to find. For example, supposing that "transits" would be considered a

1 There are even more tasks, such as balancing, but these are not included in the benchmarked cost here.

candidate parameter, there could be networks with equal (peak) transit level, but one network transmits transits in constant direction, whereas another – probably more costly – network has to transmit transit in various directions.

Consequently, the (exclusive) use of service parameters, although appealing at first glance, would bear a high risk of designing a benchmark model that would not accurately reflect true cost driving relationships and thus would be biased against some firms in an unpredictable manner.

- Therefore, in the given context, the variable "NormalisedGrid" is more appropriate than a pure service parameter model. This variable is "soft" on the companies in the sense that it accepts the assets that have actually been built and does not question whether they are needed (while a model that uses e.g. peak load instead would implicitly question whether the assets actually are indeed needed to fulfil the supply task).

- Variables reflecting the supply task tend to be more volatile and thereby have less explanatory power for cost – peak load or energy supplied may vary year-on-year even though the company needs to make a fixed commitment – valid practically for decades - to the assets needed to provide the service. A benchmark focused on volatile parameters of the supply tasks will introduce variation in the efficiency scores. This is overcome, by using a more stable variable, "NormalisedGrid". That "NormalisedGrid" is a more stable explanatory of cost is also confirmed by our statistical analysis.

Efficiency scores – e3grid2012 base model

The outputs from the cost-driver analysis are used when calculating the DEA efficiency scores. In addition we make the following specification for DEA for our base model:

- **Non-decreasing-returns to scale** – The cost-driver analysis allows the assessment of returns-to-scale in cost functions and gives an indication for returns-to-scale specification for DEA. Our statistical model indicates increasing returns to scale in the cost function, which we have reflected by a non-decreasing-returns-to-scale (NDRS) specification in DEA. NDRS makes an allowance for smaller companies potentially finding it harder to achieve the same average cost efficiency as larger firms, while not giving large firms an allowance for potentially being too large.

- **DEA outlier analysis using dominance and super efficiency test** – DEA efficiency scores may be dependent on single observations of peer companies with low cost. In order to increase the robustness of the analysis it is important to assess, if the results are driven by companies with exceptional characteristics ("outliers"). This is done by outlier analysis in

DEA, which consists of screening extreme observations in the model against average performance using two tests: dominance test and super efficiency test. We follow the tests as prescribed in the German ordinance on incentive regulation (ARegV).

- **DEA outlier analysis using selected Capex break methodology** – In e3grid2012 we introduce an additional outlier analysis in DEA to assess the robustness of the estimated efficiency frontier to the potential understatement of historic investment costs that arises as a consequence of incomplete investment data for some companies. For peer companies that were unable to provide a full history of their investments from 1965-2011 we undertake an analysis where we apply an adjustment calculation (our "Capex break methodology") to adjust their Capex. We then recalculate the DEA efficiency scores for the sample using adjusted costs for selected peer companies. This adjustment calculation has been applied to two companies in the sample. The effect of this adjustment is to improve the efficiency of certain companies (i.e. those that are compared to a peer with incomplete asset data). No company's score is reduced owing to this adjustment.

- **DEA weight restrictions** – Moving to a DEA based best practice evaluation (without weight restrictions), the relative importance of the different cost drivers will be endogenously determined and different for every TSO so as to put each TSO in its best possible light. For such reasons DEA should also be referred to as a "benefit-of-the-doubt approach". In a small data set – with potentially few peer companies – it makes the analysis cautious. Our first analysis has shown that for some companies DEA would assign strong weights to the cost drivers of value of weighted angular towers and densely populated area, while no weight is attached to the NormalisedGrid. This however stands in contradiction to engineering knowledge and our statistical analysis, which indicates that the NormalisedGrid is the main cost driver. In our base model we therefore use weight restrictions in DEA to limit the relative importance we allow to be given to the different cost drivers. We inform this analysis by the coefficients (cost elasticities) estimated in the statistical analysis. In fact we have explored the confidence interval for each of the variable and use upper and lower value restrictions on the weights which lie even outside the 99% confidence intervals (this implies that the weights we use include the true values with a probability in excess of 99%). We specify the constraints as a variation in the allowed weights within -50% and +50% of the statistical estimates for the respective coefficient (cost driver).

The e3grid2012 base model is defined as:

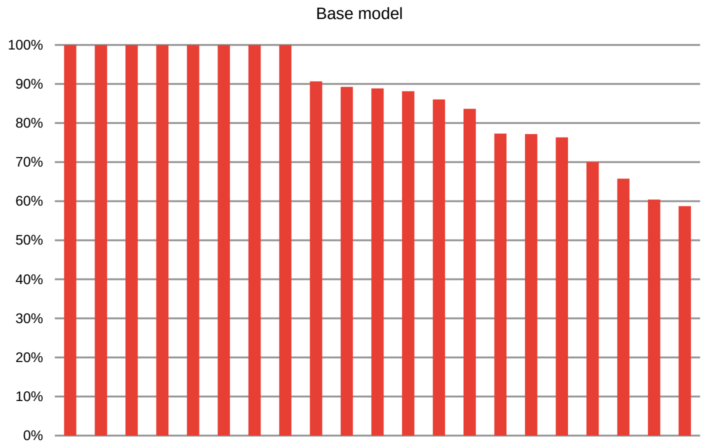
Table 2. Model parameters for e3grid2012 base model

	DEA model
Sample	21 TSOs
Input	Totex (after Call Z adjustments)
Outputs	NormalisedGrid
	Densely populated area
	Value of weighted angular towers
Returns to scale	Non-decreasing-returns to scale
Weight restriction	+/-50% of the cost elasticities estimated in a regression model with the above variables
Selected Capex break	2 TSOs

Source: Frontier/Sumicsid/Consentec

Figure 1 illustrates the distribution of efficiency scores for the e3grid2012 base model. The results are after DEA outlier analysis using dominance and superefficiency test. In addition, selected Capex break is applied to 3 TSOs who have not reported full annual investment stream data back to 1965 and who would set the efficiency frontier, without a review of their Capex data. The Totex are after cost adjustments from Call Z.

Figure 1. e3grid2012 base model



Note: The efficiency scores for the TSOs, where selected Capex break was applied, are based on the costs after selected Capex break

Source: Frontier/Sumicsid/Consentec

The average efficiency is 86% and the minimum efficiency is 59%. 8 TSOs get a score of 100% (including 4 outliers based on dominance and superefficiency test) (**Table 3**).

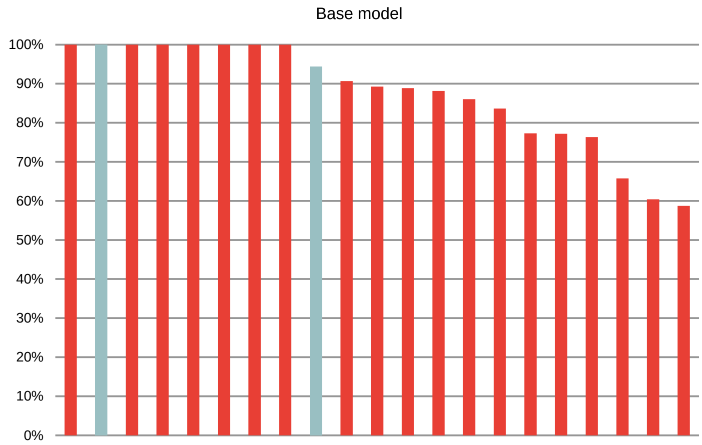
Table 3. e3grid2012 – base model

	e3grid2012 base model
Mean Efficiency (including outliers)	86%
Min Efficiency (including outliers)	59%
Outliers	4
100% companies (including outliers)	8

Source: Frontier/Sumicsid/Consentec

In addition we illustrate the distribution of efficiency scores for the e3grid2012 base model using the efficiency scores for the 2 Capex breaked TSOs before Capex break was applied.

Figure 2. Base model – efficiency scores for the 2 Capex breaked TSOs before Capex break



Note: Blue bars indicate the 2 TSOs, to which selected Capex break was applied. We note that the unrestricted DEA model is used to screen the efficiency frontier, if selected Capex break shall be applied to certain TSOs. This implies that a TSO not being 100% efficient in the base model can be selected Capex breaked.

Source: Frontier/Sumicsid/Consentec

Sensitivities – e3grid2012 base model

We have also undertaken sensitivity analysis around our base model. This includes the variations to model specification and variations to data:

- **Variations to model specification:**
  - **Unrestricted DEA** – In the base model we are using weight restrictions as a range (+/-50%) around cost elasticities as estimated in the cost-driver analysis. As sensitivity we calculate the efficiency scores without weight restrictions. Logically, by removing weight restrictions, the efficiency scores of firms cannot fall, but potentially they rise for individual companies. The average efficiency increases by 5% points to 91%, where 13 TSOs increase their efficiency. The number of 100% efficient companies increase from 8 to 12. Analysis of the factors that drive the DEA efficiency scores indicate that for many firms the physical assets of the companies (normalised grid, which has been found to be the key cost driver in the statistical analysis), only have a minor impact on the DEA efficiency scores. This is contrary to engineering logic and the results of statistical analysis.
  - **Weight restrictions based on upper/lower bound of confidence intervals from regression** – In the base model we use weight

restrictions as a range (+/-50%) around cost elasticities as estimated in the cost-driver analysis. As sensitivity we calculate the efficiency scores with weight restrictions based on the upper/lower bound of confidence intervals as estimated in the cost-driver analysis. The average efficiency decreases by 1% point to 85%. The largest decrease is 4% points. The number of 100% efficient companies reduces from 8 to 7.

- **Variations to data:**
  - **Indexation of investment data using Producer Price Index (PPI)** – In the base model we are using the Consumer Price Index (CPI) to index the investment stream data in order to calculate Capex annuities. The merit of the CPI is that it is available for all countries, based on a common methodology, and available for a long time range. As sensitivity we are using the PPI instead of the CPI, as this may reflect more the cost development of the investment stream. However, the data availability of the PPI from common sources was limited compared to CPI and extrapolation of data was necessary. The results indicate that the impact from switching to PPI on the average efficiency score is low, while the effect on individual companies may be more substantial. The average efficiency decreases by 2% points to 84%. While the average efficiency score does indicate a minor difference between the two models the impact on individual companies is substantial. The maximum increase is +14% points while the maximum decrease is -18% points. Further analysis of the results indicated that the results in the PPI model are very much driven by the necessary extrapolation of missing data. Hence we concluded that, using PPI may be an interesting approach for country-specific analysis using a national PPI index for the respective TSO, while not suitable for a general approach.
  - **Opex efficiency** – In a variant we modified the cost data in order to calculate efficiency scores only for Opex. We adjusted the Totex by replacing the companies' Capex by the NormalisedGrid Capex. This allows focussing on the efficiency of the Opex by using the same output parameters in the DEA model. The average efficiency for this specification is 86%. The number of 100% efficient companies reduces to 3 companies. The impact on individual companies may be quite large. The maximum increase is +29% points while the maximum decrease is -21% points.

Second stage analysis

We have further undertaken so-called second stage analysis. The purpose of a second stage analysis is to ensure that we have appropriately specified the best model using the available data. We do so by testing if any excluded variables should potentially have been included. In a second stage analysis, the efficiency scores are regressed against an excluded variable to determine whether it has a significant impact on efficiency scores. If the variable were to significantly explain the efficiency scores, this could be an indication that the respective variable should have been included in the base model. Therefore, second stage regression analysis provides a valuable control of the model specification.

Second stage analysis has been carried out for a number of parameters, e.g. (the list is not exhaustive):

- Energy not supplied (ENS);
- peak load;
- generation capacities; and
- various area parameters.

The second stage analysis indicates that none of these parameters serves as an additional explanatory for the identified inefficiencies.

Dynamics – e3grid2012 base model

The static efficiency measures allow us to measure the incumbent inefficiency, i.e. the excess usage of resources in a given period, of a TSO. In a next stage we engage in dynamic analyses and measure also the technological progress (or regress) of the industry. We calculated the Malmquist productivity index (MA) for 2007-2011 and the decomposition into Efficiency Change (EC) and Technical Change (TC). While MA captures the net change of productivity, EC captures catch-up effects and TC captures frontier shifts. We translate the indices in % points changes by deducting 1 from the index. We note that a positive (negative) % change indicates an improvement (regress) of the productivity.

Table 4. Malmquist for industry

2007-2011	Malmquist (% point changes)	Efficiency Change (% point changes)	Technical Change (% point changes)	Observations
All TSOs	-1.4%	2.4%	-1.0%	81
Continental Europe	0.0%	4.5%	-0.8%	50
Scandinavia	-1.4%	0.6%	-1.9%	15
UK	-7.0%	-2.8%	-1.1%	12

Note: the % point change is given by: (average of Malmquist indices for each company) – 1. The decomposition of the Malmquist index for each TSO *i* in each year *t* is calculated by: $MI_{i,t} = EC_{i,t} \times TC_{I,t}$. This implies that the net effect in the table above cannot be calculated simple by adding the EC and TC.

Continental Europe includes TSOs from all countries except UK, Scandinavia and Estland.

Scandinavia includes TSOs from Finland, Norway, Sweden and Denmark

Source: Frontier/Sumicsid/Consentec

The average results for all TSOs indicate a positive efficiency change of +2.4%, i.e. the inefficient companies improve their position against the efficiency frontier, and a regress of the efficiency frontier of -1.0%. A split of the TSOs into three groups indicated that the change in the efficiency frontier for continental Europe and UK tends to be in a similar range (-0.8% and -1.1%) while Scandinavia indicates a higher regress of -1.9%.

When interpreting the results from the dynamic analysis we note that it is necessary to keep in mind that the period 2007-2011 was characterised by various structural organisational changes due to unbundling requirements for various companies. Resulting potential one-off effects where not adjusted for in the dynamic calculations with a likely impact on the dynamic results. We note that a regress may be explained as certain companies have reported rising cost in 2011.

1 Introduction

1.1 Background

Electricity transmission system operators are regulated by national and European directives. Revenue allowances are set by national regulatory authorities (NRAs). One task of NRAs in many countries is to assess that the regulated revenues are based on efficient costs. Such analysis is often based on cost benchmarking among network companies. Given the limited number of national transmission system operators (TSOs) many European NRAs have decided to collaborate to develop an international sample of comparator companies.

The systematic and rigorous analysis of the costs and performance of other transmission system operators allows obtaining useful information.

A larger data set from an international benchmark allows distinguishing the cost drivers that are purely exogenous from the endogenous cost decisions (managerial efficiency). This can be used to assess the current and past relative cost efficiency, which may inform tariff reviews under both high- and low-powered regulatory regimes.

1.2 Objective of e3grid2012

The overall objective for the e3grid2012 project is to deliver sound estimates for the cost efficiency of European electricity TSOs using validated data for a relevant sample of structurally comparable operators.

Bundesnetzagentur on behalf of other European regulators commissioned Frontier Economics, Sumicsid and Consentec to conduct a pan-European benchmarking study, e3grid2012.

The consortium has been supported by PwC, who have acted as a subcontractor for Sumicsid with the specific task of screening cost data in order to ensure consistency across the cost data provided by different TSOs.

1.3 Milestones of e3grid2012

In the following we list the main milestones for the e3grid2012 project. The project involved several consultation processes with NRAs and TSOs.

Table 5. Milestones e3grid2012

Milestone	Date
Kick-off meeting (Berlin)	4 October 2012
Start of Data collection (Call C)	30 October 2012
Start of Data collection (Call X)	2 November 2012
Workshop on data collection and next steps	13 February 2013
R1 report (release)	24 April 2013
R1 workshop	26 April 2013
R1 data release	29 April 2013
Start of Call Z	24 April 2013
R2 workshop	21 June 2013
R2 data release	26 June 2013
e3grid2012 draft report (release to NRAs)	12 July 2013
e3grid2012 data summaries	12 July 2013
e3Grid2012 final report	25 July 2013

Source: Frontier/Sumicsid/Consentec

1.4 Participating TSOs in e3grid2012

The initial number of participating TSOs at the beginning of the project was 23. This number was reduced by 2 TSOs during the process:

- TSO 1 – we did not receive any data from these TSOs despite various data requests and reminders from the Consortium and Bundesnetzagentur;
- TSO 2 – we did receive data from this TSO, however, for the technical asset data the granularity of data was not sufficient. After discussion with the TSO and the NRA we came to the common conclusion that the TSO should drop out of the project.

Table 6 lists the remaining 21 participating TSOs in alphabetical order and the respective NRAs in the project.

Table 6. Participating TSOs in e3grid2012

	TSO	NRA	Country
1	50Hertz	Bundesnetzagentur	Germany
2	ADMIE	Regulatory Authority for Energy	Greece
3	Amprion	Bundesnetzagentur	Germany
4	APG	E-Control	Austria
5	CEPS	ERU	Czech Republic
6	CREOS	ILR	Luxembourg
7	Elering	Konkurentsiamet	Estland
8	Energinet.DK	DERA	Denmark
9	Fingrid	EMU	Finland
10	National Grid	OFGEM	UK
11	PSE Operator	URE	Poland
12	REE	CNE	Spain
13	REN	ERSE	Portugal
14	RTE	CRE	France
15	SHETL	OFGEM	UK
16	SPTL	OFGEM	UK
17	Statnett	NVE	Norway
18	Svenska Kraftnett	Energy Markets Inspectorate	Sweden
19	TenneT DE	Bundesnetzagentur	Germany
20	TenneT NL	ACM	Netherlands
21	TransnetBW	Bundesnetzagentur	Germany

Source: Frontier/Sumicsid/Consentec

1.5 Structure of the report

The report is structured as follows:

- **Section 1** includes a short summary of the project and the main milestones.
- **Section 2** describes the data collection and data validation process including the consultations with the TSOs and NRAs.
- **Section 3** describes the structure of the model specification and efficiency calculations.
- **Section 4** describes the benchmarking methodology.
- **Section 5** describes the benchmarked costs.
- **Section 6** describes the cost-driver analysis and model specification
- **Section 7** describes the static and dynamic results.

2 E3grid2012 – data collection and validation

The quality of the data is crucial in any benchmarking analysis. The e3grid2012 project therefore places a strong emphasis on data specification and data collection. The NRAs and TSOs have been heavily involved in the data specification process. PwC, as a subcontractor of Sumicsid[2], has performed a validation of the cost data of TSOs. In the following we give a short overview[3] on the process of

- Data definition and consultation;
- data collection; and
- consultation on benchmarking methodology.

2.1 Data definition and consultation

In the e3grid2012 we have used the data reporting guidelines from the E3Grid project (of 2008) as starting point. We amended and updated the data reporting guidelines based on

- Comments from NRAs and TSOs at the start of the project; and
- comments/remarks from NRAs and TSOs during the consultation process.

The scope of data definition and data consultation included:

- Call C – Cost Reporting guide;
- Call X – Data Call for EHV/HV Assets;
- Call Q – Data Call for Quality Indicators;
- Call Y – Data Call for potential output indicators and economic and macro-economic environment;
- Cost weights for different types of assets and voltage levels; and

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2 PricewaterhouseCoopers Advisory N.V. (PwC) acts as a subcontractor of Sumicsid and is only involved with validation of Call C data. PwC has not performed an audit or a review on the submitted data, but supported the consortium (i.e. Frontier/Sumicsid/Consentec) to identify potentially flawed or missing costs data. PwC is neither involved with any validation work related to the benchmarking methodology itself as used by the consortium, and has not provided any view on the benchmarking methodology or the results.

3 For a more detailed description we refer e.g. to Frontier/Sumicsid/Consentec, *Pan-European TSO efficiency benchmarking*, Workshop with NRAs and TSOs, Brussels, February, 13rd, 2013.

- Call Z – This was a free form reporting process in which the companies were allowed to explain and claim additional (exogenously driven) cost differences which have not already been reflected in the analysis.

2.1.1 Call C – Cost Reporting guide

Based on comments/suggestions received before and during the kick-off meeting, we amended the cost reporting guide Call C from the previous e3Grid project in 2008. This new guide was issued for consultation on October 10th, 2012 and the deadline for submissions from TSOs and NRAs was October 23rd, 2012. We received more than 10 submissions from TSOs and NRAs which were included in an updated Call C – Cost Reporting guide[4].

The amendments in Call C were, e.g.

- Out of scope costs – offshore grid operations was classified as out-of-scope costs (not to be included in the analysis);
- capitalization principle – some clarifications have been made, e.g. on how to treat activated interest;
- cost of services purchased externally – this item is new to obtain information on the extent of outsourcing; as well as
- investment stream – we increased the degree of details.

2.1.2 Call X – Data Call for EHV/HV Assets

Based on comments/suggestions received before and during the kick-off meeting we amended the Call X from the previous e3Grid project in 2008. This new guide was issued for consultation on October 10th, 2012 and the deadline for submissions from TSOs and NRAs was October 23rd, 2012. We received more than 10 submissions from TSOs and NRAs which were included in new Call X – Data Call for EHV/HV Assets[5].

The amendments in Call X were, e.g.

- Current ranges – the current ranges of assets have been extended;
- power thresholds for circuits of lines – instead of operational limits the nominal ratings are used; and

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4 For more details we refer to e3grid2012, *Cost Reporting Guide (Call C)*, Version 1.1, 2012.

5 For more details we refer to: e3grid2012, *Data Call for EHV/HV Assets (Call X)*, Version 1.15, 2013. In addition we released a document including a summary and evaluation of consultation responses from TSOs and NRAs. For more details we refer to: e3grid2012, *Data Call for EHV/HV Assets (Call X) – Summary and evaluation of consultation responses*, Version 1.7b, 2012.

- towers – the data request has been restructured and additional information on tower types have been included.

2.1.3 Call Q – Data Call for Quality Indicators

Based on comments/suggestions received before and during the kick-off meeting we amended the Call Q from the previous e3Grid project. This new guide was issued for consultation on October 10th, 2012 and the deadline for submissions from TSOs and NRAs was October 23rd, 2012. We received 9 submissions from TSOs and NRAs which were included in new Call Q.

We proposed to use Average Circuit Unreliability (ACU) as one option for a quality indicator. ACU was based on regulatory discussions since the last benchmarking analysis 2008, especially in the UK. On the basis of the responses received, and because of the issues identified by the respondents, we decided not to collect any information on ACU for the e3grid2012 study.

Instead, we continued to use data on Energy-not-supplied as quality indicator. These data were collected from the NRAs.[6]

2.1.4 Call Y – Data Call for Output indicators

Call Y includes two categories of data:

- Potential further cost drivers and physical environment; and
- economic environment and macro-economic environment.

We issued a consultation paper on November 20th, 2012 and the deadline for submissions from TSOs and NRAs was December 4th, 2012. We received 6 submissions from TSOs and NRAs.

One general remark of TSOs was that the relationship between potential output indicators and costs must be plausible from an engineering or business process perspective and that statistical evidence alone may not prove the actual relation itself. In addition, the analysis should be accompanied by explanations on the relationship between the costs and output parameters in "real life".[7]

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6 For details on the consultation process and the result we refer to: e3grid2012, *Data Call for Quality Indicators (Call X)*, Version 0.3, 2012.

7 "Furthermore we would like to emphasise that regression analysis / correlation analysis in itself is no prove for relationships between costs, outputs and environmental factors in 'real life'. These analyses / correlations might provide statistical evidence, however it does not prove the actual relation itself. Therefore we like to stress that the use of data from call Y in the benchmark by the Consortium should also be accompanied by explanations on the relationship between the costs in 'real life'." (TenneT NL, Comments on Call Y, 5th December 2012, p.1).

Some TSOs also stressed the importance of population density as a very significant output factor, as TSOs in densely populated areas are confronted with many additional requirements to construct the assets. One TSO asked for additional area definitions, e.g. including industrial area as a potential costs driver. Several TSOs asked for including parameters reflecting mountainous areas and areas below sea level.

We included these remarks in the structure of the cost-driver analysis and model specification.[8]

2.1.5 Cost weights

In order to obtain one output parameter to comprise all physical assets, it is necessary to transform the different asset units into a uniform number. This is done by multiplying all assets with respective cost weights and adding up the cost weighted assets. As mentioned above, new types of physical assets were included in Call X for e3grid2012. Hence, new costs weights were necessary for these new assets.

We issued a respective consultation paper on December 14th, 2012 on these new cost weights. The deadline for submissions from TSOs and NRAs was January 21st, 2013. We received 6 submissions from TSOs.

We issued a detailed document including responses to the submissions we received from the TSOs and made some clarifications on the cost weights and amendments.[9]

After the release of that document the following further steps have been taken:

- *Discussion on Opex weights* – Some TSOs expressed concerns regarding the adjustment of the Opex weights as result of the consultation. We note that the adjustments were in line with consultation responses from TSOs (e.g. amendment of the ratio of lines and cables, reduction of weights for circuit ends) and further investigations by us.[10]

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8 For details on Call Y we refer to: e3grid2012, *Call Y – Summary and evaluation of consultation responses*, Version 5, 2013.

9 For details we refer to Frontier/Sumicsid/Consentec, *Cost weights – Summary and evaluation of consultation responses*, Version 0.4f, 2013.

10 In particular, the reduction of Opex weights for circuit ends (also proposed during the consultation) to 0.85%/a is in line with figures stated in the following studies (in German language):

Consentec GmbH, IAEW, RZVN, Frontier Economics, "Untersuchung der Voraussetzungen und möglicher Anwendungen analytischer Kostenmodelle in der deutschen Energiewirtschaft.", Study commissioned by Bundesnetzagentur, November 2006, http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/BNetzA/Sachgebiete/Energie/Anreizregulierung/BerichteVeroeffentlichungenGutachten/GutachtnCONSENTEC-Id9600pdf.pdf?__blob=publicationFile p. 117;

- *Consultation on weights for AC/DC converter stations* – A specific consultation on these non-standard assets was conducted, involving the TSOs operating such assets.[11] The basic approach here was to avoid a distortion of the benchmark by these few but costly assets. Therefore, the goal of the consultation was to obtain weights that lead to the share of HVDC converter stations in the NormalisedGrid (see below) being equal to their share in actual costs. Effectively one assumes that – under the fictitious presumption that the efficiency could be separated between the converter stations and the rest of the TSOs assets or services – the efficiency of the converter stations is equal to the efficiency of the "remainder" of assets. We note that, in case that the actual efficiency of the converter stations differs from the "remainder", the overall efficiency score could be distorted, the extent of the effect depending on the relative share of converter stations' costs in the TSO's total benchmarked costs and on the difference of efficiencies.

- *Differentiation of sea and land cables* – Some TSOs pointed out that cost weights should be different for sea and land cables. Based on a scrutiny of sample projects we set the weights for sea cables to 120% of the weights for land cables.

- *Multiple vs. single DC lines* – Some TSOs operate multiple (i.e. parallel) DC lines. The original weights table contained such differentiation only for AC lines. We have therefore updated our analysis to reflect the respective relative ratios between single and multiple AC lines also for DC lines.[12]

- *High current cables* – Some TSOs operate cables in the high current classes (classes 8 and 9) that have been newly introduced in this study

Maurer, C., „Integrierte Grundsatz- und Ausbauplanung für Hochspannungsnetze", Dissertation, RWTH Aachen, 2004, 1. Auflage, Aachen, Klinkenberg Verlag, 2004 (Aachener Beiträge zur Energieversorgung, Band 101) p. 101.

Moser, A.: „Langfristig optimale Struktur und Betriebsmittelwahl für 110-kV-Überlandnetze", Dissertation, RWTH Aachen, 1995, 1. Auflage, Aachen, Verlag der Augustinus Buchhandlung, 1995 (Aachener Beiträge zur Energieversorgung, Band 35), p. 112.

Haubrich, H.-J.: „IKARUS Instrumente für Klimagas-Reduktions-Strategien. Teilprojekt 4 ‚Daten: Umwandlungssektor', Bereich ‚Verteilung und Speicherung elektrischer Energie'", Abschlussbericht für das Forschungsvorhaben für das Bundesministerium für Forschung und Technik, Förderkennzeichen: BEFT – Z/A - 78, September 1993, pp. A 42ff.

11 For details we refer to "Cost Weights for HVDC Converter Stations", ver 0.2, 2013-03-21.

12 The relative ratio reflects the cost saving by aggregating circuits on a route, i.e. a double circuit line is less costly than two separate single circuit lines.

(compared to e3grid). The cable weights have been extended accordingly.

- *Lines' conditions* – Cost weights for overhead lines are, *inter alia*, differentiated by their capacity, expressed by the maximum current. The maximum current of a line does not only depend on the design but also on the ambient conditions. To achieve the same maximum current, a more costly line is needed in a warm environment than in a colder environment. Therefore, each TSO was asked to report the ambient temperature associated to its reported lines' currents. This information was used to adjust the lines' weights for temperature differences between TSOs:

  The maximum transmittable current decreases by about 1% per degree centigrade of temperature increase.[13] This can be transformed into an increase of the cost weight, i.e. a relative increase of costs in order to obtain the same actual capacity under warmer conditions. Based on the given increase of cost weights between current classes, the following formula for the adjustment factor A_i is obtained:

$$A_i = (1 + \frac{\Delta T_i}{100°C})^{0,42}$$

  where ΔT_i is the temperature difference between the relevant ambient temperature provided[14] by the respective TSO i and a reference temperature. The reference temperature has been determined such that the average value of all adjustment factors is 1, such that here is no systematic effect of this adjustment on the cost ratio between lines and other types of assets.

The final cost weights are documented in **Annexe 6: Cost weights for NormalisedGrid.**

13 See for instance Schlabbach: "Netzsystemtechnik", VDE-Verlag, Berlin, Offenbach, p. 173.

14 For TSOs with missing or incomplete data on the ambient temperature, we retrieved the average yearly maximum temperature for a selection of cities throughout the respective country and computed the average across these cities ($T_{avg,i}$). This was also done for Germany, where the ambient temperature for lines is 35°C. The difference of the average temperatures between Germany and the respective TSO's country was then added to this 35°C in order to obtain ΔT_i: $\Delta T_i = 35°C + T_{avg,i} - T_{avg,Germany}$.

2.1.6 Call Z – Opportunity for TSOs to justify unique individual cost conditions

Companies have also been invited to claim any company specific cost differences, which are not reflected by other included (or tested and rejected variables). The claims were reflected as an adjustment to the cost base (i.e. such cost were excluded from the benchmark) if they were properly motivated and also quantified by the TSO. In preparation of Call Z a process document was released on March, 28th, 2013 before the release of the R1 report, which initiated the submission of Call Z claims from TSOs.[15]

2.2 Data collection and validation

The data collection process can be differentiated into:

- Data provided by TSOs – this includes data from Call C, Call X and Call Z;
- data provided by NRAs – this includes data from Call Q; and
- data from the public domain – this includes data from Call Y.

The process of data collection for Call C and Call X started on October, 30th, 2012 (November 2nd, 2012). The deadline for submission of data was extended twice. The process of data collection for Call Z started on May, 9th, 2013 and was concluded on May, 24th, 2013.

In principle there were three phases of data validation in the e3grid2012 project, which can be split into

- pre R1;
- post R1; and
- post R2.

2.2.1 Data validation pre R1

The data provided by TSOs were validated by

- PwC – This included reconciliation of data to annual accounts, sanity checks by investigating the movement of relevant parameters and ratios over time and checks on potentially incomplete data; as well as

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15 e3grid2012, *Data Call for Operator Specific Conditions (Call Z)*, Version 1.3, 20.03.2013. For further details on Call Z see: **Section 2.2.2 (p.20)** and **Section 5.4**.

- Consentec – validation of Call X data. This included the check for completeness, consistency and plausibility. The data validation process resulted in some amendments and clarifications on Call X data.

Call C

In accordance with Sumicsid, PwC initially performed the following steps in the data validation process:

- Public available annual reports were used to perform plausibility checks on parameters at an aggregated level (i.e. the number of FTEs, depreciation & amortisation, and the total Opex). In the case where there was no reconciliation between the annual reports and the Call C data, whilst expected, PwC contacted the TSO for further clarification.

- High-level checks on the movement of costs data over the benchmarking period 2007-2011 per function were performed, including manpower costs, administration costs, number of FTEs, direct revenues, and the out-of-scope costs. The purpose of this step was to spot unusual development of parameters, which might have indicated flawed or inconsistent data. PwC contacted the TSO for further clarification, when needed.

- The movement of relevant ratios, such as personnel expenses per FTE, share of administration costs, share of out-of-scope costs, and share of direct revenues in the total costs was investigated. The purpose of this step was to identify outliers, which required further examination and clarification.

From the initial data validation, it was observed that the reconciliation between Call C data and public annual accounts was not always possible, as some public annual accounts are based on the consolidated figures of the holding company of TSOs. There were also indications of missing or incomplete data. Our initial validation resulted in updates of the initial data sets.

In the next step of the data validation, the consortium requested PwC to focus on four TSOs with a relatively high share of out-scope-costs. Further clarification provided by these TSOs showed that the high shares of out-of-scope costs were mainly the result of relatively high corporate tax and financial incomes of some TSOs.[16] No further adjustments of the out-of-scope costs were made for these four specific TSOs.

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16 We have not further investigated the specification of out-of-scope-costs of the 3 TSOs from the UK, as they have not responded to our request.

Call X

Consentec validated the TSOs' Call X data by checking against various criteria, such as:

- Completeness.
- Correct use of Excel template (interpretation of column headings, use of proper sheets, rows either empty or complete, validity of asset codes etc).
- Suitability for automatic data processing (e.g. no modifications to Excel templates).
- Consistency of voltage levels across asset types.
- Consistency of voltage class allocation across TSOs:
  - Consistent allocation of entire network levels to the voltage classes – This particularly relates to the so-called 220 kV level, where the proper allocation needed to be clarified because the Call X data call left room for interpretation; and
  - consistent allocation of individual assets – For instance, when the asset has been designed for a higher voltage level than the one it is operated at.
- Plausibility of relative quantities (e.g. assets at lower voltage levels, high breaking current of circuit ends).
- Consistency of power count and power class.
- Outlier analysis ratios, such as estimated average circuit length per voltage level.

All identified issues were communicated to the respective TSO(s). Data corrections were either made by the TSO (and then re-validated by Consentec) or by Consentec (and then sent to the TSO for cross-checking).

2.2.2 Data validation post R1

After the e3grid2012 – First Report (R1)[17] we released all data used for the calculation on the project platform either in the public domain for data we

[17] e3grid2012, *First Report (R1) – A note on methodology for the European TSO Benchmarking study*, April 2013.

collected from public sources or in the TSOs folders on TSO specific data. Hence, TSOs had the opportunity to check their and public data used. In addition, we identified some issues during the R1 calculations which were addressed after R1.

In the following we describe the main steps taken after R1.

Call C

Based on the initial calculations conducted by the consortium, Sumicsid requested PwC to perform further data analyses, including:

- A further examination of direct revenues claimed in Call C as "cost-correcting revenues";
- a further analysis of investment stream – in particular the question of "missing" opening balances;[18] as well as
- a high-level investigation of possible differences in the capitalization policy across EU countries.

Validation of direct revenues

In accordance with Sumicsid, PwC first undertook an initial assessment of the TSOs that should be approached for further analysis with respect to direct revenues. A relatively high share of direct revenues needed to be examined further, as it might result in an underestimation of costs relevant to the benchmarking. All TSOs who were asked for extra information were cooperative and have responded timely in most cases.

With the final review and approval of the consortium, direct revenues data of the TSOs were adjusted and updated accordingly in the latest data sets.

Investment stream

Based on the outcomes of R1, it appeared that six TSOs did not provide a full range of investment stream data for the period 1965 till 2011. The reason for not providing these investment stream data was that the TSOs were founded during the mentioned period. The investment stream data for the period prior to the foundation date was not available to the TSOs as the assets were acquired at book value (lump sum).

PwC compared the investment stream data in Call C with the cost of assets in the annual accounts, so excluding (cumulative) depreciation. The difference was

18 Frontier Economics made an initial validation of the investment streams. There were indications of incomplete investment streams such as "missing" opening balances. The validation only involves TSOs with investment streams shorter than 45 years and that do not comprise an externally validated opening balance.

discussed with the TSOs and resulted in a revised call C, in which the difference was included as opening balance/investment stream in the year of foundation. The opening balance for the new founded companies is deemed to be gross.

Capitalization policies

PwC compared the current capitalization policies in different countries and also compared the capitalization policies of the TSOs as mentioned in their annual accounts. Since the implementation of IFRS (as adopted by the European Union) in 2005, no significant differences exist in the capitalization policies of the TSOs. Also local accounting policies (local GAAP), converged to the principles of IFRS.

It is common knowledge that significant differences in capitalization policies have in general existed between countries prior to the implementation of IFRS. However, TSOs were not able to provide any reliable information about their capitalization policies prior to the implementation of IFRS. Therefore, it is not possible to make any specific comments about the capitalization policies of TSOs, but only about capitalization policies in the specific countries. In general, there are two possible scenarios:

- Differences exist in the capitalization of costs of own staff (salaries and other personnel costs) and in the capitalization of borrowing costs (interest expenses). When these costs were expensed as Opex, the current Capex as well as the current asset base is lower. The impact of these differences (as they existed prior to the implementation of IFRS) is however unknown, due to lack of reliable data from the past;
- all costs related to an investment were capitalized, regardless whether these costs were uneconomic or necessary. This resulted in a higher asset base and therefore higher Capex. It is expected that these capitalized expenses are corrected by an impairment loss according to IFRS requirements, thus not impacting this benchmark.

Call Y

In order to define a direct parameter for population density we calculated the three parameters:

- *Densely-populated area* – defined by the size of the area with a population density more or equal 500 inhabitants/sqkm;
- *Intermediate-populated area* – defined by the size of the area with a population density less than 500 and more or equal 100 inhabitants/sqkm; as well as
- *Thinly-populated area* – defined by the size of the area with a population density less than 100 inhabitants/sqkm.

For geographic granularity we used the NUTS3[19] regions as reported by Eurostat for the countries where the participating TSOs are operating. For the NUTS3 regions information is available on the

- Size of the area; and
- population density in the area.

We assigned these NUTS3 regions to the TSOs in the countries and added up the NUTS3 area (in sqkm) where the population density passed certain threshold to obtain values for densely-populated, intermediate-populated and thinly-populated area.

We released this assessment to the TSOs after R1. In addition we approached the 4 TSOs in Germany and 3 TSOs in UK – countries where more than one TSO is operating – to check if the R1 assignment of the NUTS3 corresponds with their service area and/or the area where the TSOs are operating network assets. 5 TSOs reported more detailed information on the assignment of NUTS3 regions which allowed us a further refinement of theses area parameters[20].

In addition, we made some further adjustments on the data based on TSOs comments, e.g. peak load, electricity production.[21]

Call X

In general, all TSOs reported annual figures for the assets in Call X. However, for a small number of assets of some TSOs the total number reported for certain assets was larger than the sum of the annual entries for the same assets (i.e. for a small part of asset base of individual TSOs the precise age structure has not been reported by the respective TSO). In order to include all assets in the NormalisedGrid, the difference between the total figure and the sum of the annual entries was spread according to the age structure of this asset type (implying that the assets for which no age structure was provided by the TSO are presumed to have the same age structure as the assets for which the age structure had been provided). We note that this was only a minor adjustment as this only applied to 32 asset rows out of the entire asset set of more than 2,000. Also, within these few asset rows the uncertainty about age structure only relates to part of the assets (not to all assets in that row).

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19 Eurostat, *Regions in the European Union, NUTS 2006 / EU 27*, 2007.

20 For details on the calculation of the area parameters for density we refer to the Excel calculation sheet published in the public domain of the e3grid2012 worksmart platform: e3grid2012_R2_calculation of density area_assignment of NUTS3 regions-stc.

21 We note that all the Call Y data and the calculations of these data were published in the public domain of the e3grid2012 worksmart platform.

In addition, some TSOs adjusted individual misreported data by themselves.

Call Q

After R1 we approached again the NRAs to provide us with some missing Energy-not-supplied data for the years 2007-2011. This resulted in

- 19 NRAs provided data on Energy-not-supplied;
- one NRA, where Energy-not-supplied is not disclosed for regulatory purposes, confirmed that the reported figures from the TSO in the annual report may be used; and
- for one TSO no data were available.

Hence, we had a full data sample (except for 1 TSO) of Energy-not-supplied data for at least 2 years.

Call Z

As Call Z is a compensation device for TSO-specific costs not included in the model specification from the cost-driver analysis, the process for Call Z started after the release of the R1 report. In the R1 report two model candidates were presented, which allowed TSOs to assess

- to what extent TSO-specific costs were already included in the model candidates; and
- which further TSO-specific costs may be included to allow a reasonable comparison of the costs.

On April 24th, 2013 the Call Z data call was issued, with May 9th as deadline for the initial submission of claims.

During a first evaluation phase, the Consortium identified claims whose content (apart from the specific cost level) was not a TSO-specific topic, but could be relevant for other TSOs, as well. In order to avoid discriminating against other TSOs that might have thought that the respective topic does not qualify as an acceptable claim, the topics of these so-called "structural claims" were disclosed and all TSOs were given the opportunity to submit structural claims on May 16th, 2013 with a deadline on May 24th. The rulings on all Call Z claims were communicated to the respective TSOs and NRAs on June 7th, 2013.

Evaluation process

The evaluation process was based on three main criteria. Firstly, a claimed cost must be exogenous, i.e. not under the influence of the TSO. Secondly, the effect must be sizeable, i.e. concrete cost quantities needed to be provided along with supporting material that showed how the figures had been determined. And thirdly, the cost impact needs to be enduring and not just temporary. These criteria are in line with the previous e3Grid project of 2008. However, the evaluation process took into account that, in contrast to the previous study, unit costs of power lines were no longer separated into "average" and "special" conditions.

Each claim was evaluated by the team experts that were competent for the respective topic (e.g. technical vs. financial topics).

Selected TSOs were contacted during the evaluation process, e.g. by requesting more detailed information on claims that appeared, in principle, plausible, but lacked the required substantiation of the respective cost levels.

All NRAs of countries whose TSO(s) submitted Call Z claims were involved in the evaluation process, too. In cases of doubt, e.g. when a claim referred to country-specific legal regulations, the Consortium consulted the respective NRA before drafting a ruling. Moreover, all NRAs were given the opportunity to comment on the draft rulings before these were formally issued.

The ultimate decision on the acceptance of the Call Z claims was taken by the Consortium, taking into account respective consultation input. This approach ensured that balanced decision rules were applied to all claims. Comparability was achieved in two ways, depending on the topic of the claims:

Identical principles were applied, e.g. concerning the requirements for quantitative substantiation or showing the special nature of the claim.

The structural claims were analysed for comparability in quantitative terms, e.g. by analysing the claimed relative uplift on affected power lines' cost due to the topic of the claim.[22]

As a consequence of the evaluation process, claims were either completely accepted, partly accepted or rejected.

Results from Call Z

In total, 66 claims were submitted by the TSOs. Out of these, 35 claims were accepted. 14 out of the 66 claims were structural claims, of which 10 were submitted as part of the initial claims and 4 following the request for submission of structural claims.

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22 For instance, the costs claimed for mountainous conditions were related to the kilometres of lines claimed to be affected by such conditions. While it is understandable that such measure may, to some extent, vary between TSOs for justified reasons, the evaluation allowed identifying outliers.

Table 7. Call Z claims – overview

Total numbers of claims		**66**
accepted		**35**
	Completely	12
	partly	6
	Formally rejected, but considered elsewhere in process	17
rejected	Not sufficiently substantiated	**31**
	Not sufficiently substantiated	5
	invalid	25
Structural claims		**14**
	Submitted as part of initial claim	10
	Submitted after request for structural claim	4

Source: Frontier/Sumicsid/Consentec

In the following some (non-exhaustive) examples of – completely or partly – accepted claims are summarised.

- **Structural claims** – These claims allowed the TSOs to specify "special conditions" of power lines and cables. They can be understood as a refinement of the lump uplift factor applied in the previous e3Grid study. Compared to said factor, the structural claims have the potential to be more accurate, because firstly they allow for individual reporting on TSO level, and secondly they needed (as every claim) to be substantiated and thus allowed for better validation and cross-checking. The structural claims comprised three aspects:
  - Higher costs due to lines in mountainous regions;
  - higher costs due to lines in coastal areas; as well as
  - higher costs for cables in cable tunnels.
- **Trade-off between number and unit costs of assets** – The claim concerned a case where the number of certain assets had been kept low by while incurring higher unit costs. This can be efficient because the total costs of these assets, i.e. the product of their quantity and unit costs, could be

similar or even lower compared to the alternative of using a larger number of less costly assets. However, in the NormalisedGrid output parameter the actual quantities of assets are accepted albeit weighted with a fixed set of cost weights. Therefore, accepting the claim avoided a disadvantage of the claimant.

2.2.3 Data validation post R2

After the R2 workshop on June, 21st, 2013 the R2 input data used in the calculations were released on the Worksmart platform on June, 26th, 2013 for final validation by the TSOs. The deadline was set for July, 2nd, 2013.

After taking into account of the TSOs remarks we created the final data set for the final e3grid2012 calculations.

2.2.4 Data validation by NRAs

The NRAs of the participating countries reviewed the data submitted by the TSO(s) in their jurisdiction. The review was based on the audited annual reports 2007 through 2011 (so-called profit and loss comparison) and the Cost Reporting Guide (Call C). The documents and other sources underlying the annual reports were not part of the review, unless these documents were in possession of the NRA prior to the review. The review did not include a validation of the submitted data.

The NRAs declared by a so-called "Confirmation Statement of the NRA" whether discrepancies were found between the submitted data and the NRA's knowledge prior to the review. In addition some NRAs also used external auditors to prepare their "Confirmation Statement".

PwC validated the "Confirmation Statement of the NRA" of the NRAs involved and noted that no such discrepancies were reported by the NRAs.

2.2.5 Consultation on methodology

In addition to the consultation the TSOs had the possibility to give their inputs on the methodology, as well. In the following we list the main documentations to draw on:

- **R1 report** – The TSOs received a report on the initial results for the e3grid2012 model specification. There was an open-ended phase to make comments and remarks to this report.

- **R1 workshop presentation** – In addition to the R1 report the TSOs received a comprehensive presentation.

- **R2 workshop presentation** – The TSOs received a comprehensive presentation on the R2 model specification and results on June, 21st, 2013. A deadline for comments was set for July, 2nd, 2013.

The TSOs extensively used the possibility to comment on the methodology using the TSO common forum on the Worksmart platform. In addition, some TSOs provided reports from academics in support of their argumentation.

- **Tom Weyman-Jones, The e3grid2012 project of the Council of European Energy Regulators, Report for NationalGrid, July 2013** – This report was made available by National Grid in the TSO common forum on the Worksmart platform. This report comments directly the model specification in e3grid2012 based on the above mentioned documentations (R1 Report and workshop presentations).

- **Aoife Brophy Haney and Michael G. Pollitt, International Benchmarking of Electricity Transmission by Regulators: Theory and Practice, EPRG Working Paper 1226, November 2012** – Amprion, TenneT and APG gave financial support to a study by the University of Cambridge. The report discusses international transmission benchmarking in principle and comments on the previous e3grid 2008 study.

In the following we will draw on the comments from TSOs and academics in the respective parts of this report.

2.3 Summary

The data definition, data collection and data validation process provided a high degree of transparency subject to the restriction of confidentiality of TSO specific data. There has been ongoing interaction between TSOs, NRAs, and the consortium during the e3grid2012 to guarantee consistent data reporting from the TSOs and the consistency on the data from public sources provided by the consortium by various measures, e.g.

- Consultation processes;
- data validation process by consortium, NRAs (including also external auditors) and TSOs;
- data release on a dedicated internet platform (“Worksmart”); and
- bilateral communication between NRAs and TSOs with the consortium.

3 Structure of model specification and efficiency calculation

In the following we describe the steps to derive the specification of the benchmarking model and the efficiency scores. We expand on this in the following sections.

3.1 Steps of efficiency analysis

In principle any efficiency analysis can be described as a sequence of the following steps (**Figure 3**):

- **Scope of benchmarking** – This step defines the transmission tasks involved in the benchmarking analysis.

- **Benchmarking methodology** – Several benchmarking approaches are available. The approaches may differ e.g. in relation to assumptions on forms of the cost function (parametric vs. non-parametric) or how they deal with noise in the data (deterministic vs. stochastic). Which approach is best employed depends on the size of the sample of comparators among other factors.

- **Definition of benchmarked costs** – The costs may include operating expenditures (Opex) or total expenditures (Totex) also including capital expenditures (Capex). Some standardisation of costs may be necessary to make cost data between firms comparable.

- **Cost-driver analysis and model specification** – This step constitutes an important part of the benchmarking analysis. The cost-driver analysis shall identify the parameters, which reflect the
  - supply task of the transmission system operator; and
  - other structural and environmental parameters that have an impact on the TSOs' costs.

- **Calculation of efficiency scores and sensitivity analysis** – In the final step, the efficiency scores of the TSOs are calculated using the benchmarking methodology, benchmarked costs and identified costs drivers. In addition sensitivity analysis may be used to validate the robustness of the results. E.g. outlier analysis may provide important information on the impact of individual TSOs on the efficiency scores of the other companies. Second stage regression analysis has been used whether there would have been other parameters that could have helped explained identified inefficiencies.

Figure 3. Steps in benchmarking analysis

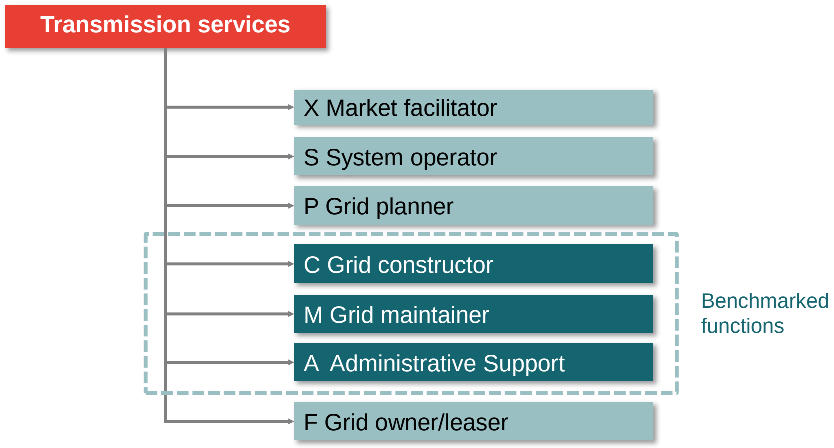
Source: Frontier/Sumicsid/Consentec

3.2 Scope of benchmarking – grid maintenance and construction

The fundamental objective of a transmission system operator is to ensure the electrical stability of the interconnected system so that electrical energy can be transported from generators to distribution networks.[23]

[23] For further details in the description of the different transmission services we refer to e3grid2012, *Cost Reporting Guide (Call C)*, Version 1.1, 2012.

Figure 4. Transmission functions and benchmarked functions



Source: Frontier/Sumicsid/Consentec

Distinguishing seven possible functions or roles, enables among other things, meaningful performance assessments. The functions of a TSO can be classified as (where not all TSOs undertake all tasks):

- **X Market facilitation** – Includes *inter alia* the establishment, monitoring and enforcement of an advanced electricity exchange. The TSO will necessarily be involved in the final settlement of the delivery of the good and may also raise additional fees for its transmission.
- **S System operations** – Includes *inter alia* maintenance of the real-time energy balance, congestion management, and ancillary services such as disturbance reserves and voltage support.
- **P Grid planning** – Includes *inter alia* planning and drafting of grid expansion and network installations involving the internal and /or external human and technical resources, including access to technical consultants, legal advice, communication advisors and possible interaction with governmental agencies for preapproval granting.
- **C Grid construction** – Involves *inter alia* tendering for construction and procurement of material, interactions, monitoring and coordination of contractors or own staff performing ground preparation, disassembly of potential incumbent installations, and recovery of land and material.
- **M Grid maintenance** – Involves *inter alia* the preventive and reactive service of assets, the staffing of facilities and the incremental replacement of degraded or faulty equipment.

- **A Administrative Support** – This function includes *inter alia* the administrative support and associated costs include the non-activated salaries, goods and services paid for, central and decentralized administration of human resources, finance, legal services, public relations, communication, organizational development, strategy, auditing, IT and general management.

- **F Grid owner/financing** – Is the function that ensures *inter alia* the long-term minimal cost financing of the network assets and its cash flows.

The first three functions (X, S and P) are *strategic functions* with long-term impact on system performance. The functions C (grid construction) and M (maintenance) are *operational functions* with comparatively fewer long-term system-wide impacts. The ownership is normally tightly connected to regulatory and institutional practices. The last function is indirect and delivers no specific service to the grid.

The e3grid2012 defines the scope of the benchmarked functions as

- *C Grid* construction;
- *M Grid* maintenance; and
- *A Administrative support.*

Hence, this means that the focus lies mainly on *operational functions*. This allows a good alignment of the costs in scope with potential outputs. Other services and their associated costs are not included in the benchmark.

Structure of model specification and efficiency calculation

4 Benchmarking methodology

In the following we describe approaches to measure

- static efficiency of TSOs for a certain year; as well as
- dynamic efficiency (productivity) over time.

4.1 Measurement of static efficiency – approaches

In general, benchmarking procedures are mathematic models which relate the quantities of output and input of specific companies to each other and – using the resulting index of productivity – estimate the efficiency of certain companies compared to other companies.

Benchmarking procedures can be differentiated based on the following criteria:

- **Parametric vs. non-parametric** – Parametric procedures (e.g. OLS, COLS, MOLS and SFA) involve an evaluation of the cost drivers, within the estimation of the efficiency frontier (hereafter referred to as "frontier"). This evaluation is based on a statistical regression of costs on those factors which cause those costs. E.g. by using the method of ordinary least squares (OLS) a coefficient to explain the relationship between cost and each cost factor is calculated. By contrast non-parametric procedures (e.g. DEA) use a (piece-wise) optimization procedure without presuming a clear functional relationship between cost and cost drivers.

- **Stochastic vs. deterministic** – Stochastic procedures consider that the frontier could be determined by outliers, e.g. by companies which recorded an exceptionally high maximum network load in the year of analysis. Stochastic approaches make a statistical correction of the frontier reflecting the possibility of data noise, resulting in the relative efficiency of the lower companies to rise.

Figure 5 classifies some of the analytical benchmarking models developed in literature. [24]

[24] It is passed on a more detailed description of the benchmarking models for lack of space. The array in Table 1 is not exhausting and there exists more literature and advanced modifications. For an introduction to benchmarking approaches we refer to: Coelli/Prasada Rao/Battese (2000), Bogetoft/Otto (2011).

Figure 5. Possible methods of Benchmarking

	deterministic	stochastic
non-parametric	**Data Enevelopment Analysis (DEA)** *-CRS: Charnes, Cooper, Rhodes (1978),* *-VRS: Banker, Charnes & Cooper (1984), Fare, Grosskopf & Lovell (1994);* *-non-convex FDH: Desprins, Simar &Tulkens (1984)*	**Stochastic and chance constrained Data Envelopment Analysis (SDEA)** *-CRS/VRS:* *Land, Lovell & Thore (1993), Weyman-Jones (2001)*
parametric	**Corrected/Modified Ordinary Least Squares CRS & VRS regression** *(COLS, MOLS & goal programming)* *Greene (1997), Lovell (1993), Aigner & Chu (1968)*	**Stochastic Frontier Analysis (SFA)** *-CRS/VRS:* *Aigner, Lovell & Schmidt (1977), Battese & Coelli (1992), Coelli, Rao and Battese (1998)*

Source: Frontier/Consentec/Sumicsid

The choice of the benchmarking methodology depends on the size of the sample of companies under consideration. The e3grid2012 project includes 21 TSOs which restricts the application of certain approaches, e.g. Stochastic Frontier Analysis.

4.1.1 Data Envelopment Analysis (DEA)

By applying DEA, the relatively simple approach of comparison of partial indicators of efficiency (e.g. employees per kWh, length of transmission line per kWh etc.) is generalized, in order to compare companies with multiple inputs and outputs. The formal approach consists of enveloping the recorded input and output data of the companies by an optimal frontier. The frontier is described by those companies which realize the most favourable output-input combination. Formally, this frontier is calculated by a linear optimization program. The relative efficiency of those companies which do not meet the frontier is calculated as relative distance to the frontier. DEA determines – from the multidimensional input-output area – a one-dimensional summary measure of efficiency relative to the best-performing companies.

Returns to scale

DEA can further be distinguished by how it considers economies of scale, i.e. to what extent size of a company is being accepted as a cost factor. The relevant academic literature has developed a number of specifications:

- *Constant returns to scale (crs)* – this approach presumes that there is no significant disadvantage of being small or large. All companies are compared amongst each other irrespective of their scale or size;

- *non-increasing returns to scale (nirs)* – this specification considers that there may be disadvantages of being large but no disadvantages of being small and adjusts for it accordingly;
- *non-decreasing returns to scale (ndrs)* – this specification considers that there may be disadvantages of being small but no disadvantages of being large and adjusts for it accordingly; and
- *variable returns to scale (vrs)* – in this specification the model considers disadvantages of being too small and too large and adjusts for it.

In the following we will base our specification on returns to scale on empirical analysis from cost-driver analysis and on goodness of fit test performed directly on the DEA models.

Weight restrictions

DEA is a useful modelling approach for benchmarking in the context of regulation. There are however some particular challenges in the use of DEA on small data sets, namely that

- the inclusion of multiple cost drivers has the potential to let a disproportionate large share of the TSOs appear fully efficient by default simply because within the small sample there are no sufficiently many similar entities to allow comparison; and
- even where there is scope for some limited comparison, certain parts of the cost-service space will be sparsely populated giving rise to a potentially significant (upward) bias in the estimation of efficiency scores.

In short, because we may not observe best practices across the entire mix of input and outputs, empirical estimates of best practice may be too lenient.

There are methodologically sound ways to alleviate these problems and in particular to make sure that the bias is not primarily favouring TSOs with an uncommon blend of outputs. One such option is to use restrictions on the dual weights in DEA.

In the following, we briefly introduce the method of weight restriction and discuss practical implementation.

Consider a case in which there are three cost drivers and regression analysis suggests that the relative importance of the three cost drivers y1, y2, y3 are A (high), B (medium) and C (low).

Table 8. Importance of the cost drivers in average cost estimations

Cost driver	Importance (Regression coefficient)
y1	A (high)
y2	B (medium)
y3	C (low)

Source: Frontier/Sumicsid/Consentec

However, in the context of a DEA-based analysis (without weight restrictions), the relative importance of the different cost drivers will be endogenously determined by the linear optimisation procedure. Consequently the weights placed on each variable could be different for every TSO – indeed, given that DEA seeks to portray each TSO in its best possible light, this is to be expected. This property of DEA is often regarded as one of its strengths when used in regulatory proceedings, since it results in the benchmarked entities receiving the "benefit-of-the-doubt".

In the context of a large sample, with a good spread of different characteristics, it may not be considered necessary to constrain the weights that are placed on each output, since the researcher can be confident that each benchmarked unit will have been compared to a reasonable number of peers. However, when working with a small data set this property of DEA can limit the number of cost drivers that can sensibly be included in the model (without rendering the analysis meaningless by letting all firms seem to be efficient). Even if everyone would intuitively agree that y1 is a more important driver of costs than y2 and must play an important role in any assessment of efficiency, given the logic of DEA some TSO implicitly invoke a weight of y2 that is far larger than the weight of y1, or there might be cases where the weight placed on the most important cost driver is very small, so as to result in those drivers playing little or no role in determining the efficiency estimate for that company. This may result in certain companies being found to be largely efficient on the basis of outputs of secondary importance, irrespective of relatively poor performance on more critical outputs. As noted above, one consequence of this is that a disproportionate share of the TSOs may notionally be judged as fully efficient.

One solution to this problem is to restrict the weights that are implicitly assigned to the different service dimensions. We may for example say that the weight of the cost drivers cannot deviate more than 50% below and above the weights that we derive in the average cost model based on regression analysis.

Table 9. Restricting the absolute dual prices in DEA

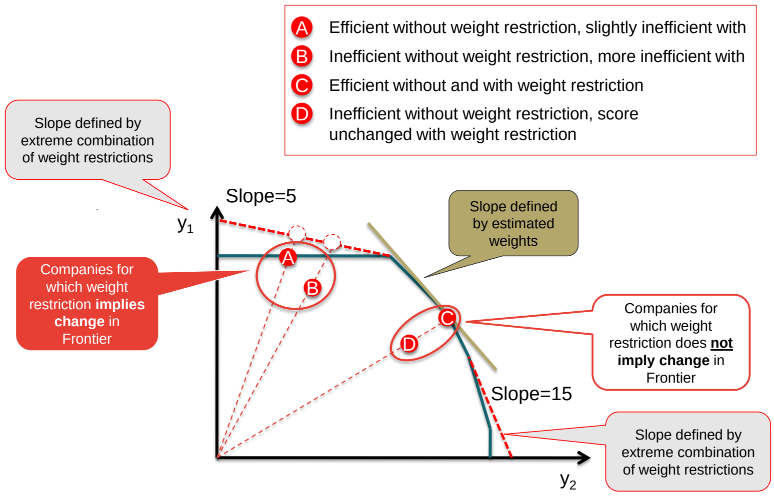
Cost driver	Importance (Regression coefficient)	Lower limit	Upper limit
y1	A	50%*A	150%*A
y2	B	50%*B	150%*B
y3	C	50%*C	150%*C

Source: Frontier/Sumicsid/Consentec

Following the above example, this means that the weights may be restricted according to **Table 9**.[25]

The effect from the weight restriction can be illustrated in **Figure 6** for the outputs y1 and y2.

Figure 6. Restricting the importance of y2



Source: Frontier/Sumicsid/Consentec

We consider here four TSOs that have used the same costs to produce different mixes of outputs (y_1 and y_2). The output efficiency of a TSO is now the largest

25 Since it is not the absolute but only the relative weights that matter in a DEA analysis, an alternative approach is to use the most important cost driver as the numeraire and to restrict the weights of the others relative to this.

proportional expansion of the outputs.[26] A score of 100% suggest that the TSO is fully efficient while a score below 100% suggest inefficiency.

The efficiency frontier indicated by the blue line in **Figure 6** does not assume any weight restrictions. This means that TSO A and C are both classified as fully efficient and form part of the efficiency frontier. TSO B and D are inefficient. Only however, we note that the relative weights assigned to the outputs are very different for each TSO. For example,

- TSO C performs well by claiming that y_1 and y_2 are both important cost drivers; while
- TSO A suggests that only y_1 matters (A performs better in the dimension of y_1/cost than any other firm).

The dotted red lines in **Figure 6** indicate a part of the Frontier that is now defined by weight restrictions. We now assume that *y1* should not be the only factor to matter but that also *y2* should affect the efficiency of the companies to an extent. This is achieved mathematically by restricting the slope of the output isoquant as illustrated by the dotted red line. Now, only TSO C is fully efficient and TSO A could be expected to improve its cost efficiency. TSO B should now improve a little more than in the case of DEA without weight restrictions.[27] For TSO D the weight restriction has no impact on the inefficiency score as the relevant efficiency for this company does not change as a consequence of imposing weight restrictions.

The challenge in applying weight restrictions is of course to establish reasonable values for the restrictions on the output weights. A number of different approaches can be considered:

- **Price and cost data (Option 1)** – One approach is to use information on prices or costs. The relative value of outputs may in some cases be estimated by using existing market prices or market prices for related (similar) services. It is often more appropriate to use a confidence interval than extract exact prices (or price ratios), because prices may vary over time and by location. However, specific resources and services may not be priced individually which could limit the ability of the researcher to implement this approach.

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26 Cost efficiency is a corresponding measure on the input side but it complicates the illustrations further and is therefore dropped here.

27 For technical details about dualizations and the imposition of weight restriction in the linear programming problems, see Bogetoft/Otto (2011, Ch 5), Bogetoft (2012, Ch.4), Thanassoulis/Portela/Allen R (2004, Ch 4), Charnes/Cooper/Wei/Huang (1989), Olesen/Petersen (2002), Podinovski (2004), Wong and J. E. Beasley (1990).

- **Expert opinion (Option 2)** – Another approach is to use expert opinions. However, expert opinion is subjective and it is possible that experts may disagree. Should it be possible to reach a consensus view then it could be applied directly, otherwise it might be possible to form a final view on weights through averaging.

- **Accounting, engineering or statistical methods** (**Option 3)** – A third approach is to use models and methods from accounting, engineering or statistics to determine possible aggregations of different services or resources. However, since such methodologies may contain some margin of error, the extracted information may be best used as a guide. Approaches based on this third method have the benefit of being more objective.

In our case the last approach, Option 3, appears a reasonable way forward, principally since our statistical analysis has delivered statistically robust results that can be objectively determined and verified. We have used our extensive statistical analysis of alternative cost drivers to inform on the relative importance of the cost drivers in the DEA model. In addition we note that some industry representatives agree that at least one of the cost drivers, namely the NormalisedGrid, must play some role in the final evaluation. In this sense, we additionally rely, qualitatively, on Option 2 as a plausibility check.

4.2 Measurement of dynamic productivity – Malmquist index

With a dynamic efficiency analysis the productivity development of the transmission system operators (TSOs) should be illustrated over the last years by means of appropriate and approved methods. When calculating productivity developments one can distinguish between:

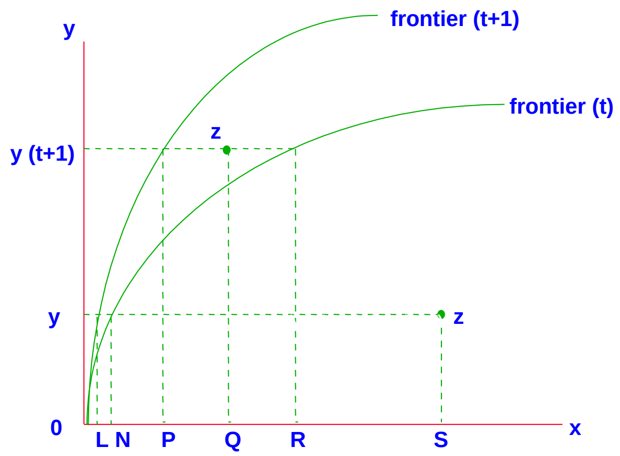
- the general productivity development of all TSOs (shift of the efficiency frontier); and
- the individual productivity development in proportion to the industry (individual catching-up factor).

The results of the dynamic efficiency analysis can indicate why single companies perform better or worse than other companies with regard to a statistical efficiency comparison.

If company data are available for several years, the degree of efficiency improvement can be determined over this period of time by using the DEA method with the aid of the so-called Malmquist index. In the following we explain the principle of a dynamic DEA method with Malmquist index in more detail.

In **Figure 7** we illustrate the frontiers for the periods t and t +1 (in order to simplify we assume an input factor x and an output y). In addition, we show the performance of the company z in these periods. With the aid of the DEA method it is possible to determine the efficiency variations of company z and its variations relative to the industry leader.

Figure 7. Schematic illustration of efficiency growth



Source: Frontier/Consentec/Sumicsid

The notation shows the efficiency variation of company z in relation to the frontier between the periods t and t+1 that is expressed by the following ratio:

$$\text{Index of efficiency variation} = \frac{0R/0Q}{0N/0S}.$$ [28]

The efficiency variation can be split into

$$\text{a catching-up index (CI)} = \frac{0P/0Q}{0N/0S}; \text{ and}$$

$$\text{a frontier shift effect (FI)} = 0R/0P,$$

where

the index of efficiency variation equals to CI • FI.

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[28] The denominator ($0N/0S$) represents the position of *z* in period *t* in relation to the *frontier* in the same period. The numerator ($0R/0Q$) represents the relative efficiency position of *z* in period *t* + 1 in relation to the *frontier* in period *t*.

One advantage of an efficiency variation index (compared to an index for the relative static efficiency level) is that the environmental variables (like density of supply, network topology, geographic conditions) are less important for the efficiency analysis. Since most of the environmental variables do not (or only marginally) change over time, the variation ratio of the environment variables is (close to) zero. This means that the variation ratio of efficiency is not influenced by the environment variables and that these variables can be neglected when analysing the efficiency variation. In practice we actually observe that the consideration of environment variables has an influence on the efficiency levels, however, no significant influence on efficiency growth.

Since the Malmquist index for efficiency growth is calculated by a sequential usage of the DEA method, the DEA method can be used to calculate efficiency growth to a robust extent. It is not important for the quality of the estimation if environmental variables are considered or not (see above).

4.3 Benchmarking methodology – summary

In the following we summarize our approach for the benchmarking methodology:

- **DEA as main benchmarking methodology** – DEA has the advantage to allow for assessing the efficiency also for a smaller data sample. The final data sample in e3grid2012 consists of 21 TSOs. In order to restrict the impact from companies with extreme observations on the efficiency frontier we use various outlier tests on the DEA efficiency frontier.[29]

- **Returns to scale** – We base the specification on returns to scale on empirical analysis from cost-driver analysis.[30]

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29 Weyman-Jones (2013: 14) comments on the drawbacks of DEA in relation to the deterministic character of the approach. He proposes to use parametric approaches (in particular Stochastic Frontier Analysis) to include the impact of noise into the assessment of efficiency. However, he mentions one caveat of using SFA relating to data availability. A sample of 21 TSOs may not be sufficiently large to run sensible SFA. He proposes to concentrate research effort on constructing a much larger panel data sample comprising pan-European and pan-continental TSOs. While we believe this is a useful approach, we note that we do not have complete panel data for all companies and all years. (2007-2011). We also note that our preferred choice of output includes parameters (normalised grid, value of weighted angular towers and population density) which are less volatile than those used in many other studies.

30 Weyman-Jones (2013: 4/17) criticizes the "arbitrary scale assumptions" for DEA. He refers to the R1 report. We note that in the R2 workshop presentation, we state that the choice for returns to scale is based on statistical analysis which suggests the presence of increasing returns to scale. The presentation was available to Prof. Weyman-Jones as it is included in the references of his report.

- **Weight restrictions in DEA** – We consider including weight restrictions on outputs, if the analyses of the DEA efficiency scores indicate that some key cost drivers have only a minor impact on the efficiency scores. We consider using accounting, engineering and statistical methods (Option 3) when setting the appropriate weights.[31]

- **Dynamic analysis** – We calculate the productivity development based on the Malmquist index. This allows distinguishing between the general productivity development of all TSOs (shift of the efficiency frontier), and the individual productivity development in proportion to the industry (individual catching-up factor).

31 Weyman-Jones (2013: 4) writes that: "Use of weight restricted data envelopment analysis (DEA) that is poorly motivated and for which no engineering or econometric rationale is provided". We refer to **Section 7.3** on details on the rationale and calculation of the weight restrictions in our sample.

5 Definition of benchmarked costs

In the following we discuss the costs used for the e3grid2012 project.

5.1 Scope of costs

Benchmarking models can be grouped into two alternative designs with an effect on the scope of the benchmarked costs:

- **A short-run maintenance model**, in which the efficiency of the operator is judged-based on the operating expenditures (Opex) incurred relative to the outputs produced, which in this case would be represented by the characteristics of the network as well as the typical customer services.

- **A long-run service model**, in which the efficiency of the operator is judged-based on the total cost (Totex) incurred relative to the outputs produced, which in this case would be represented by the services provided by the operator.

One drawback of the first model is that regulated companies may have an incentive to game the regulatory process by distorting its input use, e.g. substituting operating cost by investments resulting in low Opex but suboptimal (i.e. excessive) capital intensity. One particular instrument to deal with this problem is to adopt the second of the benchmarking models – total cost benchmarking. In this approach a total cost measure is constructed that reflects, in a consistent way, the capital costs of the business as well as the operating and maintenance costs. There are a number of reasons why this approach is attractive:

It supports the benchmarking of the operating expenditure, by ensuring that firms that have chosen a high Opex/low Capex mix that is not penalised relative to an equally efficient business that has adopted a low Opex/high Capex mix.

It provides the option of writing off relative inefficiency that has been accrued over a particular historical period, such as the last five years, or even the entire life of the assets currently in operation.

It can be used as a basis to set relative prices from which to roll forward an average performance yardstick mechanism.

Consequently, even if it is not the intention to put all Capex to scrutiny, total cost benchmarking can still provide useful information for the regulator and the industry.

The e3grid2012 is a long-run service model as it covers:

- *Operating costs* (Opex); as well as

- *Capital costs* (Capex).

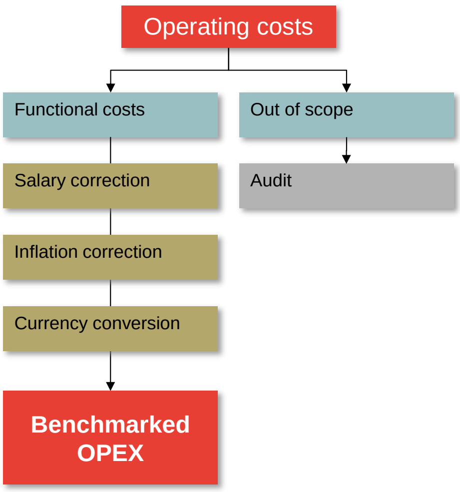
5.2 Benchmarked Opex

The standardised definition and standardisation of costs play a crucial role in any benchmarking study, especially, if the study is international in scope as is the case for e3grid2012.[32]

There are various steps involved in order to derive the respective benchmarked Opex for the benchmarked functions:

- *C Grid* construction;
- *M Grid* maintenance; and
- *A* Administrative *support*.

Figure 8. Steps in deriving benchmarked Opex



Source: Frontier/Sumicsid/Consentec

In the following we describe the principles for the calculation of benchmarked Opex. For the detailed transformation from reported operating costs provided by the TSOs in the data response (Call C) into the benchmarked Opex that enters the efficiency analysis we refer to the TSO specific documents.[33]

32 For further details on the description of the different cost items and the out of scope cost items we refer to e3grid2012, *Cost Reporting Guide (Call C)*, Version 1.1, 2012.

33 The Excel calculations were released in the TSOs specific folders on the e3grid2012 worksmart platform: e3grid2012_R2_CAPEX_OPEX_Explanation.xls.

5.2.1 Relevant cost items for Functional costs C, M and A

As already described above the scope of the e3grid2012 project includes the costs for *C Construction*, *M Maintenance* and *A Administrative Services*. In an initial step the relevant cost items from the TSOs' data response (Call C) for these activities are added together. This involves the cost items:

- direct manpower cost;
- + direct cost of purchased services;
- + direct cost of expensed goods;
- + depreciation of non-grid related assets;
- + leasing fees;
- + indirect cost and overhead;
- + other costs; and
- - direct revenues (revenues achieved for non-benchmarked services).

Depreciation of grid-related assets is excluded from this list, as this will be covered by the benchmarked Capex.

5.2.2 Allocation key for Administrative Services

The cost of Administrative Services may relate to functions included in the benchmark as well as functions excluded from the benchmark. To ensure a standardized allocation of administrative overhead costs, an allocation key for the costs from function A Administrative Services to the functions included in the benchmark is necessary. In the e3grid project an allocation key based on full-time equivalents was used. For operators with a validated staff head count in the functions, this allocation key has been used to allocate costs for A to the functions C (construction) and M (maintenance).

First analysis for the intermediate R1 report indicated that an allocation key based on full-time equivalents may not be fully appropriate. For the R1 report we decided to use no allocation key for the costs for A and included the full amount of A costs in the benchmarked Opex and to determine an allocation key after further analysis. In addition during the Call Z process some TSOs remarked that an allocation key based only on full-time equivalents may not be appropriate as it does not take into account the degree of outsourcing of services at the TSOs. Hence, a broader allocation key based on – certain – cost item was proposed, which should take into account that even e.g. if all maintenance work has been outsourced and there are no full time equivalent staff members for this function any more, there is still a need for some overhead function to manage processes e.g. to manage the contractors.

The consortium analysed various options for allocation keys supported by PwC, as elaborated below:

PwC performed analyses of different options for allocation keys:

- Option 1 – Based on manpower costs per function;
- Option 2 – Based on total operational costs per function (minus cost-correcting direct revenues and depreciations); and
- Option 3 – Based on selected costs per function, where relevant costs consist of direct manpower cost, direct cost of purchased services, direct cost of expensed goods and other costs.

First of all, it is reasonable to assume that the number of FTEs (or alternatively manpower costs) required for a given function is positively correlated with the overhead costs, as the personnel administration will probably increase when more employees are involved. For this reason, the manpower costs are considered as a possible allocation key (Option 1). As expected, this option resulted in similar allocation keys as the ones based on the number of FTEs.

However, the headcount or manpower costs will probably not be the only driver influencing the overhead costs. It is plausible to assume that the amount spent on a given function will probably affect administration handling, as costs in general are related to activities. Cost spent as an allocation base has also been adapted by some grid network companies in Australia. Therefore we have considered this option as well. However, all costs as the allocation base may not be always appropriate, as the correlation between administration and some costs (such as depreciation and leasing fees) may be not strong.

As Option 3, PwC proposed a relevant-costs-based allocation, excluding "irrelevant" costs such as deprecation, leasing fees and indirect costs. This allocation assumes a positive correlation between the relevant expenses associated to a given function and the amount of administration costs. As result of using the relevant-costs-based allocation: (1) the number of "outliers" was reduced significantly; and (2) the average share of administrations costs allocated to functions Construction and Maintenance was on average reduced significantly as well, compared to the case with FTE-numbers as the allocation base. PwC defined outliers as those TSOs with high shares of administration costs that were allocated to functions Construction and Maintenance.

The consortium agreed to use Option 3 of relevant costs (consisting of manpower costs, direct cost of purchases of services and expensed goods and other costs) as the final alternative to the FTE-number-based allocation. Also the consortium has chosen to use the (weighted) average of the allocation keys for the entire benchmarking period of 2007-2011, instead of using different allocation keys for each year. In addition, PwC made an analysis of the impact of including the function X (Market Facilitator) in the calculation of the allocation key, and identified substantial distortions for single TSOs. Hence, the consortium decided to exclude X from the calculation of the allocation key and restricted the allocation of costs for administrative services to the functions S, P, C and M.[34]

Some TSOs mentioned that administrative service costs should also be allocated to part of the out-of-scope costs, in particular the costs for off-shore grids. Hence, we also included for those TSOs having off-shore grids and reporting the costs for these grids as operating costs and capital costs in the calculation of the allocation key and allocated a share of the administrative service costs to the off-shore grid.

5.2.3 Salary adjustment

In order to make the operating costs (Opex) comparable between countries a correction for differences in national salary costs has been applied. Otherwise TSOs would be held responsible for cost effects, e.g. high wage level, which are not controllable by them.[35]

The salary adjustment consists of two steps:

- *Step 1 – adjustment of direct manpower costs* by increasing/decreasing the direct manpower costs of the companies using the respective salary index; and
- *Step 2 – reversal of part of salary* adjustment. Step 1 applies to a gross value, while the Opex entering the benchmarking is a net value after deducting direct revenues (for services outside the scope of the benchmark). Hence, some part of the salary adjustment has to be reversed taking into account that the share of direct manpower costs is proportionally smaller in the Opex used for benchmarking.

The EUROSTAT EU salary index provides information on the salary differences on an average national level.

In the e3grid 2008 project a salary index based on TSOs data was used to cover this issue. However, due to changes in the organisational structure of the TSOs, e.g. more extensive outsourcing of services, a similar approach was not practical for the e3grid2012 TSOs cost and staff data.

34 We note that in the presentation at the R2 workshop (June, 21st, 2013) there was an erratum on this in the text, as we stated that S is not included. We note that there was no change in the calculation of the allocation key since the R2 workshop.

35 We note that there is some simplification involved in the logic of salary cost adjustment. Had the respective frim truly had lower (or higher) salary cost then it may in practice also have chosen a different mix of production factors - e.g. operate less (or more) capital intensively. However, we do not consider this in the context of salary cost adjustments. Explain why

TSOs proposed to use an electricity industry salary index and referred to national statistical data. However, we note that respective European data from public sources, e.g. EUROSTAT, OECD, for an electricity industry salary index were not available for all participating countries.

To conclude, we note that in cost-driver analysis and our base case DEA model we used the EUROSTAT EU salary index to normalise staff related cost.

5.2.4 Inflation adjustment

Opex data has been collected for 2007-2011. Hence, an indexation to a base year is necessary to make the costs comparable over the years (for the cost driver analysis and dynamic DEA analysis). We have used the consumer price index (CPI) and defined 2011 as the base year.

5.2.5 Currency conversion

We convert all currencies to EUR values in 2011 by the average exchange rate in 2011.

Table 10. Exchange rates (average 2011)

	EUR	CZK	NOK	PLN	SEK	GBP	EEK
2011	1	24.59	7.45	4.12	9.03	0.87	15.65

Source: Eurostat

5.3 Benchmarked Capex

The standardised definition and standardisation of costs play a crucial role in any benchmarking study, especially, if the study is international in scope as is the case for e3grid2012. In an ideal world capital cost would be standardised in a number of ways, e.g. in terms of:

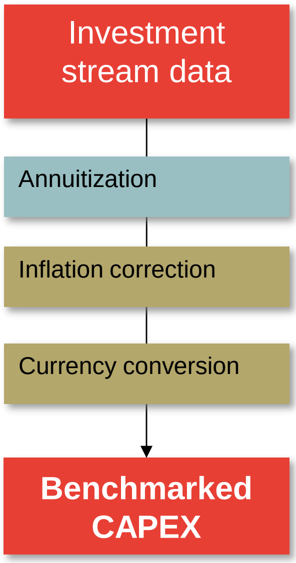
- accounting procedures – historic versus current cost;
- depreciation assumptions and in particular depreciation procedures; as well as
- asset ages or "market value" of the established asset base.

Given the differences in the calculation of capital costs between the involved TSOs, e.g. different depreciation periods, different valuation of the assets, the capital costs cannot simply be taken from the companies' annual reports. They are rather to be calculated separately for e3grid2012.

Definition of benchmarked costs

There are various steps involved in order to derive the respective benchmarked Capex:

Figure 9. Steps in calculating benchmarked Capex



Source: Frontier/Sumicsid/Consentec

In the following we describe the principles for the calculation of benchmarked Capex. For the detailed transformation from the reported year-by-year historic investment stream provided in the data response (Call C) to the benchmarked Capex (annuity) that enters the efficiency analysis we refer to the TSO specific document.

5.3.1 Investment stream data

In a first step we have collected the annual investment data from the TSOs for the period 1965-2011 in Call C. The investment stream contains the undepreciated (i.e. gross) asset values for a variety of grid asset classes corresponding to the equivalent asset in the Asset Data Base (Call X)[36].

For those TSOs with no full range of the investment stream data for the period 1965-2011 we made use of the opening balance figures for a starting year. This starting year may correspond with the establishment of the company, the revaluation of the assets and/or privatisation of the company.

For the 21 TSOs included in the e3grid2012 project:

36 For the details on reporting we refer to: e3grid2012, *Cost Reporting Guide (Call C)*, Version 1.1, 2012.

- 9 TSOs reported investment for the full range 1965-2011; and
- 12 TSOs reported investment for less than the full range 1965-2011 and at a certain year in their investment stream an opening balance based on revaluated assets, market values and opening book values appears. To the extent that such companies later become peers to others in the efficiency benchmark we subject the investment data to additional scrutiny in order to ensure that efficiency results are not unfairly biased by the estimation of historic investment streams for peer companies.[37]

5.3.2 Annuitization

Capex consists of depreciation and a return on capital. The actual investment streams are annualized using a standard annuity factor $\alpha\ (r,T)$, where

- r stands for a real interest rate; and
- T stands for the average life-time of the investments in the respective year.

The annual investments from the investment stream data are multiplied with the annual standard annuity factor $\alpha\ (r,T)$.[38]

Real interest rate

We note that a real interest rate here is applied in order to translate annual investments from the investment stream into annuities. As the assessment of the financing function of a TSO is not in the scope of e3grid2012 a common rate of return is used for all TSOs. When setting the real interest rate we are following the logic of setting a weighted average capital cost (WACC) used in the regulation of many European energy networks.

The elements of the WACC calculation are set out in **Table 11** below.

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37 See **Section 7.2.2**.

38 Weyman-Jones (2012: 9) comments on the calculation of Totex and in particular the Capex: "The first is to directly measure the flow of services from the accumulated capital stock by considering the dynamic patterns in the way that capital is consumed over time: capital consumption is a corporate finance approach that measures actual depreciation of the capital stock of the firm together with the rate of return on capital…Neither approach has been used in the e3grid project. Instead, the single TSO input is measured by current Totex in a cross-section one period sample with no adjustment for the different stages of the capital accumulation cycle." We note that calculating annuities corresponds to "the corporate finance approach that measures actual depreciation of the capital stock of the firm together with the rate of return on capital" Prof. Weyman-Jones is proposing.

Table 11. Real WACC

Parameter	Value
Risk-free rate*	4.56%
Levered beta**	0.66
Market premium***	4.4%
Cost of equity	7.47%
Risk-free rate*	4.56%
Debt spread****	1.2%
Cost of debt	5.76%
Gearing	60%
WACC nominal	6.44%
Inflation rate*****	2%
WACC real******	4.36%

Source: Frontier calculations based on data provided by ECB, Bundesnetzagentur, Reuters, Eurostat

* 5-year average of European government bonds with a remaining maturity of ten years

** Taken from Bundesnetzagentur decision 2011 (assumed capital structure: 60% debt, 40% equity)

*** Taken from Bundesnetzagentur decision 2011

**** Based on comparisons of Reuter's corporate spreads for industrials (average for 10-year spreads for ratings Aa3/AA- to Baa3/BBB-) and Frontier calculations

***** 5-year average of the inflation rate in the Euro area (17 countries)

******* Based on Fisher's formula $realWACC = \frac{1+nomWACC}{1+inflation}$-1.

For e3grid2012 we use a real interest rate of 4.36%. Inflation adjustment is carried out by using current cost values of assets (see below).

Life-time of assets

The accounting life of the grid assets varies by asset class depending on regulatory and fiscal rules, time and ownership form. Since the benchmarking is based on a standardized measure that is to reflect the technical and economic life of the assets, we have harmonized the life time per asset type. For e3grid2012 we have used the following lifetimes for the asset classes/groups.

Table 12. Life times used for e3grid2012

Group	Lifetimes (yrs)
Lines	60
Cables	50
Circuit ends	45
Transformers	40
Comp. devices	40
Series comp	40
Control centers	30
Other installations	30

Source: Frontier/Sumicsid/Consentec

Since the actual investment values are not decomposed into assets (or assets groups), a weighted average lifetime for every year is used to estimate investments per asset group and year.

The average lifetime of any investment basket for any operator, used in the annuity calculations for standardized Capex, is set to the weighted average life of their investments undertaken in the same year.

$$\tau_{it} = \sum_k \left\{ \frac{T_k w_k x_{ikt}}{\sum_k w_k x_{ikt}} \right\}$$

where τ_{it} is the average weighted lifetime for assets of TSO i in year t, x assets of type k invested by TSO i in year t, and w normalized Capex weight for asset-type k, T_k is the standardized asset lifetime for asset type k.

For TSOs with no full range of investment stream data the entry in the first year of investment data also includes an opening value. This value reflects the value of the assets built from 1965 to the year of the first entry in the accounts available to us. Hence, in order to derive the weighted average lifetime of the assets for this entry not the single year data for the physical assets are used but the weighted average lifetime of the physical assets until the year of first entry.[39]

39 We note that this issue was raised by one TSO in a submission after the R2 workshop. We adjusted the calculations accordingly.

5.3.3 Inflation indexation

The current value of the past investments relative to the reference year is calculated using inflation indices. Ideally, a sector-relevant index would capture both differences in the cost development of capital goods and services, but also the possible quality differences in standard investments. However, such index does not exist to our best knowledge. Several indices have been collected from EUROSTAT and OECD. The only generally-defined index for the full-time horizon for all 21 participating grids is the simple Consumer Price Index (CPI).

In addition we have evaluated further indices. Sector-specific indices only exist for a handful of countries and require additional assumptions to be used for countries outside of their definition.

We evaluated the suitability of a Produces Price Index (PPI) published by the OECD. Specifically, the PPI for investment goods measured in domestic prices was used. The chosen index captures the inflation of capital goods in a given country compared to the base year (2007). As the indices are used to inflate past investments, the index is needed for every year that a company has submitted investments data for. In order to meet this criterion, extrapolation of data had to be used. In average over all companies PPI data was missing for 19 years, ranging from 0 missing years to 27 missing years.[40]

To create a comparable base, we decided to use CPI in the cost-driver analysis and the DEA base model. In addition, we have calculated as sensitivity for the DEA base model efficiency scores using the above describes PPI index.

5.3.4 Currency conversion

In a final step we convert all currencies to EUR values in 2011 by the average exchange rate in 2011 using Eurostat exchange rates.

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40 To extrapolate, the average growth rate of the five preceding years has been used.

Table 13. Exchange rates (average 2011)

	EUR	CZK	NOK	PLN	SEK	GBP	EEK
2011	1	24.59	7.45	4.12	9.03	0.87	15.65

Source: Eurostat

5.4 Call Z – TSO specific costs adjustments

In the following we describe how the accepted claims from Call Z were incorporated into the costs. The purpose of Call Z[41] was to identify and adjust for TSO-specific costs which are not yet reflected in the model specification described in **Section 6**. Hence, Call Z serves as a compensation device for TSO-specific costs not included in the model specification from the cost-driver analysis. Based on the preliminary model candidates from the R1 report TSOs assessed

- to what extent TSO-specific costs were already included in the model candidates; and
- which further TSO-specific costs may be included to allow a reasonable comparison of the costs.

The adjustment of the costs depended on the specific claims. We have considered three variants for cost adjustment:

- **Adjustment of Opex** – If the claim referred to Opex a corresponding deduction of the accepted claim was undertaken, e.g. if certain environmental factors result in an incremental cost of 1 Mio. € in 2011, the Opex in year 2011 would be reduced by 1 Mio.€ (to make the firm's cost better comparable to other firms).

- **Adjustment of Capex by absolute amount** – If the claim referred to higher investment costs for a certain asset category and the higher incremental costs were reported for the stock of the assets, the Capex were reduced by an absolute amount based on annuities, e.g. if certain assets in total have a higher cost of 100 Mio. €, the annuity based on the life time of the certain asset is calculated and then deducted from the Capex.

41 For more details in Call Z and the evaluation process of the claims submitted by the TSOs we refer to **Section 2.2.2**. The rulings on the Call Z claims and the corresponding adjustments of the costs were released to the TSOs on May, 31st, 2013.

- **Adjustment of Capex by investment stream** – If a claim referred to higher investment costs for the whole (part) of the investment stream then these higher costs were deducted from the investment stream. The Capex were then calculated based on this adjusted investment stream, e.g. a company claimed higher annual costs for investments of 5% due to structural factors, then the annual investment stream was reduced by 5%. Afterwards the annual annuities were calculated from this reduced investment stream.

5.5 Capex break methodology

Where there is incomplete investment data, we have used opening asset values to proxy for the missing data. However, for a variety of reasons (e.g. re-evaluation of assets) it appears likely that there are cases where those opening values are inappropriately low. If we continue to use that data, there is a risk that we base the efficiency frontier on distorted data and identify efficiency catch-up targets that would be infeasible. Hence, to address this issue, a generic approach has been developed to re-estimate opening balances for those operators that have less than a full investment stream ("Capex break methodology").

The logic behind this adjustment is based on the assumption that the investment behaviour following the years, e.g. where unbundling took place, is the best indication of the managerial behaviour prior to unbundling. This means, we estimate an average ratio between investments and the Capex Grid size contribution, defined as the physical assets multiplied with their cost weights, for the horizon after unbundling and then – in knowledge of the assets built in the years prior to reporting an opening balance – use this to adjust the value of the opening balance. The corrected opening balance is then obtained as the sum of normalized grid assets up to and including the unbundling year, multiplied with the empirical average ratio between Capex and NormalisedGrid for the years for which we hold detailed investment stream data.

This approach can be illustrated in the following example (**Table 14**)[42], where we assume that a TSO has made investments in selected years since 1965. However, we do not know the full investment stream, but only a – biased – opening balance of 90 reported in year 2000 and the annual investments since then. We assume again that there is no inflation, that all monetary units are in EUR, and that all investments are in the same assets with a normalized life length of 50 years.

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42 The example is drawn from the note on the Capex break methodology. For further details on the Capex break methodology we refer to this note: e3grid2012, *Method Note 1: Capital break methodology – Opening balance adjustment*, Version 1.6, March 2013.

Table 14. Capex break methodology – illustration

Year	Asset number (#)	Weights (*Euro*)	Capex Grid Size Contribution (*Euro*)	Capex Grid Size Cont. Annuity. (*Euro*)	Investment (*Euro*)	Constructed likely Inv. (*Euro*)	Invest-ment Annuity (*Euro*)
1965	10	1.1	11.00	0.43		11.25	0.44
1970	12	1.1	13.20	0.51		13.50	0.52
1975	6	1.1	6.60	0.26		6.75	0.26
1980	8	1.1	8.80	0.34		9.00	0.35
1985	13	1.1	14.30	0.56		14.63	0.57
1990	14	1.1	15.40	0.60		15.75	0.61
1995	7	1.1	7.70	0.30		7.88	0.31
2000	5	1.1	5.50	0.21	**90**	5.63	0.22
2005	7	1.1	7.70	0.30	5		0.19
2006	8	1.1	8.80	0.34	7		0.27
2007	1	1.1	1.10	0.04	2		0.08
2010	5	1.1	5.50	0.21	10		0.39
2011	3	1.1	3.30	0.13	3		0.12
SUM				**4.23**			**4.33**

Source: Frontier/Sumicsid/Consentec

Now, comparing the investments and the Capex Grid Size Contribution after 2000, we can calculate the ratio between the sum of investments and the sum of Capex Grid Size Contribution after 2000 as E = 1.023 (27/26.4). Assuming that this ratio was the case in the years 2000-1965, we can reconstruct the likely investment stream from the assets bought, e.g. for 1980 we reconstruct the investment by 8.80 × 1.023 = 9.00. This is done for all years 2000-1965. We then transform the likely investments from 2000-1965 into annuities and sum them up for the whole period 1965-2011 to get a value of 4.33. This value is then used as the Capex for the respective TSO in the benchmarking analysis.

On the application of this generic approach we refer to **Section 7.2.2**.

5.6 Definition of benchmarked costs – summary

In this section we describe how we calculated the costs used in the following cost-driver analysis and calculations of efficiency scores. The calculation consists of various steps and adjustments. In order to calculate the Capex used in the following analysis we are using annuities to translate the investment stream data (from 1965 to 2011) into one value.

In addition the adjustment of costs based on the Call Z process was described. In this process we identified structural and individual claims. For the accepted claims we adjusted Opex and Capex accordingly.

6 Cost driver analysis and model specification

Any efficiency comparison should account for differences in the outputs and the structural environment of the companies. A key challenge in e3grid2012 is to identify a set of variables:

- that describe the tasks (the cost drivers) that most accurately and comprehensively explain the costs of the TSOs;
- that affect costs but cannot be controlled by the firm (environmental factors); and
- for which data can be collected consistently across all firms and with a reasonable effort.

6.1 Criteria for Parameter Selection

In principle the selection of benchmarking parameters should comply with some basic criteria in order to guarantee an appropriate comparison and efficiency assessment. The following generic criteria may be applied in the selection of output and structural parameters. The criteria constitute an ideal, although in practice some trade-offs may be required:

- **Exogeneity** – Output and structural parameters should be exogeneous, i. e. outside the influence of TSOs to control or change them by their decisions.
- **Completeness** – The output and structural parameters should cover the tasks of the TSOs under consideration as completely as reasonable.
- **Operability** – The parameters used must be clearly defined and they should be measurable or quantifiable. Qualitative indicators or subjective assessments should not be used.
- **Non-Redundancy** – The parameters should be reduced to the essential aspects, thus avoiding duplication and effects of statistical multi-collinearity and interdependencies which would affect the clear interpretation of results.

Not least given the limited number of TSOs (21) for e3grid2012, when selecting the output parameters the number of parameters should be limited (at least for DEA application) to asset that describes the different dimensions of the supply task and can explain the largest part of cost variations between firms. If the model is over-specified (too many parameters) there is a possibility that almost all firms appear notionally efficient, even though the true efficiency in the sector may be lower than this (as discussed in **Section 4.1.1**).

6.2 Process of Parameter selection

The process of parameter selection in e3grid2012 combines engineering and statistical analysis and is organised according to the following steps:

- **Definition of parameter candidates** – In a first step we have established a list of parameter candidates which may have an impact on the costs of TSOs. The relationships between indicators and costs must be plausible from an engineering or business process perspective if these indicators are to be used as output parameters.

- **Statistical analysis of parameter candidates** – Statistical analysis is then used to test the hypotheses for cost impacts from different parameter candidates and combinations of parameter candidates. The main advantage of statistical analysis is that it provides transparent decision rules to include or not include a certain parameter candidate in the model. We note that rejecting one parameter candidate (B) for statistical reasons does not necessarily mean that this parameter (B) does not have an influence on costs. For example, it may be that the cost influence may be already covered by other included parameters (A) and that the additional parameter (B) cannot make a further incremental statistical contribution to explaining cost structures.

- **Plausibility check of final parameters** – The final parameters from the statistical analysis are finally checked for plausibility. This plausibility check is based *inter alia* on engineering expertise.

In the following we describe the above-mentioned steps in more detail.

6.3 Definition of parameter candidates

The e3grid2012 defines a long list of parameter candidates which draws on the experience of the e3grid study. In addition, based on suggestions received after the e3grid project and in consultations with the NRAs and TSOs during the current project, the list of parameter candidates was amended to include new candidate parameters, e.g. more details on the design of towers as a proxy for the complexity of the operating environment. The parameter candidates are derived from three separate data requests:

- Call X – this call collects the physical asset base of the TSOs and is reported by the TSOs;

- Call Y – this call includes further potential costs drivers. The data are from the public domain collected by the consortium and checked by the NRAs and TSOs; and

- Call Q (quality parameters) – this call includes quality parameters, namely Energy-not-supplied. The data is provided by NRAs.

The parameter candidates cover the following dimensions of the supply task of a TSO:

- Providing physical assets;
- Transportation services;
- Capacity services;
- Physical environment and customer services; and
- Quality.

We note that the technical asset base is considered as an output parameter in e3grid2012, although it may be regarded as not strictly exogenous as it is controllable by the TSO, strictu senso. Given that the configuration (dimensioning and evolution) of the grid is not subject to evaluation in this project, it is appropriate to define the technical assets as an output. This implies that the technical asset base serves as a proxy for the complexity of the operating environment of the firm. The efficiency analysis then no longer questions whether the assets are needed, but questions whether the assets have been procured prudently (at low prices) and whether the company and the assets are operated efficiently.

Prof. Weyman-Jones (2013: 3) – on behalf of national Grid of the UK – has pointed out that the use of the technical asset base – reflected by the NormalisedGrid – as a cost driver is unconventional and that alternatively service parameters – such as e.g. peak load – should have been used. We agree that in principle this can be a logical consideration, although in the instance this may on balance be against the interest of the benchmarked companies:

- There are examples of distribution system benchmarking studies that relied mostly or completely on parameters reflecting the supply tasks, such as peak load, number of costumer connections or service area. However, it is a non-trivial task to adopt this principle for benchmarking of TSOs. The reason is that TSOs are facing a supply and transmission task.[43] On the one hand, their networks serve to connect and/or supply customers, be it generators, large consumers or distribution networks. But on the other hand, they also serve for bulk transmission of power, including the exchange of power with neighbouring TSOs. Both functions are realised by the same network assets;

43 There are even more tasks, such as balancing, but these are not included in the benchmarked cost here.

it is, therefore, not possible to separate the assets (or, more generally, the costs) into supply and transmission parts, respectively.

- The consequence of this overlapping of functions is that typical exogenous service parameters for distribution networks, e.g. peak load, are not equally sufficient for explaining the costs of transmission networks. For example, two equally-efficient transmission networks could have identical peak load, but if only one of them has to transmit significant amounts of transits between neighbouring networks, it is certainly more costly.

  However, simply enlarging the benchmarking model by adding service parameters that reflect the transmission task does not necessarily result in a proper model, for the following reasons. Firstly, the number of parameters that can usefully be included in a DEA model with a small sample size is limited. Secondly, separate parameters for supply and transmission tasks fail to account for the interactions among these tasks. And secondly, parameters properly reflecting the actual cost impact of the transmission task are hard to find. For example, supposing that "transits" would be considered a candidate parameter, there could be networks with equal (peak) transit level, but one network transmits transits in constant direction, whereas another – probably more costly – network has to transmit transit in various directions.

  Consequently, the (exclusive) use of service parameters, although appealing at first glance, would bear a high risk of designing a benchmark model that would not accurately reflect true cost-driving relationships and thus would be biased against some firms in an unpredictable manner.

- Therefore, in the given context, the variable "NormalisedGrid" is more appropriate than a pure service parameter model. This variable is "soft" on the companies in the sense that it accepts the assets that have actually been built and does not question whether they are needed (while a model that uses e.g. peak load instead would implicitly question whether the assets are indeed needed to fulfil the supply task).

- Variables reflecting the supply and transmission task tend to be more volatile and thereby have less explanatory power for cost – peak load or energy supplied may vary year-on-year even though the company needs to make a fixed commitment – valid practically for decades – to the assets needed to provide the service. A benchmark focused on volatile parameters of the supply tasks will introduce variation in the efficiency scores. This is overcome, by using a more stable variable, "NormalisedGrid". That "NormalisedGrid" is a more stable explanatory of cost is also confirmed by our statistical analysis.

The inclusion of the technical asset base results in a distinction between two output categories:

- **Outputs driving size of the technical asset base** – These outputs, e.g. peak load, connections of load and generation, are in principle already reflected through the technical asset base. Hence, even if these outputs are not explicitly included in the model specification, their main cost effects on the technical asset base will be reflected, if only indirectly.

- **Outputs driving the costs of constructing and maintaining the technical asset base** – Reflect the potential impacts from environmental factors on the costs of the given technical asset base, e.g. higher construction costs due to topographic reasons.

6.3.1 Providing physical assets

Aggregation of physical assets using cost weights

The information on physical assets of the TSOs constitutes essential information for e3grid2012, as it is used as a main output parameter in the benchmarking analysis. The physical assets are collected in different units (km, MVA). In order to obtain "one" output parameter including all physical assets it is necessary to transform the different units into one single number. Cost weights are used for this task. In fact, this allows for a very detailed reporting and consideration of assets with a high level of differentiation – e.g. by asset type (lines, transformers, etc.), by voltage level, by capacity (e.g. maximum current or power) – while at the same time respecting the need to limit the total number of output parameters in the benchmarking analysis.[44]

Haney/Pollitt (2012: 13-14) have argued that the use of the cost weights for the aggregation of the physical assets is in contradiction with the principle of DEA, which chooses input and output weights in such a way as to give the firm the highest efficiency score possible. We agree that in principle this can be a logical consideration, although in the instance this may on balance be against the interest of the benchmarked companies:

- The variable "NormalisedGrid" includes all technical assets from the TSO in a high granularity, e.g. differentiated between voltage levels, asset categories, etc.[45] Aggregation of these assets to one parameter allows keeping all detailed information while making the parameter usable for DEA.

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44 For details on the reporting structure we refer to e3grid2012, Data Call for EHV/HV Assets (Call X), version 1.15, 2013-02-20.

45 Haney/Pollitt (2012: 13) referring to the e3grid project 2008 note: "The normalised grid size measure was calculated starting from 1200 different grid characteristics using assumed weights." In FN 4 they continue: "These characteristics cover eight asset classes: lines, cables, circuit ends,

- The high granularity of the technical asset data does not allow DEA to find the weights for the different assets based on a sample consisting of 21 TSOs. This would imply a DEA model with 21 input data and more than thousand output data. It is straightforward that this will lead non-sensible results.

- Letting DEA choose the weights for the assets given the sample of 21 TSOs would mean to sharply reduce the granularity of the asset data, e.g. only including total line length and number of transformers. We note that this will results in a substantial reduction of the information contained in these parameters compared to the variable "NormalisedGrid".

In addition, we note that we include variations of the cost weights in the sensitivity analysis to explore the possible effect of setting a certain basket of cost weights.

NormalisedGrid – output parameter reflecting physical assets

The use as a cost driver of the NormalisedGrid Grid has various implications for the use of cost weights for the calculation of the NormalisedGrid Grid:

- *Cost weights for Opex and Capex* – as e3grid2012 is a total cost benchmarking study, the NormalisedGrid should be a cost driver for Opex and Capex, hence, cost weights are necessary for Opex and Capex.

- *Cost weights proportional to assets* – as not all assets in the data request Call X have the same Opex and Capex, different costs weights are necessary for the different asset categories reflecting the relative difference in costs between the asset categories. Hence, the cost weights shall be proportional to the costs associated with the different asset categories.

- *Cost weights for Opex and asset base* – operating costs occur for all assets in use. Hence, the age of the asset does not matter when calculating the Opex part for NormalisedGrid.

- *Cost weights for Capex and asset base* – capital costs only occur for assets within the life-time of the asset. Hence, the age of the asset does matter when calculating the Capex part for NormalisedGrid, e.g. for the calculation of the Capex part for NormalisedGrid for lines only lines not older than 60 years are used.

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transformers, compensating devices, series compensations, control centers and other assets (such as HVDC)."

Cost weights multiplied with the assets as reported by the companies in response to Call X constitutes the NormalisedGrid, which is used as an output parameter

(Assets from Call X) x (Capex cost weights) x (Annuity factor) +
(Assets from Call X) x (Opex cost weights)

The resulting NormalisedGrid from the above calculation are then adjusted as to correspond with the mean standardized Opex and Capex for the operators in the study ("Calibration factor"). The ratio was estimated to be 1.08075 for Opex and 0.88013 for Capex.[46]

For the detailed transformation of the reported Call X into the NormalisedGrid we refer to the TSO specific document.

6.3.2 Transportation service

This comprises parameters such as delivered energy or annual generation differentiated by generator types. Although the NormalisedGrid parameter is likely to cover their cost impact to a large extent, we analyse whether these additional parameters can explain cost differences in addition to the NormalisedGrid.

6.3.3 Capacity service

One important criterion for dimensioning a power system is usually related to the peak demand for transmission. Therefore, parameters such as peak load or installed generation capacity (differentiated by fuel type) may better reflect investment needs than energy related figures. However, we note that investments in physical assets due to the connection of power plants and/or the provision of network capacity to meet peak demand are already largely reflected in the NormalisedGrid parameter. We statistically test for the relevance of parameters for capacity service, nonetheless.

6.3.4 Physical environment and customer service

The physical environment can affect TSOs' costs beyond what is already expressed by the amount and capacity of assets (as contained in the NormalisedGrid parameter). For instance, a high population density or a large share of industrialised area can require more costly assets. However, it remains a challenge to identify the appropriate incremental impact of an increase in such parameters on the increase of efficient costs. Therefore, e.g. data on towers

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46 For the detailed description of the calculation of the NormalisedGrid we refer to the Excel file "asset list_R2" available for each TSO.

(material and construction properties) as collected through Call Y is tested as a potential proxy of such environmental conditions.[47]

6.3.5 Quality

The appropriate consideration of the repercussion of quality on costs of power systems is a challenging task. This applies particularly to transmission systems. Based on a respective consultation process[48] among TSOs and NRAs we decided to collect data on energy-not-supplied (ENS).

6.4 Statistical analysis of parameter candidates

In order to test the cost impact from the above-defined parameter candidates using statistical analysis one has to define a statistical model which consists of:

- *Regression approaches* – in the following we used OLS and robust regressions[49];
- *Functional form* – which makes specific assumptions about the type of relationship between the inputs and outputs. In the following we started with the linear and log-linear form;
- *Inputs* – in the following we used Totex (= benchmarked Opex + benchmarked Capex + adjustments from Call Z);
- *Outputs* – in the following we used the parameter candidates derived from Call X and Call Y; as well as
- *Decision rules for parameter selection* – in the following we used various decision rules to include/exclude a parameter candidate from the final model in particular statistical significance.

Structure of statistical analysis

The statistical analysis is organised as a stepwise procedure.

The initial phase in the model specification investigates the complexity of the cost function in terms of how many variables are necessary to capture the variance in average costs. In this exercise, the optimal path is found between

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47 By considering tower information through a separate parameter, the cost driver analysis as well as the DEA can implicitly derive the relevant magnitude its cost impact, as opposed to the alternative to impose fixed weights on tower types and integrate them into the composite parameter of the NormalisedGrid.

48 For details we refer to e3grid2012, *Data Call for Quality Indicators (Call Q)*, Version 0.3, 2012.

49 The regression technique for robust regression used was Iteratively reweighted least squares (IRLS).

model misspecification (too many variables leading to imprecise estimates and erroneous signs and significance of the chosen terms, multi-collinearity) and model bias (too few variables chosen, the estimate is skewed in some direction). For this stage, we use standard techniques for econometric model specification using Mallows' C_p and additional tests for multi-collinearity.

We determined that an adequate model size based on model selection criteria such as Akaike Information Criterion (AIC) and Mallows' C_p above should have 2-3 parameters.

After analysing the model size we use the forward procedure to select the model specification. This means that we start with a base model and extend the base by adding variables. As long as the added variables are "adding value" to the model, the forward procedure continues to select variables. We consider the forward procedure is an appropriate approach given the small number of TSOs in the sample.

The base model starts with one output: *NormalisedGrid*. In a first step, we add single parameter candidates as factors reflecting the

- Transportation service;
- capacity service;
- customer service; as well as
- physical environment.

These factors have to add explanatory power to the model and are only retained if this is validated.

The parameter candidate with the highest statistical *t*-value will be added to the base model as the second output. In addition, multi-collinearity between the outputs is tested. This procedure continues until no further significant parameters can be found and/or no multi-collinearity can be detected in the model.

The stepwise procedure ensures that

- all supply tasks of the TSO are considered in the analysis;
- all parameter candidates are tested; and
- the selection of parameter is based on transparent decision rules.

We note again, that due to this procedure the rejecting of one parameter candidate for statistical reasons does not mean that this parameter may not have an influence on costs but that the cost influence is already and better covered by other parameters included in the model.

Model specification – e3grid2012

When using statistical analysis in the cost-driver analysis a functional form for the cost function has to be determined. The selection of functional form is guided by intuition and data as well as theory. With possibly data transformations and sufficient degrees of freedom the functional form should provide a reasonable goodness of fit of the data at hand. In addition, theory guides the selection by imposing reasonable properties on the estimated function, e.g. that costs function is homogeneous in prices or that output sets are convex. A good general principle is to use the simplest possible representation with the sufficient flexibility to represent data.

The simplest possible form is the linear one. A slightly more complicated specification is the log-linear one being linear in the log of the variables, corresponding to a multiplicative relationship in the original variables, well-known from Cobb-Douglas type functions from economic theory.

Regression analysis on the data indicated non-linear cost-relationships between the costs and various outputs in the e3grid2012 data sample. In addition the differences in the size of the companies indicated some data transformation to deal with heteroscedasticity in the regression analysis. Hence, we decided to use a log-linear functional form, as

- It better fits the data, in particular with regard to difference sizes of the companies;
- coefficients in the log-linear functional form can be interpreted as cost elasticities; and
- the log-linear form allows implication for returns to scale in the cost function.[50]

The statistical analysis is performed on a panel of 102 observations consisting of 5 years. Using panel data allows more rigorous statistical testing, which is also noted by Weyman-Jones (2013: 15

- 2007: 19 TSO;
- 2008: 20 TSO;
- 2009: 21 TSO;
- 2010: 21 TSO; and
- 2011: 21 TSO.

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50 In the R1 report we used linear and log-linear functional forms for the cost-driver analysis. Further analysis since the release of the R1 report resulted in focussing on the log-linear form.

In the final model, 4 observations have been identified as outliers and therefore been excluded from the sample.[51]

The stepwise procedure in the cost-driver analysis resulted in a model with three outputs:

- *NormalisedGrid* – This is a cost-weighted measure of the assets in use. The technical asset base serves as a proxy for the supply task and the complexity of the operating environment of the firm. The efficiency analysis then no longer questions whether the assets are needed, but questions whether the assets have been procured prudently (at low prices) and whether the company and the assets are operated efficiently;
- *Densely populated area* – The size of the area with a population density more or equal 500 inhabitants/sqkm may require more complex routing of transmission lines (e.g. more corners to pass houses or to cross traffic routes, higher towers to fulfil minimum distance requirements), combining of multiple circuits on one tower in order to save land; and
- *Value of weighted angular towers* – This is a weighted measure of the angular towers in use, where the weight is based on the NormalisedGrid for overhead lines per voltage level. This parameter constitutes a correction factor for a "special condition" class of lines. The parameter is technically well motivated and exhibits the expected sign in the regression model in the log-linear form. In addition this parameter includes information on towers, which were newly collected from the TSOs in e3grid2012[52].

51 We use a MM-type regression estimator for identifying OLS-outliers, as described in Yohai (1987) and Koller and Stahel (2011). We also used detailed inspection using Cook's distance with the conventional limits, resulting in only 3 observations identified, i.e. a subset of the MM-method above. The regression technique used was iteratively reweighted least squares (IRLS).

52 We note that towers are not included in the calculation of the NormalisedGrid. For the detailed description of the calculation of the NormalisedGrid we refer to the Excel file "asset list_R2" available for each TSO.

Table 15. Model parameters base model (robust regression)

OLS log-linear (robust)	Coefficient	t-value
Intercept	9.477	28.1***
NormalisedGrid	0.475	9.2***
Densely populated area	0.137	14.51***
Value of weighted angular towers	0.284	7.18***
adjR^2 (OLS)	91.2%	
p-value for Breusch-Pagen Test for Heteroscedasticity (OLS)	0.09699	
Multicollinearity *(maximal VIF)*	8.3	

Source: Frontier/Sumicsid/Consentec

All parameters are significant and have the expected signs. The regression has an adjusted R^2 of 91.2%. The regression shows no heteroscedasticity[53] as the p-value of 0.09699 is above the critical p-value of 0.05 (95% significance level). The maximum VIF (8.3) lies below the critical VIF value of 10, hence, implying no multicollinearity.

The coefficients in **Table 15** for the NormalisedGrid, Densely populated area and Value of weighted angular towers allow inferences about returns to scale of the cost function:

- If the sum of the coefficient equals 1 this would imply constant returns to scale;
- if the sum of the coefficient is lower than 1 this would imply increasing returns to scale; and
- if the sum of the coefficient is higher than 1 this would imply decreasing returns to scale.

53 The shown model characteristics refer to a robust regression without any heteroscedasticity issue. We note that no heteroscedasticity has been found in the standard OLS (log-lin) model, indicated by Breusch-Pagan test (p-value not significant).

As the sum from **Table 15** is lower than 1 the cost function on the given data sample implies increasing returns to scale. Hence, the cost-driver analysis gives an indication for returns-to-scale specification for DEA. We use a non-decreasing-returns-to-scale (NDRS) specification, thereby not giving large companies the benefit of potentially being "too large".[54]

Environmental factors from Call Z

Besides the explicit environmental factors defined by the densely-populated area and the value of weighted angular towers we note that some further environmental parameters are included in the final model. We refer to the structural claims from Call Z which may trigger adjustments on the cost side of the model and results in a correction of the cost for certain environmental factors. In particular three factors are relevant in this context: Higher costs due to:

- Lines in mountainous regions;
- lines in coastal areas; and
- cables in cable tunnels.

These factors have been reflected through a cost adjustment where the companies had substantiated a respective claim.

Further analysed model variants

In the following we describe a subset of additional output and model variants we analysed:[55]

- **Peak load** – In the R1 report we discussed peak load instead of the value of weighted angular towers as a potential cost driver. However, we already mentioned in R1 that the coefficient for peak load had the "wrong" (negative) sign in the regression analysis, indicating that costs will decrease when peak load increases. Further analysis showed that the negative sign

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54 Weyman-Jones (2013: 17) criticizes the choice of scale assumptions referring to the preliminary R1 report: "The contrast is significant: there has been no argued justification of the NDRS assumption and certainly no report of any tests of the model, despite the fact that such tests are easily computable and are related to the outlier tests that e3grid itself uses. This poses the question: why has the assumption of NDRS been arbitrarily imposed without any testing?" We agree with Prof. Weyman-Jones that the choice of the returns to scale specification should be soundly argued either from an econometric or regulatory point of view. In this report we primarily argue based on the results from the cost-driver analysis. We already included this line of argumentation in the presentation for the R2 workshop on June, 21st, 2013. This presentation was already available to Prof. Weyman-Jones as it is included in the references of the report.

55 For details on the model specification we refer to **Annexe 4: Cost driver analysis**.

persists also with the data set after R1, e.g. after cost adjustments from Call Z claims. A criticism by Weyman-Jones (2013: 12) was that the negative sign of peak load may indicate that other cost drivers, in particular the NormalisedGrid, are not good indicators to measure the transmission service. We refer to our discussion on the use of Normalised Grid to **Section 6.3**. In addition we point out that:

- Peak load is typically a variable driving the size of the technical asset base. Hence, the cost impact from peak load should already be largely reflected in NormalisedGrid;
- TSOs pointed out in the consultation on Call Y that the relationship between potential output indicators and costs must be plausible from an engineering or business process perspective and that statistical evidence alone may not prove the actual relation itself. Hence, the negative sign of peak load tends to be in contradiction to the costs and output parameters in “real life”, as one would expect an increase in costs by increasing peak load;
- Given the size of the sample and the restriction on the number of potential outputs in the final model specification to 2 or 3, a balance has to be made between certain outputs. In other words, peak load and value of weighted angular towers are mutually exclusive output parameters. In direct comparison the value of weighted angular towers has superior properties from a statistical point of view, e.g. correct sign, but also from an engineering perspective, as it explains additional costs for constructing and maintaining the technical asset base.

Hence, we decided to drop peak load as output in our final model specification and retained the value of weighted angular towers instead.

- **Density parameters** – In addition to the densely-populated area we analysed further options for density parameters. Statistical analysis indicated that „households in densely-populated area“ may be an option. However, statistical analysis suggested no preference for „households in densely-populated area“ compared to “densely-populated area”. In addition, we undertook to refine the parameter “densely-populated area” in cooperation with the TSOs after release of the R1 report and some Call Z claims explicitly related to this parameter. Based on these considerations we decided to stick to “densely-populated area” as a parameter.
- **Options for parameter for area** – Statistical analysis indicated that other area parameters, e.g. agricultural use, residential area, could also be a cost

driver. However, we note that these area definitions are based on a lower geographical granularity than that for „densely populated area (based on NUTS2[56] regions compared to NUTS3 regions for "densely populated areas"). This implies that information from higher granularity of the area would be lost by using NUTS2 regions instead of NUTS3 regions (i.e. population density). In addition, some area variables failed the plausibility check, mostly due to wrong sign or causality e.g. engineering expertise would indicate that agricultural area tends to have a low cost impact due to flat land and good accessibility, which was not reflected in the statistical analysis.

- **Pure asset model** – Haney/Pollitt (2012: 13-14) have raised that the use of the cost weights for the aggregation of the physical assets is in contradiction to the principle of DEA. Hence, we analysed a pure asset model – excluding environmental variables – which allowed us to assess models with NormalisedGrid for different asset groups. Statistical analysis was used to define the „best" grouping of physical assets. Although the statistical analysis indicated the significance of certain groupings of assets, we decided to drop the pure asset model for various reasons:
  - In principle model specifications with – at least one – exogenous parameter are preferable in regulatory settings. Once we use a decomposition of asset data we effectively exclude potential other cost parameters. This would lead to a model where cost is purely explained by assets. A pure asset model is in contradiction to this.
  - The statistical grouping of physical assets omitted the share of certain assets, which tend to be important for a TSO. Hence, the statistical grouping finally failed the plausibility check based on engineering expertise.
- **Voltage differentiated model** – As a variant of the pure asset model we analysed a voltage differentiated model for EHV and HV by splitting the NormalisedGrid into EHV and HV parts. Statistical analysis indicated the significance of parameters, however, some of them had the „wrong sign". In particular, EHV assets had the „wrong sign" for two important groups. Hence, we decided to drop the voltage differentiated model based on similar arguments than for the pure asset model.

56 NUTS3 data were not available for these area definitions. On the definition of NUTS2 regions we refer to: Eurostat, *Regions in the European Union, NUTS 2006 / EU 27*, 2007.

6.4.2 Plausibility check of final parameters

In a final step we checked the plausibility of the resulting model from the statistical analysis. We conclude that the model also reflects cost impacts which are well motivated from an engineering and business process point of view:

- **NormalisedGrid** – This tends to be one important cost driver, which is reasonable as the physical asset base is a natural driver for maintenance and investment costs.

- **Densely populated area** – Areas of high population density may require more complex routing of transmission lines (e.g. more corners to pass houses or to cross traffic routes, higher towers to fulfil minimum distance requirements), combining of multiple circuits on one tower in order to save land, etc. It may also be more difficult to access the network for maintenance purposes. Only some of these effects are captured by the NormalisedGrid parameter. Hence, it is reasonable to assume that some cost impact is explained by densely populated areas complementary to other parameters.

- **Value of weighted angular towers** – Angular towers are required whenever a transmission line needs to deviate from a straight route. As angular towers need to sustain higher (lateral) forces, they require more material and are thus more costly. In addition, this parameter may also capture planning constraints, difficulty in getting wayleaves for the otherwise optimal route. Therefore, the value of weighted angular towers can be interpreted as a proxy parameter representing the cost impact of topography or high population and/or load density. The concrete definition of the parameter (weighting of lines [as contained in the NormalisedGrid] with share of angular towers per voltage level) has been selected such that it inherently corrects for scale and for different shares of angular towers per voltage level.

7 DEA – Static and dynamic results

In this section we describe the calculation of the static efficiency scores based on the findings from the cost-driver analysis in **Section 6**. The calculation consists of various steps:

- Calculation of efficiency scores for the full sample;
- outlier analysis to detect TSOs with extreme observations;
- removing outliers from the full sample and recalculate efficiency scores; and
- applying our selective Capex break methodology where appropriate.

In addition we undertake sensitivity analysis for the DEA efficiency scores.

Finally, we show dynamic results for the base model.

7.1 DEA – Output parameters and Returns to scale

Based on the cost-driver analysis we define the following output parameters for the DEA model used for calculating static efficiency scores (see **Table 16**). The cost function from the statistical cost-driver analysis indicates increasing returns to scale. Hence, we adopt a non-decreasing-returns-to-scale DEA specification to reflect this.[57] The size of the sample consists of 21 TSOs.

[57] We are calculating efficiency scores using constant-returns to scale as sensitivity.

Table 16. Model parameters

	DEA model
Sample	21 TSOs
Input	Totex (after Call Z adjustments)
Outputs	NormalisedGrid
	Densely populated area
	Value of weighted angular towers
Returns to scale	Non-decreasing-returns to scale (NDRS)

Source: Frontier/Sumicsid/Consentec

7.2 DEA outlier analysis

In order to increase the robustness of the analysis it is important to assess if the efficiency scores from the DEA calculation are driven by companies with characteristics materially different from those of the majority of the sample. We identify two such characteristics:

- TSOs with extreme observations in the model against average performance; and
- TSOs with no full range of the investment stream (1965-2011), where a low opening balance may result in low costs not achievable by the other TSOs.

We note that the outlier analysis with regard to the DEA calculations is focussed on identifying outliers defining the DEA efficiency frontier, as these companies may have a substantial impact on the efficiency scores of the other TSOs.

The DEA outlier analysis should be distinguished from the statistical outlier analysis in the regression based cost-driver analysis (see **Section 6.4**). The DEA outlier analysis serves to find realistic peer companies, the outlier analysis in the cost driver investigation serves to develop robust conclusion on the identification of cost drivers and a quantitative assessment of their relative importance.[58]

[58] Weyman-Jones (2013: 19-20) notes that the terminology outlier analysis used in the R1 report in relation to the DEA calculations may be misleading. This is why we refer to "DEA outlier analysis" in this report.

7.2.1 DEA outlier analysis – Dominance and Superefficiency test

These tests consist of screening extreme observations in the model against average performance.

In DEA, particular emphasis is put on the quality of observations that define best practice. In DEA extreme observations are those that dominate (i.e. define the frontier for) a large part of the sample directly or through convex combinations.

The outlier detection used in this study follows the German Ordinance for Incentive Regulation and the notion of DEA outliers herein (ARegV, Annex 3). We use a dual screening device to pick out units that are extreme as individual observations and that have an extreme impact on the evaluation of the remaining companies.

To do so, we investigate a

- **dominance criterion** (sums-of-squares deviation indicator**)** similar to that commonly seen in parametric statistics;[59] and
- **super efficiency criterion** similar to the Banker and Chang (2005) approach, although we let the cut-off level be determined from the empirical distribution of the super efficiency scores.

Companies which are qualified as positive (i.e. super-efficient) outliers are eliminated from the analysis as peers for other firms, with the efficiency score of the efficient outliers set to 100%.

Dominance test (sum of squares indicator)

In order to test whether a company sets the frontier for the majority of the sample, we compare the mean efficiency of all companies, including the potential outlier, to the mean efficiency calculated excluding the potential outlier.

First, we calculate the efficiency scores for all companies including and excluding the potential outlier. The efficiency score can be described as:

- *E(k;K):* k represents the single TSO, whereas K stands for the sample of all TSO. Therefore, *E(k;K)* is the efficiency score of TSO k calculated including the full sample of TSO.
- *E(k; K\i):* Again, k represents the single TSO, whereas K stands for the sample of all TSO. The potential outlier is labelled by *i*. Therefore, *E(k;K\i)* is the efficiency score of TSO k calculated including all TSO excluding the potential outlier *i*.

59 See: Banker/Rajiv/Natarajan (2011); Banker (1996).

Both efficiency scores, $E(k;K)$ and $E(k; K\backslash i)$, are the basis for the test statistics T used in the dominance test. The test statistic is the quotient of the sum of squares of the inefficiencies for both cases, including and excluding the potential outlier.

$$T = \frac{\sum_{k \in K \backslash i} (E(\mathrm{k}; \mathrm{K}\backslash i) - 1)^2}{\sum_{k \in K \backslash i} (E(k; K) - 1)^2}$$

The test statistic is designed such that T is decreasing with an increasing influence of the potential outlier i on the efficiency scores of the remaining sample $(K\backslash i)$. Further, T equals 1 if the potential outlier does not impact the efficiency scores of other companies, $E(k;K) = E(k; K\backslash i)$.

This property allows the definition of hypothesis that can be tested on the basis of the F-distribution:

H_0: $T = 1$ (*TSO i* ***does not*** *have an impact on the efficiency scores of the remaining sample)*

and

H_1: $T < 1$ (*TSO i* ***does*** *have an impact on the efficiency scores of the remaining sample*)

The null hypothesis can be rejected at a significance level of 95% if T is smaller than the value of the F-distribution at $F_{0.05,\ J\ ,\ J}$ (J represents the degrees of freedom). We evaluate the null-hypothesis based on the p-value:[60] The null-hypothesis can be rejected and i can be identified as an outlier if $p(H_0)<0.05$. In this case the TSO i has a significant influence on the efficiency score of the remaining TSO. Therefore, TSO i has to be excluded from the sample.

Following the dominance test, we conduct the analysis of the superefficiency criterion.

Super efficiency

The super efficiency criterion allows the quantification of the influence of extreme observations (efficiency score) above 100%. Following the German Ordinance for Incentive Regulation, we identify a TSO as being an outlier if its efficiency exceeds the upper quantile limit (75%) by more than one and a half times the inter-quantile range. The inter-quantile range is defined as the range of the central 50% of the data set ((q(0,75) – q(0,25)). An extreme efficiency score is therefore excluded from the sample if it meets the following condition.

$$E(k; K\backslash i) > q(0.75) + 1.5 \times [q(0.75) - q(0.25)]$$

60 The p-value describes the lowest significance level at which the null-hypothesis can be rejected.

Companies that have been identified as outlier within the DEA analysis have their efficiency scores set to 100%.

7.2.2 DEA outlier analysis – Selected Capex break methodology

In the e3grid2012 we use the Capex break methodology as an additional DEA outlier analysis to assure the structural comparability among firms in the reference set. This means that the DEA efficiency frontier defined by the so-called peer companies should be feasible for all companies, i.e. derived cost targets for inefficient companies should be feasible.

The DEA outlier analysis using selected Capex break follows several steps:

- **Step 1** – Calculation of DEA efficiency scores for all TSOs.
- **Step 2** – Analyse investment stream of Peer companies[61] (ensure investment stream is not understated).
- **Step 3** – Apply individual Capex break to peer companies without a full history of annual investment stream data.
- **Step 4** – Recalculate DEA efficiency scores for the sample reflecting adjusted costs from Capex break for certain (selected) peer companies.

We note, that the application of the Capex break methodology as an instrument for outlier analysis is new in e3grid2012.

7.3 DEA – Base Model

In this section we describe the results for our base model for e3grid2012. The final efficiency scores for the base model are influenced by various factors. In order to make the impact of these factors visible we show the development of the efficiency scores step by step starting from a simplified model.

In addition we apply sensitivity analysis, including second-stage analysis, on the base model by variants of the model specification and data.

7.3.1 Development to base model

In the following we describe the impact from the following factors on the efficiency scores of the TSOs.

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61 We note that we are using the DEA model without weight restrictions for this calculation. The reason is that by relaxing the weight restrictions the number of peer companies tend to increase. Hence, we are screening even more TSOs increasing the accuracy of the outlier analysis.

- **Impact from Call Z cost adjustments** – To make the adjustment from TSO specific costs explicit we show the impact on the Unit Cost scores for the individual TSOs.
- **Impact from returns to scale assumptions** – To make the impact explicit we show the show the difference between Unit Cost scores, which assumes constant returns to scale, and DEA with the NormalisedGrid as single output and Non-Decreasing returns to scale.
- **Impact from adding environmental parameters** – To make the impact from the two environmental parameters – densely populated area and value of weighted angular towers – explicit we add those two parameter to the DEA using a composite variable made up of the weighted sum of NormalisedGrid, densely populated area and value of weighted angular towers, where we are using the cost elasticities estimated in the log-liner cost function to inform the weights.
- **Impact from relaxing weights** – Using a composite variable as a single output in the DEA may be a too strict restriction of the logic of DEA. Hence, we relax the weight restriction by allowing weights within -50% and +50% of the statistical estimates for the respective coefficient (cost driver). This also constitutes the base model.
- **Impact from selected Capex break** – As a final step we illustrate the application of the selected Capex break (to peer companies that were unable to report full annual investment stream data back to 1965) on the efficiency scores from the base model.

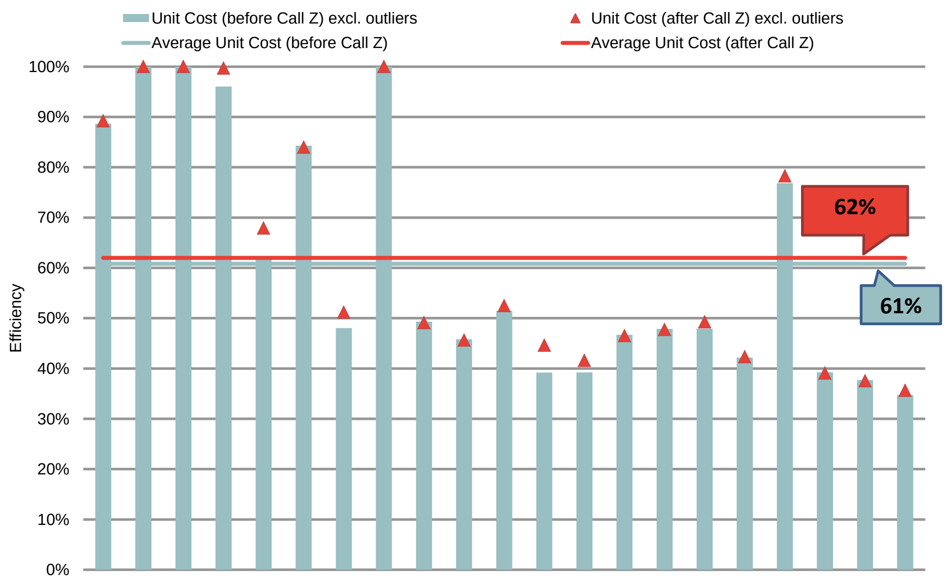
Impact from Call Z cost adjustments

We start the analysis with a stylised model, the unit cost model. In the unit cost approach we simply compare the total costs of the TSO with the technical assets reflected by the NormalisedGrid (Unit Cost = Totex/NormalisedGrid).[62] Hence, Unit Cost scores may serve as a first rough indication on the cost position of the companies with regard to the key cost driver NormalisedGrid.

We note that we use the Unit Cost scores for didactical purposes and to illustrate the impact from the cost adjustments from Call Z on the TSOs costs (and as a result on their Unit Cost scores). This serves as an illustration on the size of cost adjustments from Call Z.

62 For more details on the Unit Cost approach we refer to: **Annexe 2: Unit Cost approach.**

Figure 10. Influence of Call Z cost adjustments on Unit Cost scores



Source: Frontier/Sumicsid/Consentec

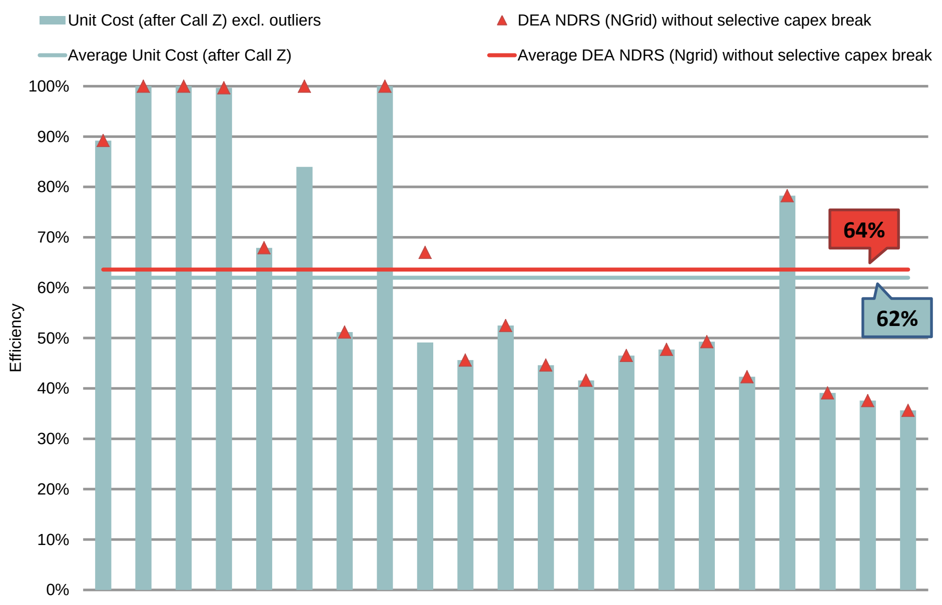
On average the Unit Cost scores after Call Z adjustment increase by 1% point, whereas the largest impact for any individual firm is 6% points (**Figure 10**). As the cost adjustment from Call Z serves only as a compensation device for TSO-specific costs not included in the model specification from the cost-driver analysis it is not surprising that on average the incremental impact of the call Z adjustment is relatively low. Nevertheless, the results show that for single TSOs the additional correction for cost impacts outside the adjustments for densely-populated area and value of weighted angular towers e.g. due to certain other topographical characteristics can be substantial and do have an (improving) impact on efficiency scores.

However, we note that if the cost adjustment from Call Z leads to a reduction of costs for peer companies, this will tighten the efficiency frontier for everyone else.

Impact from returns to scale assumptions

In principle the Unit Cost approach can be described as a DEA with one single output (NormalisedGrid) and an assumption of constant returns to scale. In the following we apply a reduced DEA model with non-decreasing returns to scale (NDRS) and compare the results with the Unit Cost scores. We use the total costs after Call Z adjustments. For the DEA we apply outlier analysis based on the dominance and superefficiency test, however, no selected Capex break is applied (yet).

Figure 11. Influence from returns to scale on Unit Cost scores



Note: Totex post Call Z adjustments

Source: Frontier/Sumicsid/Consentec

The implementation of non-decreasing-returns-to-scale affects two TSOs. The efficiencies increase by more than 15% for both of them (**Figure 11**). The scores of the other 19 firms are unaffected when moving from a CRS to an NDRS specification.

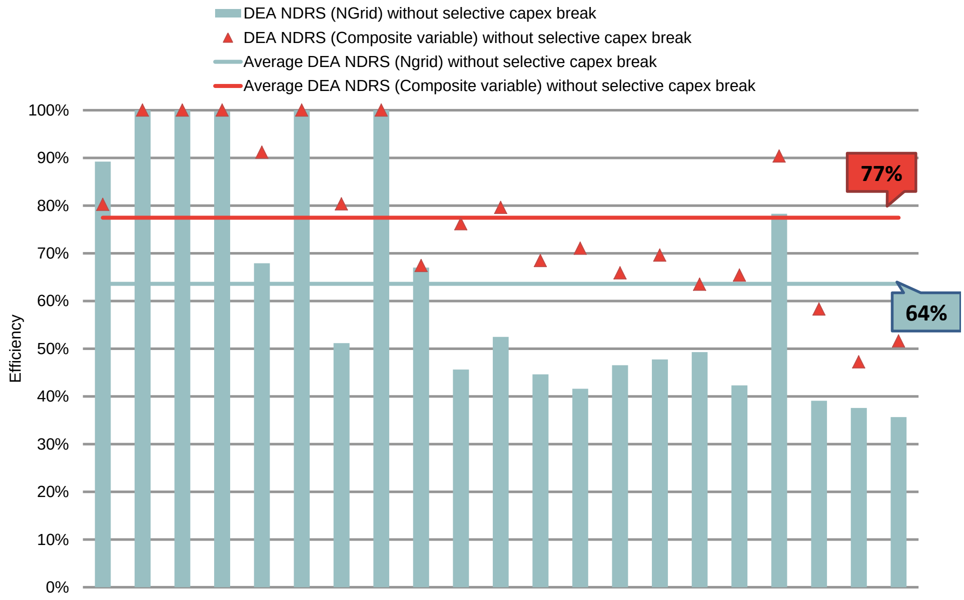
Impact from adding environmental parameters

The cost-driver analysis from **Section 6** shows that NormalisedGrid although a key cost driver does not explain all cost differences between companies. We have identified two further parameters that have an additional and statistically significant incremental impact on costs and which should be included in the assessment of companies' efficiencies, namely

- Densely-populated area; and
- value of weighted angular towers; in addition to
- NormalisedGrid.

The cost-driver analysis from **Section 6** also indicated the relative average importance of these three costs drivers. Hence, we use this information on the average importance to create a composite variable made up of the weighted sum of NormalisedGrid, densely populated area and value of weighted angular towers, where we use the cost elasticity from the log-liner cost function as respective weights. This means that we still include only one output in the DEA, but that this output now includes more information from environmental factors.

Figure 12. Impact from adding environmental parameters by composite variable (weighted sum of NormalisedGrid, Densely-populated area and value of weighted angular towers)



Note: cost post Call Z adjustments

Source: Frontier/Sumicsid/Consentec

Including the composite variable instead of only the NormalisedGrid has a substantial impact on the efficiency scores of many firms. The average efficiency increases by 13% points from 64% to 77%. The efficiency scores of 8 TSOs increase by more than 20%. Only for 1 TSO the efficiency score decreases (**Figure 12**).

We note that this result is expected as the cost-driver analysis indicated the cost impact from the two environmental parameters – densely-populated area and value of weighted angular towers.

Impact from relaxing weights on composite variable

One advantage of applying DEA as a technique is that the relative importance of the different cost drivers can be endogenously determined and be different for every TSO so as to portray each TSO in its best possible light. However, in a small data set – with potentially few peer companies – it makes the analysis extremely cautious. One solution to this problem is to somewhat restrict the weights that are implicitly assigned to the different service dimensions.

The definition of a composite variable as described above can be defined as a strict weight restrictions implicitly assigned to the three parameters:

- NormalisedGrid;
- densely-populated area; and
- value of weighted angular towers.

The advantage of this composite variable is that it allows the alignment of the cost impact with the efficiency impact from the three parameters based on their importance of costs. This avoids that the efficiency from companies may be mainly driven by "less important" cost drivers.

However, one caveat remains. To take account of the statistical uncertainty in econometric models and to account for the possible differences in what drives frontier and average costs for companies that serve varying environments, we should use relatively wide ranges of the relative importance assigned to the less important cost drivers.

The range of the intervals can be informed by the upper and lower bound for the confidence intervals of the cost elasticities for the log-linear cost function from **Section 6**. The upper and lower bounds of the 99% confidence interval indicates a range for the coefficients of +/-29% points for NormalisedGrid, +/- 18% points for densely populated area and +/- 37% points for the value of weighted angular towers (**Table 17**).

Table 17. Confidence intervals of coefficients based on log-linear robust OLS

Cost driver	Regression coefficient	Lower limit (0.05%)	Lower limit (99.5%)	+/-% range around coefficient
NormalisedGrid (log)	0.474907	0.339	0.610	29%
Densely populated area (log)	0.136593	0.112	0.161	18%
Value of weighted angular towers (log)	0.284083	0.180	0.388	37%

Note: "+/-% range around coefficient" stands for the upper and lower range of the 99% confidence interval for the regression coefficient, e.g. upper range for NormalisedGrid: 0.474907 * (1+29%) = 0.610.

Source: Frontier/Sumicsid/Consentec

In the following, we specify the constraints as a variation in the allowed weights within -50% and +50% of the statistical estimates for the respective coefficient (cost driver). This means that the allowed range for the weight restriction lies even outside the 99% confidence intervals (this implies that the weights we use include the true values with a probability in excess of 99%) of the cost elasticities.

However, as the data is best described by a log-linear cost model a transformation of the cost elasticities to cost per units is necessary. The natural choice here is to use the average values of the cost drivers in this transformation.[63] The transformation is illustrated in **Table 18**:

Table 18. Restricting the dual prices based on log-linear Robust OLS

Cost driver	Regression coefficient	Mean cost driver	Absolute weights dy_1/dy_k	± 50%
NormalisedGrid (log)	0.51355	354504.817	1	1
Densely populated area (log)	0.12777	5206.476	16.9	8.5 – 25.4
Value of weighted angular towers (log)	0.27428	39072.162	4.8	2.4 – 7.3

Source: Frontier/Sumicsid/Consentec

Note that it is the importance of the two less important cost drivers that we restrict relative to the most important cost driver, NormalisedGrid. Technically, we use so called Type 1 assurance regions, a technique that has long been available in the DEA literature[64]. This means, we say that

$$8.5 \leq \frac{Weight\ on\ Densely\ populated\ area}{Weight\ on\ NormalisedGrid} \leq 25.4$$

$$2.4 \leq \frac{Weight\ on\ Value\ of\ weighted\ angular\ towers}{Weight\ on\ NormalisedGrid} \leq 7.3$$

Another way to put this is to say that if densely-populate area increases with 1 unit, we expect the cost impact to be equivalent to a change in the NormalisedGrid of between 8.5 and 25.4 units.[65]

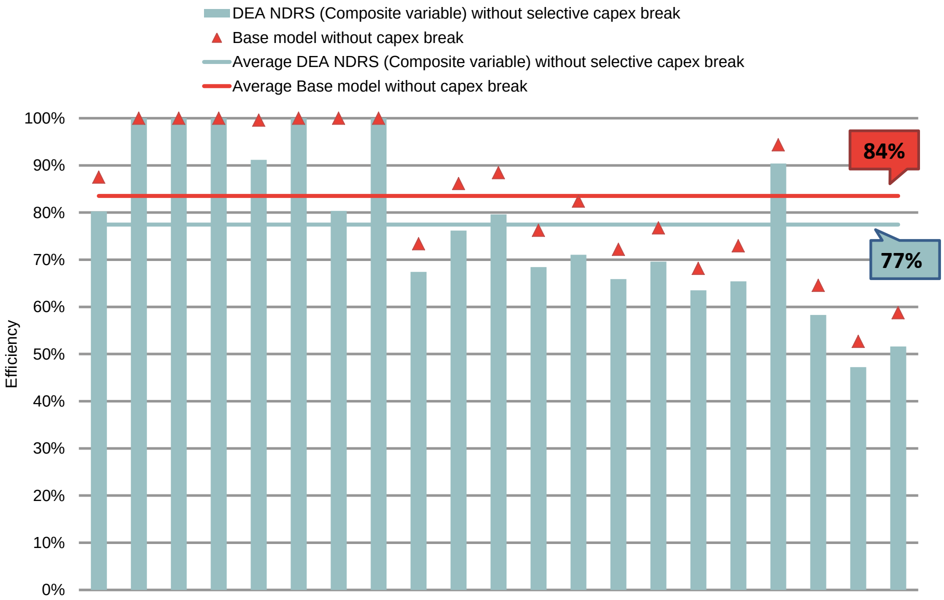
We have calculated efficiency scores by reflecting the three single outputs, while at the same time restricting the weights (and as a consequence the impact on the efficiency scores) for the three parameters. We define this model in the following as the e3grid2012 base model.

63 Formally, we derive a linear approximation from a loglinear specification using the implicit function theorem: $x=Ay_1^a y_2^b y_3^c$ implies that $dy_1/dy_2=-(b/a)(y_1/y_2)$. The a, b and c are the coefficients derived from the loglinear OLS. To set a given restriction on the slope, dy_1/dy_2, we need to fix a point where we do it. The natural choice here is at the values of the cost drivers.

64 For a survey of assurance regions we refer to: Thanassoulis et al (2004).

65 Note that the specific numbers may not be particularly meaningful as they depend on the measurement units we use for the different cost drivers.

Figure 13. Impact from relaxing weights on composite variable



Source: Frontier/Sumicsid/Consentec

Relaxing the strict weights on the composite variable has a material impact on the efficiency scores. The average efficiency increases by 7% points from 77% to 84%. The efficiency scores for all TSOs (not on the efficiency frontier) increases, for 1 TSO the increase is more than 20% and it becomes fully efficient (**Figure 13**). We note that this result is expected as more freedom in choosing the weights in DEA allows portraying each TSO in the better possible light. Hence, the characterisation of DEA as a "benefit-of-the-doubt approach" is emphasised and the estimation of efficiency scores becomes more cautious.

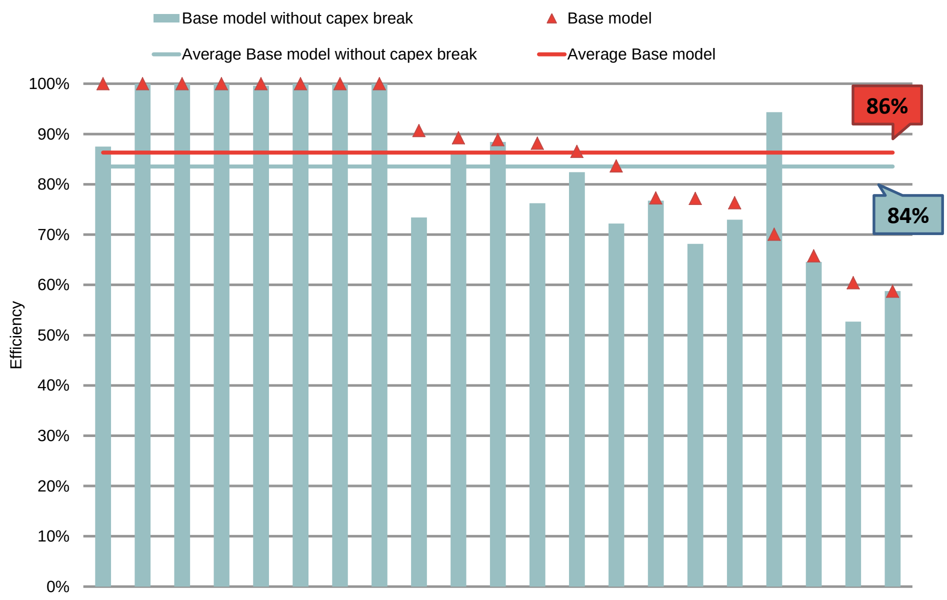
Impact from selected Capex break

As outlined above we introduced a further DEA outlier analysis – the so called "selected Capex break" – to ensure that the efficiency frontier spanned by the peer companies sets feasible cost targets that are not unduly influenced by the absence of historical investment data. In the following we have screened the efficiency frontier[66] and identified two companies where selected Capex break may be applied. In the following we have adjusted the costs (to be precise the

66 We note that we used the efficiency frontier for the DEA model (NDRS) including NormalisedGrid, Densely-populated area and value of weighted angular towers with no weight restrictions for screening the efficiency frontier.

Capex) of these companies accordingly and recalculated the DEA efficiency scores for the e3grid2012 base model.

Figure 14. Impact from selected Capex break



Source: Frontier/Sumicsid/Consentec

The impact from the selected Capex break is illustrated in **Figure 14**. The average efficiency increases by 2% points from 84% to 86%. The efficiency scores for nearly all TSOs (not on the efficiency frontier) increase, for 4 TSOs the increase is above 10% points.

There is a sharp decrease in the efficiency score for one TSO of more than 20%. This is a company on which selected Capex break was applied.[67] Due to the resulting increase in Capex this company is now assessed to be less efficient. The logic in relation to this company is that the value of its opening balance appears to have understated the value of the historic assets. The other TSO on which selected Capex break was applied remain 100% efficient. However, their increase in Capex resulted in a more modest DEA efficiency frontier lowering the distance of the other inefficient companies to the new adjusted DEA efficiency frontier.

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67 We note that we used the DEA model without weight restriction to screen the efficiency frontier. The TSO with the sharp decrease of the efficiency score in **Figure 14** was 100% efficient in the unrestricted model while slightly above 90% in the base model. This explains why a TSO is negatively affected by selected Capex break although not 100% efficient in the base model.

E3Grid2012 – Base Model

We conclude that the e3grid2012 base model is defined as:

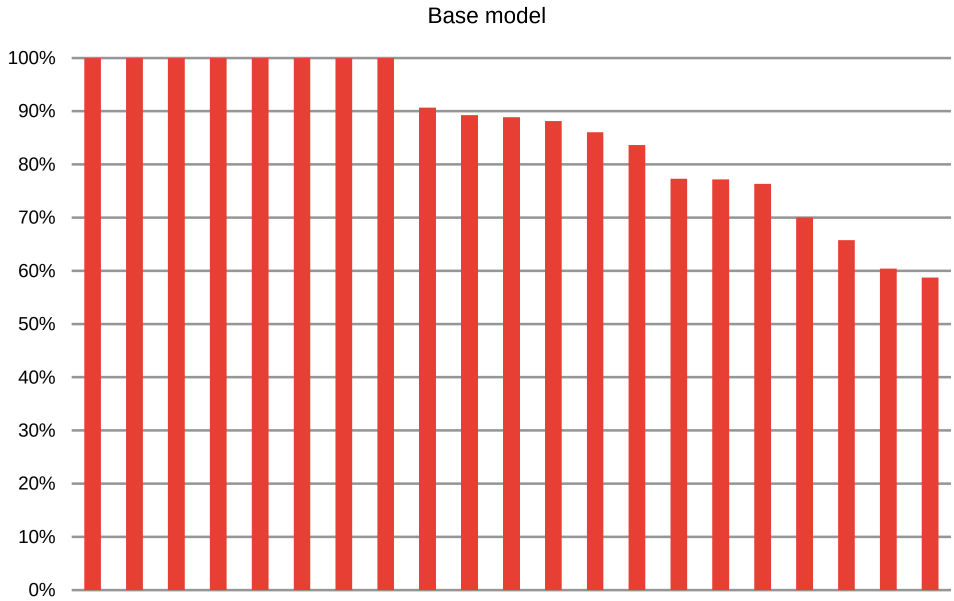
Table 19. Model parameters for e3grid2012 base model

	DEA model
Sample	21 TSOs
Input	Totex (after Call Z adjustments)
Outputs	NormalisedGrid
	Densely populated area
	Value of weighted angular towers
Returns to scale	Non-decreasing-returns to scale (NDRS)
Weight restriction	Within a range of +/-50% around the parameter estimates in regression analysis
Selected Capex break	2 TSOs

Source: Frontier/Sumicsid/Consentec

Figure 15 illustrates the distribution of efficiency scores for the e3grid2012 base model. The results are after DEA outlier analysis using dominance and the superefficiency test. In addition selected Capex break is applied to 2 TSOs, where **Figure 14** illustrates the efficiency scores for the 2 TSOs after selected Capex break has been applied.

Figure 15. e3grid2012 base model



Note: The efficiency scores for the TSOs, where selected Capex break was applied, are based on the costs after selected Capex break

Source: Frontier/Sumicsid/Consentec

The average efficiency is 86% and the minimum efficiency is 59%. 8 TSOs get a score of 100% (including 4 outliers based on dominance and superefficiency test) (**Table 20**).

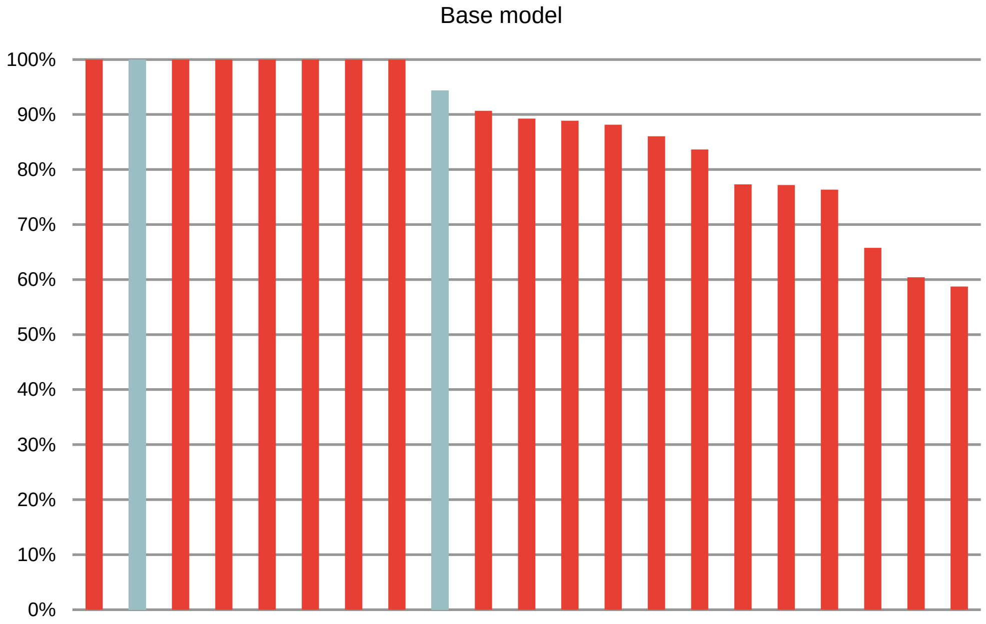
Table 20. e3grid2012 – base model

	e3grid2012 base model
Mean Efficiency (including outliers)	86%
Min Efficiency (including outliers)	59%
Outliers	4
100% companies (including outliers)	8

Source: Frontier/Sumicsid/Consentec

In addition we illustrate the distribution of efficiency scores for the e3grid2012 base model using the efficiency scores for the 2 Capex breaked TSOs before Capex break was applied.

Figure 16. Base model – efficiency scores for the 2 Capex breaked TSOs before Capex break



Note: Blue bars indicate the 2 TSOs, to which selected Capex break was applied. We note that the unrestricted DEA model is used to screen the efficiency frontier, if selected Capex break shall be applied to certain TSOs. This implies that a TSO not being 100% efficient in the Base model can be selected Capex breaked.

Source: Frontier/Sumicsid/Consentec

7.4 DEA Base Model – Sensitivities

In the following we discuss sensitivity analysis we made on the base model. The sensitivity analysis can be categorised into three groups:

- **Variations to model specification –** Where we varied the model specification. We calculated the base model without weight restrictions and then assess the impact from a variant of weight restriction.

- **Variations to model data –** We assessed the impact from using the Producer Price Index (PPI) instead of the CPI for indexation of the investment stream. In addition we assessed the Opex efficiency only by adjusting companies' Capex and removing Capex inefficiencies.

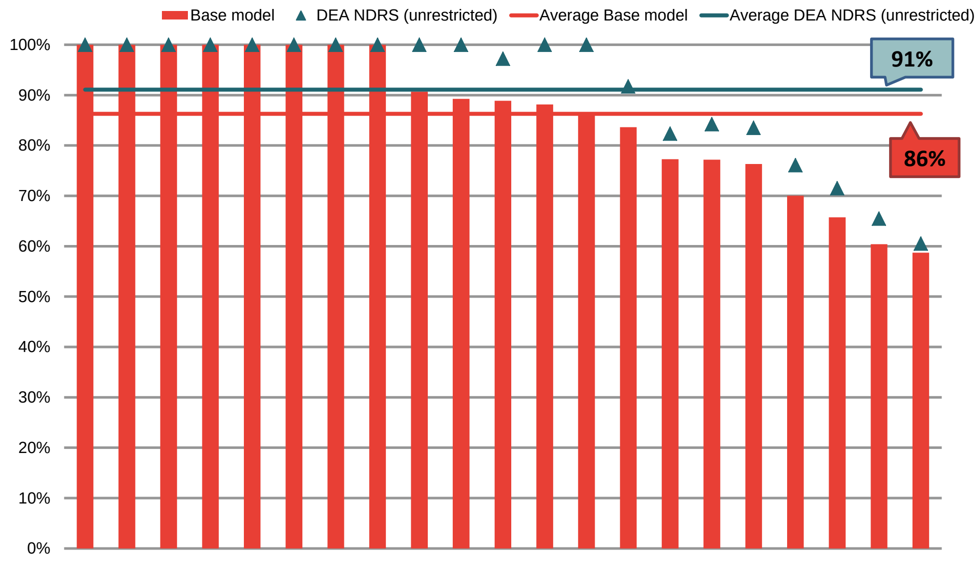
- **Second-stage analysis** – May serve as a further sense check, whether there are indications that certain parameters may be considered for the analysis, which have a systematic impact on the efficiency scores.

7.4.1 Variations to model specification

DEA without weight restrictions

As sensitivity to the base model we relax the weight restriction and calculate a model without weight restrictions (DEA (NDRS) unrestricted).

Figure 17. Base model compared to DEA NDRS (unrestricted)



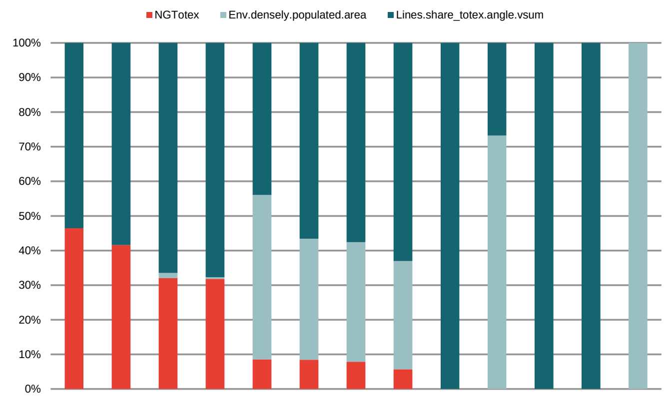
Note: costs after Call Z correction and after selected Capex break

Source: Frontier/Sumicsid/Consentec

The impact from the unrestricted model is illustrated in **Figure 17**. The average efficiency increases by 5% points from 86% to 91%, where 13 TSOs increase their efficiency. The number of 100% efficient companies increases from 8 to 12.

In the following we analysed the weights DEA puts on the three output parameters for these 13 TSOs, when DEA can choose freely (unrestricted) the respective weights. The weights give information which output parameters drive the efficiency scores in the unrestricted DEA.

Figure 18. DEA weights for 13 TSOs with increasing efficiency scores in DEA (NDRS) unrestricted



Note: costs after Call Z correction and after selected Capex break

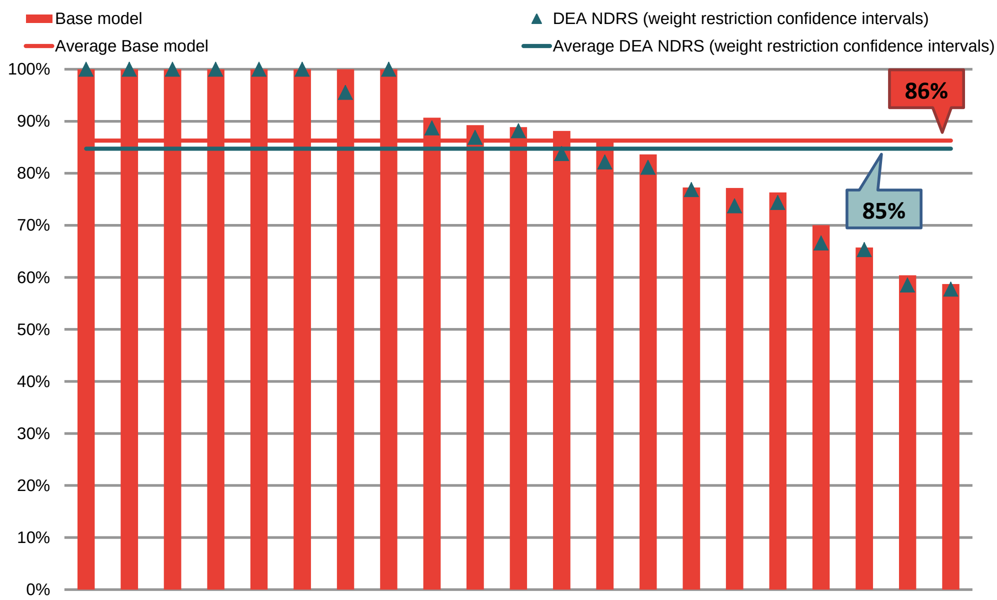
Source: Frontier/Sumicsid/Consentec

Figure 18 illustrates that in the unrestricted DEA for 5 TSOs improving their efficiency the technical asset base covered by the NormalisedGrid has no impact on the efficiency scores, which is not intuitive and contradicts the result from the cost-driver analysis. For 3 TSOs the efficiency scores are only driven by the value of the weighted angular towers and for 1 TSOs only by the densely-populated area, ignoring the other two output parameters. For 1 TSOs only the value of weighted angular towers and densely-populated area matters. For 4 TSOs the weight DEA puts on NormalisedGrid is below 10%, which again contradicts the results from the cost-driver analysis.

DEA with weight restrictions based on confidence intervals

As sensitivity to the base model we adjust the +/-50% range for the weight restriction. Instead of the +/-50% range around the estimated value we use the upper/lower bounds from the confidence intervals for the output parameters from the regression in **Table 17**. The range of the upper/lower bounds lies inside the +/-50% range we apply in the base model. This implies stricter weight restriction compared to the base model, which should have an adverse effect in the efficiency scores.

Figure 19. Base model compared to DEA NDRS (weight restriction based on range from confidence intervals)



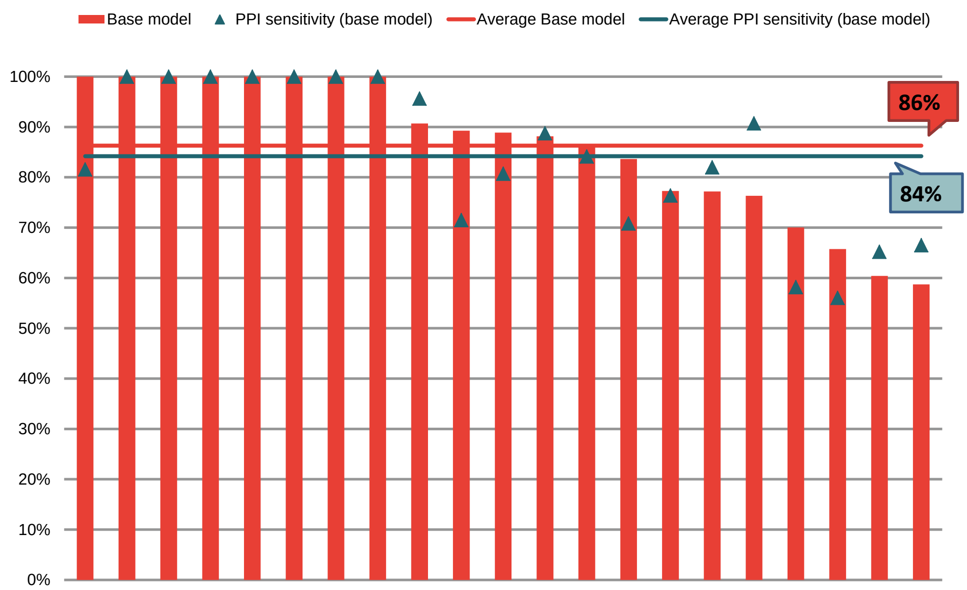
Source: Frontier/Sumicsid/Consentec

The impact from the unrestricted model is illustrated in **Figure 19** and is as expected. The average efficiency decreases by 1% points from 86% to 85%, where 14 TSOs decrease their efficiency (and no TSO improves as is to be expected). The largest decrease is 4% points. The number of 100% efficient companies reduces from 8 to 7. Variations to model data

Producer Price Index

We assessed the impact from using the Producer Price Index (PPI) instead of the CPI for indexation of the investment stream on the efficiency scores in the base model. We used the PPI described in **Section 5.3.3.**

Figure 20. Base model compared to DEA NDRS (+/-50%) PPI



Note: costs after Call Z correction and after selected Capex break

Source: Frontier/Sumicsid/Consentec

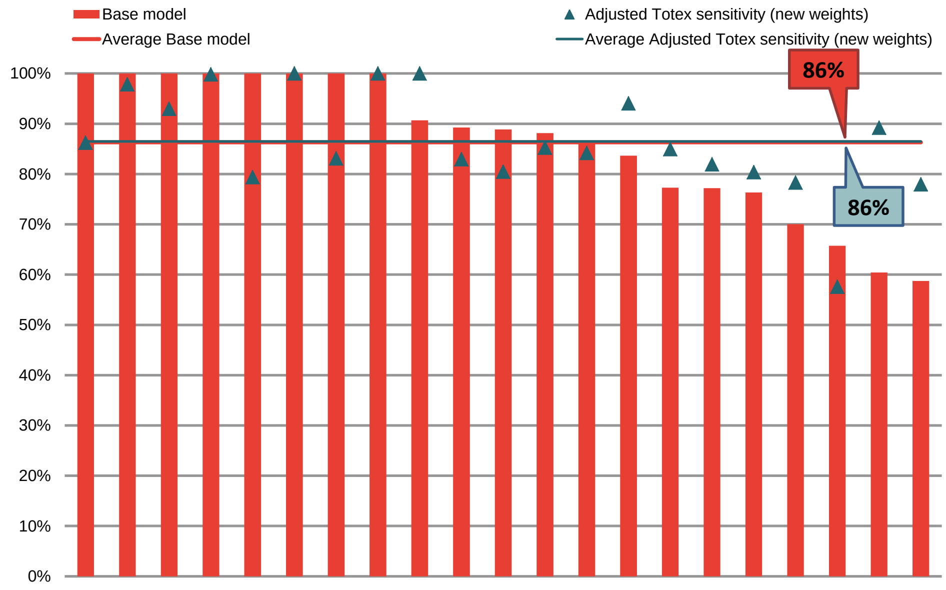
The impact from the PPI instead of the CPI is illustrated in **Figure 20**. The average efficiency decreases by 2% points from 86% to 84%. The number of 100% efficient companies reduces from 8 to 7 companies. While the average efficiency score indicates a minor difference between the two models the impact on individual companies is substantial. The maximum increase is +14% points while the maximum decrease is -18% points.

Further analysis of the results indicated that the results in the PPI model are very much driven by the necessary extrapolation of missing data. As the PPI is used to inflate past investments, on average over all companies PPI data we had to extrapolate 19 years, ranging from 0 missing years to 27 missing years. Hence, using PPI may be an interesting approach for country specific analysis using a national PPI index for the respective TSO, while not suitable for a general approach.

Opex efficiency

In a variant we modified the cost data in order to calculate efficiency scores only for Opex. We adjusted the Totex by replacing the companies' Capex by the NormalisedGrid Capex. This allows focussing on the efficiency of the Opex by using the same output parameters in the DEA model. As the change of costs may also have an impact on the coefficients from the cost-driver analysis we adjusted the coefficients for the weight restriction, as well. We kept the range around the adjusted coefficients at +/-50%.

Figure 21. Base model compared to DEA NDRS (+/-50% around new weights) adjusted Totex



Source: Frontier/Sumicsid/Consentec

Figure 21 gives an indication of the efficiency only for companies' Opex compared to Totex in the base model. The average efficiency is 86% compared to 86% in the base model. The number of 100% efficient companies reduces to 3 companies. The impact on individual companies may be quite large. The maximum increase is +29% points while the maximum decrease is -21% points.

7.4.2 Second stage analysis

The purpose of a second stage analysis is to ensure that we have appropriately specified the best model using the available data. We do so by testing if any excluded variables should potentially have been included. In a second stage analysis, the efficiency scores are regressed against an excluded variable to determine whether it has a significant impact on efficiency scores. If the variable were to significantly explain the efficiency scores, this could be an indication that the respective variable should have been included in the base model. Therefore, second stage regression analysis provides a valuable control of the model specification.

However, we note that second stage analysis serves only as a sanity check on the final results. The selection for cost-driver in this study is done by statistical analysis in the cost-driver analysis (**Section 6.4**).[68]

The second-stage analysis included:

- all parameters from Call Y used in the cost-driver analysis; and
- energy-not-supplied.

In the following we only illustrate the results for Energy-not-supplied. A more comprehensive list of the second-stage-analysis on the other parameters from Call Y is included in **Annexe 5: Second-stage analysis**.

Table 21. Second stage analysis – Energy Not Supplied

Regressor	Degree of freedom	F value	Pr(>F)
Energy not supplied	1	1.325038	0.26475196

Note: For a bivariate regression model, the null hypothesis for the F-test is equivalent to the null hypothesis for a t-test of the slope coefficient

Source: Frontier/Sumicsid/Consentec

The result of the second-stage analysis for Energy-Not-Supplied is illustrated in **Table 21**. A large value of the F test statistic would be an indication that there may be a structural impact on the efficiency scores. The significance level is given in the last column (p=0.26). This shows that energy-not-supplied is not significant at the 5% level, which would imply a value of $p=0.05$. We did the same calculations for the other parameters from Call Y. None of the other tested variables was found to be significant (see **Table 32** in **Annexe 5: Second-stage analysis**).

Hence, we conclude that the base model includes all relevant cost-drivers for the TSOs.

7.5 DEA Base Model – dynamic results

In the previous section we concentrated on the static performance of the TSOs. The static efficiency measures allow us to measure the incumbent inefficiency, i.e. the excess usage of resources in a given period, of a TSO. In a next stage we engage in dynamic analyses and measure also the technological progress (or regress) of the industry. This corresponds to so-called frontier shifts. These

68 For a critical assessment of second-stage analysis in DEA we refer to: Simar/Wilson (2010).

dynamic changes are of considerable interest to regulators and TSOs alike. They are important for example to determine reasonable dynamic trajectory in regulatory contexts. In addition we also calculated the efficiency change, i.e. the productivity development in proportion to the industry (so-called catch-up).

As some TSOs did not provide the full range of historic data from 2007-2011 (in accordance with their NRAs) the productivity development for the years is based on:

- 2007-2008: 19 TSOs;
- 2008-2009: 20 TSOs;
- 2009-2010: 21 TSOs; as well as
- 2010-2011: 21 TSOs.

Hence, we have calculated the Malmquist productivity index (MA) for these periods and the decomposition into Efficiency Change (EC) and Technical Change (TC). While MA captures the net change of productivity, EC captures catch-up effects and TC captures frontier shifts. We translate the indices in % points changes by deducting 1 from the index. We note that a positive (negative) % change indicates an improvement (regress) of the productivity.

Table 22. Malmquist for industry

2007-2011	Malmquist (% point changes)	Efficiency Change (% point changes)	Technical Change (% point changes)	Observations
All TSOs	-1.4%	2.4%	-1.0%	81
Continental Europe	0.0%	4.5%	-0.8%	50
Scandinavia	-1.4%	0.6%	-1.9%	15
UK	-7.0%	-2.8%	-1.1%	12

Note: the % point change is given by: (average of Malmquist indices for each company) – 1. The decomposition of the Malmquist index for each TSO *i* in each year *t* is calculated by: $MI_{i,t} = EC_{i,t} X TC_{I,t}$. This implies that the net effect in the table above cannot be calculated simple by adding the EC and TC.

Continental Europe includes TSOs from all countries except UK, Scandinavia and Estland.

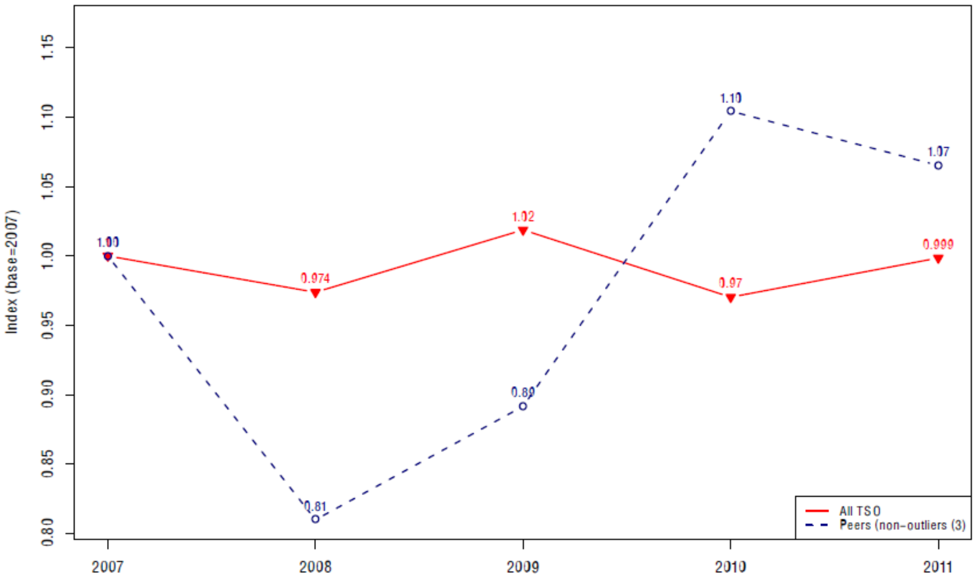
Scandinavia includes TSOs from Finland, Norway, Sweden and Denmark

Source: Frontier/Sumicsid/Consentec

The average results across the TSOs across periods are shown in **Table 22**. The average results for all TSOs indicate a positive efficiency change of +2.4%, i.e. the inefficient companies improve their position against the efficiency frontier, and a regress of the efficiency frontier of -1.0%. A split of the TSOs into three groups indicated that the change in the efficiency frontier for continental Europe and UK tends to be in a similar range (-0.8% and -1.1%) while Scandinavia indicates a higher regress of -1.9%. However, the efficiency change in particular for continental Europe and UK go in the opposite direction. In Scandinavia the efficiency change tends to be stable in 2007-2011.

When interpreting the results from the dynamic analysis we note that it is necessary to keep in mind that the period 2007-2011 was characterised by various structural organisational changes due to unbundling requirements for various companies. Resulting potential one-off effects where not adjusted for in the dynamic calculations with a likely impact on the dynamic results. We note that a regress may be explained as certain companies have reported rising cost in 2011.

Figure 22. Development of maintenance costs (inflation adjusted)



Source: Frontier/Sumicsid/Consentec

This can be illustrated for example by the cost developments for certain functions. **Figure 22** illustrates the cost development for the function M maintenance for 2007-2011. The development for all companies indicates nearly stable costs between 2007-2011. However, the development for the peer companies alone indicates a different pattern. While the costs decrease for these companies from 2007-2009 they increase above the level of 2007 in the years 2010 and 2011.

DEA – Static and dynamic results

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9 Glossary

- AC = Alternating current
- ARegV = German ordinance on incentive regulation
- Call C = Data call for TSOs' costs
- Call Q = Data call for Energy-not-supplied
- Call X = Data call for TSOs' physical assets
- Call Y = Data call for other potential cost drivers and indices
- Call Z = Data call for TSO-specific costs
- Capex = Capital expenditures defined by annuities
- CM = Construction, Maintenance and the Administration that can be directly associated with C and M
- CMA = Costs for Construction, Maintenance and Administration
- CPI = Consumer price index
- CRS = Constant returns to scale
- DC = Direct current
- DEA = Data envelopment analysis
- EC = Efficiency Change
- EHV = Extra high voltage
- ENS = Energy-not-supplied
- MA = Malmquist productivity index
- HV = High voltage
- NDRS = Non-decreasing-returns to scale
- NormalisedGrid = Weighted sum of TSOs' physical assets
- NRA = National regulatory authority
- NUTS = Nomenclature of territorial units for statistics from EUROSTAT
- PPI = Producer Price Index
- Opex = Operating expenditures
- R1 = First model run
- R2 = Final model run

- R 1 Report = e3grid2012, First Report (R1) – A note on methodology for the European TSO Benchmarking study, April 2013.
- TC = Technical Change
- Totex = Total costs
- TSO = Transmission system operator

Annexe 1: Call Y – parameter candidates

In the following we describe the parameter candidates for the different supply tasks.

The main data source for the following parameters is EUROSTAT.

The data were made available to the TSOs and NRAs using the dedicated internet platform ("Worksmart"). As the data were gathered from public sources access to the data was possible for all participating TSOs and NRAs.

In addition calculations files (in Excel format) were made available to the TSOs and NRAs where a data transformation was necessary, e.g. calculation of densely-populated area, etc.

Table 23. Call Y parameter candidates

Appreviations	Indicators for Transportation service	Unit	Source
yEnergy.del	Total production of electricity (net)	GWh	Eurostat
yEnergy.gen.ren	Total electricity generation from renewables (ex hydro) (net)	GWh	Eurostat
yEnergy.gen.hydro	Total electricity generation from hydropower (net)	GWh	Eurostat
y.Energy.gen.CHP	Total electricity generation from CHP (net)	GWh	Eurostat
yPower.gen	Total generation capacity	MW	Eurostat
yPower.gen.ren.incl.hydro	Total generation capacity renewables including hydro	MW	Eurostat
yPower.gen.ren.excl.hydro	Total generation capacity renewables excluding hydro	MW	Eurostat
yPower.gen.solar	Total generation capacity solar panels	MW	Eurostat
yPower.gen.wind	Total generation capacity wind mills	MW	Eurostat
yPower.gen.hydro	Total generation capacity hydropower	MW	Eurostat
yPower.gen.gas turbine	Total generation capacity gas turbines	MW	Eurostat
yPower.gen.nuclear	Total generation capacity nuclear power	MW	Eurostat
yPower.gen.thermal	Total generation capacity thermal plants	MW	Eurostat
yPower.max.peak.load	Maximum peak demand	MW	ENTSO-E
Appreviations	**Indicators customer service**		
yService.population.total	Population-total	#	Eurostat
yService.population.Densely.populated.area	Population-Densely-populated area	#	Eurostat
yService.population.Intermediate.urbanised.area	Population-Intermediate urbanised area	#	Eurostat
yService.population.Thinly.populated.area	Population-Thinly-populated area	#	Eurostat
yEnv.households.total	Households-total	#	Eurostat
yEnv.households.Densely-populated area	Households-Densely-populated area	#	Eurostat
yEnv.households.Intermediate urbanised area	Households-Intermediate urbanised area	#	Eurostat
yEnv.households.Thinly-populated area	Households-Thinly-populated area	#	Eurostat
Appreviations	**Indicators for physical environment**		
yEnv.total land use	Total land use	km^2	Eurostat
yEnv.total land use.agr	Total land use-agriculture	km^2	Eurostat
yEnv.total land use.forest	Total land use-forest	km^2	Eurostat
yEnv.total land use.hunting fishing	Total land use-hunting and fishing	km^2	Eurostat
yEnv.total land use.heavy environmental impact	Total land use-heavy environmental impact	km^2	Eurostat
yEnv.total land use.service and residental	Total land use-service and residental	km^2	Eurostat
yEnv.total land use.service and residental.residental	Total land use - residental	km^2	Eurostat
yEnv.total land use.service and residental.nature reserves	Total land use - Nature reserves	km^2	Eurostat
yEnv.total land use.service and residental.commerce	Total land use - Commerce	km^2	Eurostat
yEnv.total land use.service and residental.community serive	Total land use - Community services	km^2	Eurostat
yEnv.total land use.service and residental.recreation leisure sport	Total land use - recreation leisure sport	km^2	Eurostat
yEnv.total land use.no visible use	Total land use - no visible use	km^2	Eurostat
yEnv.total land cover.water	Total land cover-water	km^2	Eurostat
yEnv.total land cover.wetland	Total land cover-wetland	km^2	Eurostat
yEnv.total land cover.bareland	Total land cover-Bareland	km^2	Eurostat
yEnv.total land cover.artificial land	Total land cover-artifical land	km2	Eurostat
yEnv.total land cover.cropland	Total land cover-cropland	km^2	Eurostat
yEnv.total land cover.woodland	Total land cover-woodland	km^2	Eurostat
yEnv.total land cover.shrubland	Total land cover-shrubland	km^2	Eurostat
yEnv.densely-populated area	Densly populated area	km^2	Eurostat
yEnv.Intermediate area	Intermediate populated area	km^2	Eurostat
yEnv.thinly-populated area	Thinly-populated area	km^2	Eurostat
yEnv.coastal region.total	Coastal area - total	km^2	Eurostat
yEnv.coastal region.with a sea border	Coastal area -with a sea border	km^2	Eurostat
yEnv.coastal region.with no sea border	Coastal area -with no sea border but 50% of population living 50 km from sea border	km^2	Eurostat
yEnv.temp.summer	Average temperature (Summer)	C	WMO
yEnv.temp.winter.average	Average temperature (Winter)	C	WMO
yEnv.precipation	Average precipitation (rain)	mm	WMO

Source: Frontier/Sumicsid/Consentec

Annexe 1: Call Y – parameter candidates

Annexe 2: Unit Cost approach

The idea of the unit cost approach is very simple. If we consider the set of assets A as the cost drivers, if we assume that the cost of operating one unit of asset type k is w_k, and if we assume that a TSO has an asset base given by the vector **N**, where N_k is the number of assets a, then the norm cost is simply

$$NormGrid(.) = \sum_k w_k N_k$$

The cost norm derived in this way is sometimes referred to as the *Grid Volume*, *SizeOfGrid* or *NormalisedGrid NG*.

Now by comparing the actual costs to such a measure of the size of the grid, we obtain a cost per grid unit, here called *unit cost*. That is, Unit Cost is cost per grid unit

UC= cost / grid size

It is comparable in the interpretation to a simple partial measure like cost per [circuit] km of lines, for example. The advance of the UC approach, however, is that by using weights we can aggregate different asset types together such that we do not need to rely on partial indicators.

Now, given the unit costs, we can proceed to benchmark by comparing the performance of a given TSO to the performance of the TSO with lowest unit costs. That is the benchmark in this approach is the company with lowest unit costs

Benchmark = min {unit costs}

The efficiency can therefore be calculated as

E = benchmark / unit cost

This has the same interpretation as the efficiencies derived from Data Envelopment Analysis (DEA). A score of 0.8 would for example suggest that it is possible to save 20% of the costs.

Depending on the interpretation of the weights – e.g. if they are reflecting the total, the operating or the capital cost of one unit of the assets, this approach can be used to derive Totex, Opex and Capex efficiency measure. That is, we get three measures

$$\text{Opex } E^i = \min\{\text{Opex } UC^k\} \ / \ \text{Opex } UC^i$$

$$\text{Capex } E^i = \min\{\text{Capex } UC^k\} \ / \ \text{Capex } UC^i$$

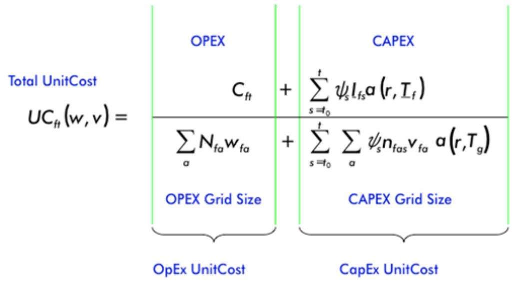
$$\text{Total } E^i = \min\{\text{Total } UC^k\} \ / \ \text{Total } UC^i$$

The partial measures for Opex and Capex efficiency provide intuitive interpretations as to how efficient a TSO is in its daily operations today and how efficient it has been in its past investments. For this reasons they have some partial appeal and they are still quite developed compared to the usual partial measures since the Size of Grid measure provides an informed aggregate.

On the other hand, the partial measures ignore the substitution between capital expenditures and operating expenditures and they also do not yet reflect the role of other environmental factors.

So far we have explained the basic idea of the unit cost approach. The implementation of this idea however relies on a series of more specific standardizations of the actual costs and corresponding standardizations of the size of grid measures. Indeed, as explained in details in the main text, we shall rely on a standardization as illustrated in **Figure 23**.

Figure 23. Three unit cost measures



Source: Frontier/Sumicsid/Consentec

UC_{ft}	Unit Cost of firm f at time t
C_{ft}	Total Opex for firm f and time t
I_{fs}	Investment budget firm f and time s after inflation and currency correction)
N_{fa}	Number of assets of type a that firm f operates at time t
n_{fas}	Number of assets of type a acquired by firm f in period s
v_{fa}	Weights (raw) for Capex, firm f asset a
w_{fa}	Weights (raw) for Opex, firm f asset a
$a(r,T_g)$	Annuity factor for asset with life time T_g and interest rate r
ψ_s	Forgiveness factor used to curtail the evaluation horizon

Annexe 2: Unit Cost approach

Annexe 3: E3grid2012 process

In the following we describe the process and main milestones in more detail. The below mentioned documents and presentations are available from the dedicated internet platform ("Worksmart").

Table 24. E3grid2012 process – overview

Topic	Numbers
Workshops	6 (5 full day)
Consultations on documents and presentations	9
Workshop presentations	4
R1 report (interim report)	1
Method Note (Capex break methodology)	1
Data release (R1 and R2)	2
Ongoing communication	e.g. > 80 postings in TSO/NRA common forum, > 100 postings in TSO Help Desks

Source: Frontier/Sumicsid/Consentec

Workshops with NRAs and TSOs

Four workshops were held together with TSOs and NRAs during the e3grid2012 project. Additionally, the consortium held a workshop only with NRAs on July, 13th, 2013 and a presentation of the status of the project at the CEER Taskforce meeting on January, 24th, 2013.

- **Kick-off Workshop (Berlin, October, 4th, 2012)** – In this workshop the consortium presented i.a. the project scope, project team, timeline and the proposed data collection process. The presentation already included some points raised by NRAs and TSOs after the previous e3grid project in 2008 and at the start of the e3grid2012 project. These points were then included in the consultation on the amendment for Call C guidelines (Cost reporting) and Call X (technical assets) which started at October, 18th, 2013.

- **Workshop on Data collection and next steps (Brussels, February, 13th, 2013)** – In this full day workshop the consortium presented the results regarding the consultations on Call C (cost reporting guideline), Call X (technical asset data), Call Q (quality indicator) and Call Y (outputs and other indicators). The consortium presented the current status on the consultation on the Call X –cost weights, as well. As a next topic the consortium presented the current status of the data submissions for Call C and Call X from the TSOs and the preliminary results of data validation. The consortium then presented the current status of data collection by the consortium, itself. At the end of the presentation the consortium gave an outlook how the collected data will be used for the model specification and the benchmarking analysis. Finally, the consortium illustrated the process for Call Z – TSO specific costs.

- **Workshop on R1 (Brussels, April, 26th, 2013)** – In this full day workshop the consortium presented the preliminary results from the model specification. The workshop was organised as an interim reporting to discuss insights in the model specification and to obtain feedback from the TSOs and NRAs on the preliminary findings. In addition the consortium provided feedback on the data collection and started the first round of data validation with the TSOs by releasing all data used for the preliminary R1 calculations. The consortium presented two model candidates at this workshop, which allowed TSOs to assess if all their relevant cost-drivers are already included in the model. This allowed them to scope their Call Z claims on TSO specific costs not yet included in the model candidates. At the end of the workshop the consortium pointed out the next steps on further data validation, Call Z and further model specification analysis.

- **Workshop on R2 (Brussels, June, 21st, 2013)** – In this full day workshop the consortium presented the preliminary final results for the model specification and the efficiency scores. After the workshop all data used for the calculations for R2 were disclosed to the TSOs for a final data check. The remarks of the TSOs were then taken into account for the final calculations.

Consultation on documents

There were various structured consultation processes during the E3grid2012 project.

- **Call C (Cost Reporting guide)** – Based on comments/suggestions received before and during the Kick-off meeting, we amended the cost reporting guide Call C from the previous e3Grid project in 2008. This new guide was issued for consultation on October 10th, 2012 and the deadline for submissions from TSOs and NRAs was October 23rd, 2012. We received more than 10 submissions from TSOs and NRAs which were included in an updated Call C – Cost Reporting guide.

- **Call X (Data Call for EHV/HV Assets)** – Based on comments/suggestions received before and during the Kick-off meeting we amended the Call X from the previous e3Grid project in 2008. This new guide was issued for consultation on October 10th, 2012 and the deadline for submissions from TSOs and NRAs was October 23rd, 2012. We received more than 10 submissions from TSOs and NRAs which were included in new Call X – Data Call for EHV/HV Assets. In addition we published a document including comments from TSOs/NRAs and how we took them into account.

- **Call Q – Data Call for Quality Indicators** – Based on comments/suggestions received before and during the Kick-off meeting we amended the Call Q from the previous e3Grid project. This new guide was issued for consultation on October 10th, 2012 and the deadline for submissions from TSOs and NRAs was October 23rd, 2012. We received 9 submissions from TSOs and NRAs which were included in new Call Q. In addition we published a document including comments from TSOs/NRAs and how we took them into account.

- **Call Y Data Call for Output indicators –** The consortium issued a consultation paper on November 20th, 2012 and the deadline for submissions from TSOs and NRAs was December 4th, 2012. We received 6 submissions from TSOs and NRAs. Based on the submissions from TSOs/NRAs we released a document "Call Y – Summary and evaluation of consultation responses" on February, 4th, 2013 including the Call Y data collected by the consortium.

- **Call X – cost weights –** The consortium issued a consultation paper on December 14th, 2012 on cost weights. The deadline for submissions from TSOs and NRAs was January 21st, 2013. We received 6 submissions from TSOs. After this consultation steps have been taken, e.g. consultation with specific TSOs on weights for AC/DC converter stations. Finally, we issued a detailed document including responses to the submissions we received from the TSOs and made some clarifications on the cost weights and amendments on March, 12th, 2013. The final cost weights were released on March, 13th, 2013.

- **Call Z –** The TSOs were informed about this process to claim company specific cost at the workshop of February, 13th, 2013. The companies were asked to hold back claims until a preliminary benchmarking model was known. In preparation of the Call Z process the consortium issued a process document on Call Z on March, 28th, 2013. The Call Z process was completed after the release of the R1 report to give TSOs the opportunity to claim specific costs not yet included in the preliminary R1 models. On April 24th, 2013 the final Call Z data call was issued, with May 9th as deadline for the initial submission of claims. During a first evaluation phase, the Consortium identified claims whose content (apart from the specific cost level) was not a TSO-specific topic, but could be relevant for other TSOs, as well. In order to avoid discriminating against other TSOs that might have thought that the respective topic does not qualify as an acceptable claim, the topics of these so-called "structural claims" were disclosed and all TSOs were given the opportunity to submit structural claims on May 16th, 2013 with a deadline on May 24th. The rulings on all Call Z claims were communicated to the respective TSOs and NRAs on June 7th, 2013.

In addition the consortium asked TSOs and NRAs for submissions on the documentations on the workshops and the R1 report. In principle this was organised as an open end process. Only for the submissions on the R2 workshop presentation the consortium set a deadline. TSOs and NRAs had the opportunity to comment on this from June, 21st, 2013 to July, 2nd, 2013.

Data release after R1 and R2

The consortium released the data used for the R1 calculations on April, 29th, 2013. TSOs had the opportunity to comment and validate the data used in the calculations. The comments were taken into account and data adjusted accordingly.

The consortium released the data used for the R2 calculations on June, 26th, 2013. TSOs had the opportunity to comment and validate the data used in the calculations. The comments were taken into account and data adjusted accordingly.

Method note – Capital Break Methodology

The consortium released a method note on the so-called Capital break methodology on March, 28th, 2013 following the suggestions from TSOs at the workshop on February, 13th, 2013.

Ongoing communication

There was an ongoing communication between the Consortium, NRAs and the TSOs using a dedicated internet platform (so-called "Worksmart platform"). On this platform TSOs could make postings on various issues either using their TSO's helpdesk, which were only accessible by the TSO itself, the Consortium, the respective NRA, or using the common forum accessible to all participants in the project. More than 80 postings were issued in the common TSO and NRA forums and more than 100 postings in the TSO specific help desks.

In addition the consortium had organised telephone conferences with some TSOs and regular bilateral communications with individual TSOs per Email or telephone.

Annexe 4: Cost driver analysis

In the following Annexe we present more detailed information on the performed cost driver analysis:

- **Correlation analysis** – Correlation coefficients give an indication on the impact (variance) of possible cost drivers on costs (Totex).

- **Model runs** – The section on model runs includes the statistical characteristics of the additional models discussed in **section 6.4.**

Correlation analysis

In **Table 25** we describe the correlation coefficients of a selection of possible cost drivers. The parameters NormalisedGrid (*NGTotex)* and Value of weighted angular towers (*Lines.share_Totex.angle.vsum)* used in the final model exhibit very high correlation to the costs (Totex) with a correlation coefficient higher than 90%. The parameter Densely-populated area (*Env.densely.populated.area)* shows lower correlation with a coefficient of 57%. We note that the correlation analysis represents only a first step in the cost driver analysis and should not overweight any further statistical analysis.

Table 25. Correlation analysis for selected outputs

	Totex
yNGTotex	0.969
yPower.max.peak.load	0.937
yPower.gen.ren.excl.hydro	0.471
yEnv.total.land.use	0.598
yEnv.total.land.use.agr	0.857
yEnv.densely.populated.area	0.570
yEnv.thinly.populated.area	0.478
yEnv.total.land.use.service.and.residental.commerce	0.848
yEnv.Intermediate.area	0.814
yService.population.total	0.879
yService.population.Thinly.populated.area	0.602

yService.population.Densely.populated.area	0.845
yLines.share_Totex.angle.vsum	0.945

Note: Terminology of parameters is described in **Annexe 1: Call Y – parameter candidates**

Source: Frontier/Sumicsid/Consentec

Additional model runs

In the following we describe in detail the statistical cost driver analysis that lead to the model selection presented in **section 6.4.** Several models have been taken into consideration.

Peak load

In the R1 report we discussed peak load instead of the value of weighted angular towers as a potential cost driver. However, we already mentioned in R1 that the coefficient for peak load had the "wrong" (negative) sign in the regression analysis, indicating that costs will decrease when peak load increases. Further analysis showed that the negative sign persists also with the data set after R1, e.g. after cost adjustments from Call Z claims. A criticism by Weyman-Jones (2013: 12) was that the negative sign of peak load may indicate that other cost drivers, in particular the Norm[alized]Grid, are not good indicators to measure the transmission service. We refer to our discussion on the use of Norm[alized]Grid to **Section 6.3**. We conclude that Norm[alized]Grid in conjunction with peak load does not offer a good model specification (as Norm[alized]Grid in part proxies the cost effect of load). In the following table we illustrate the statistical characteristics of the model.

Table 26. Model parameters "peak load"

OLS log-linear (robust)	Coefficient	t-value
Intercept	8.344	30.96***
NormalisedGrid	0.941	18.65***
Densely populated area	0.149	18.65***
Peak load	-0.194	-3.82***
adjR2	91.6%	
Test for heteroscedasticity *(p-value of Breusch-Pagan)*	0.101	
Multi-collinearity *(maximal VIF)*	6.4	

Source: Frontier/Sumicsid/Consentec
*** 99%

Density parameters

In addition to the densely-populated area we analysed further options for density parameters. Statistical analysis indicated that „households in densely populated area“ may be an option. However, statistical analysis suggested no preference for „households in densely populated area“ compared to "densely populated area". For example the adjusted R2 is lower compared to the base model. In addition, we undertook to refine the parameter "densely populated area" in cooperation with the TSOs after release of the R1 report and some Call Z claims explicitly related to this parameter. Based on these considerations we decided to stick to "densely populated area" as a parameter. In the following table we illustrate the statistical characteristics of the model.

Table 27. Model parameters „households in densely populated area“

OLS log-linear	Coefficient	t-value
Intercept	6.523	11.395***
NormalisedGrid	0.457	3.857***
Households in densely populated area	0.350	6.946***
Value of weighted angular towers	0.173	1.745
adjR2	87.7%	
Test for heteroscedasticity *(p-value of Breusch-Pagan)*	0.1928	
Multi-collinearity *(maximal VIF)*	9.05	

Source: Frontier/Sumicsid/Consentec
*** 99%

Options for parameter for area

As substitute for the parameter "densely-populated area" we tested a parameter representing "thinly-populated area" indicating areas with less than 100 inhabitants per km². The statistical analysis shows lower explanatory power for this specification rather than "densely-populated area" (lower adjusted R^2). In the following table we illustrate the statistical characteristics of the model.

Table 28. Model parameters „ thinly populated areas“

OLS log-linear	Coefficient	t-value
Intercept	6.920	10.416***
NormalisedGrid	0.688	5.257***
Thinly populated area	-0.045	-3.087**
Value of weighted angular towers	0.40	3.255**
adjR2	83.3%	
Test for heteroscedasticity *(p-value of Breusch-Pagan)*	0.101	
Multi-collinearity *(maximal VIF)*	9.3	

Source: Frontier/Sumicsid/Consentec
*** 99%

Pure asset model

Haney/Pollitt (2012: 13-14) have raised that the use of the cost weights for the aggregation of the physical assets is in contradiction to the principle of DEA. Hence, we analysed a pure asset model – excluding environmental variables – which allowed us to assess models with Norm[alized]Grid for different asset groups. Statistical analysis was used to define the „best“ grouping of physical assets. Although the statistical analysis indicated the significance of certain groupings of assets, we decided to drop the pure asset model for various reasons:

- In principle model specifications with – at least one – exogenous parameter are preferable in regulatory settings. Once we use a decomposition of asset data we effectively exclude potential other cost parameters. This would lead to a model where cost is purely explained by assets. A pure asset model is in contradiction to this.

- The statistical grouping of physical assets omitted the share of certain assets, which can be important for specific TSOs. Hence, the statistical grouping finally failed the plausibility check based on engineering expertise.

In the following table we illustrate the statistical characteristics of the model. We illustrate the results for the linear model only.

Table 29. Model parameters „asset model“

OLS linear	Coefficient	t-value
NormalisedGrid Group 2	1354.4	3.120**
NormalisedGrid Group 3	2171.1	4.701***
NormalisedGrid Group 4-7	2059.5	5.488***
Value of weighted angular towers	1835.1	2.235*
adjR2	96.2%	
Test for heteroscedasticity *(p-value of Breusch-Pagan)*		
Multi-collinearity *(maximal VIF)*		

Source: Frontier/Sumicsid/Consentec
*** 99% / ** 95%

Voltage differentiated model

As a variant of the pure asset model we analysed a voltage differentiated model for EHV and HV by splitting the NormalisedGrid into EHV and HV parts. Statistical analysis indicated the significance of parameters, however, some of them had the „wrong sign“. In particular, EHV assets had the „wrong sign“ for two important groups. Hence, we decided to drop the voltage differentiated model based on similar arguments than for the pure asset model. In the following table we illustrate the statistical characteristics of the model. We illustrate the results for the linear model only.

Table 30. Model parameters „Voltage differentiated model “

OLS linear	Coefficient	t-value
NormalisedGrid Group 1 (EHV)	-17.21	-0.110
NormalisedGrid Group 1 (HV)	1611.30	3.979***
NormalisedGrid Group 2-7 (EHV)	2123.75	12.754***
NormalisedGrid Group 2-7 (HV)	649.85	1.549
adjR2	97.1%	
Test for heteroscedasticity *(p-value of Breusch-Pagan)*		
Multi-collinearity *(maximal VIF)*		

Source: Frontier/Sumicsid/Consentec
*** 99%

E3grid 2008 model

In addition we illustrate the model used in e3grid 2008 based on current data.

Table 31. Model parameters „e3grid 2008 "

OLS log-linear	Coefficient	t-value
Intercept	5.53313	10.234***
NormalisedGrid	0.95466	19.919***
Population/Service area	0.20326	4.283***
Renewables capacities (excluding hydro)	0.09872	2.354**
adjR2	86.6%	
Test for heteroscedasticity *(p-value of Breusch-Pagan)*	0.6904	
Multi-collinearity *(maximal VIF)*	1.7	

Source: Frontier/Sumicsid/Consentec
*** 99%; **95%

Annexe 5: Second-stage analysis

We used OLS regression for the second-stage analysis. We note that in some regulatory studies Tobit[69] regression is also applied for the second-stage analysis. However, given the data sample of 21 TSOs, we could not apply Tobit regressions. We note that second-stage analysis serves only as a sanity check on the final results. The actual selection of cost drivers is undertaken by statistical analysis in the cost-driver analysis.

A large value of the F test statistic would be an indication that there may be a structural impact of the analysed parameter on the efficiency scores. The significance level is stated in the last column. A significant impact on a variable at a 95% significance level would require a *p value* equal or smaller than 0.05 ($p \leq 0.05$). The results from second-stage analysis do not suggest any significant impact of any further analysed variable on the efficiency scores (no *p*-value below 0.05 = 5%, **Table 32**).

[69] Tobin, James (1958).

Table 32. Second-stage analysis

Regressor	Df	F value	Pr(>F)
yNGOpex	1	0.876224	0.3609844
yNGCapex	1	1.344714	0.26057014
yNGTotex	1	1.220916	0.28297748
yEnergy.del	1	1.846186	0.19014082
y.Energy.gen.CHP	1	0.002974	0.95708055
yEnergy.gen.hydro	1	0.515595	0.4814638
yEnergy.gen.ren	1	0.041359	0.84100912
yPower.gen	1	1.369925	0.25629647
yPower.gen.ren.incl.hydro	1	0.479416	0.49706283
yPower.gen.ren.excl.hydro	1	0.005817	0.94000342
yPower.gen.solar	1	0.084516	0.77441795
yPower.gen.wind	1	0.022956	0.88116838
yPower.gen.hydro	1	0.838953	0.37117604
yPower.gen.nuclear	1	0.846824	0.36898914
yPower.gen.thermal	1	1.421668	0.24780831
yPower.max.peak.load	1	1.799989	0.1955301
yService.population.total	1	2.962526	0.10145786
yService.population.Densely.populated.area	1	3.055106	0.09662551
yService.population.Intermediate.urbanised.area	1	1.697259	0.20821648
yService.population.Thinly.populated.area	1	2.616868	0.12221445
yEnv.households.total	1	3.064566	0.09614719
yEnv.households.Densely-populated area	1	3.268007	0.08650225
yEnv.households.Intermediate	1	1.825425	0.19253951

Annexe 5: Second-stage analysis

urbanised area			
yEnv.households.Thinly-populated area	1	2.634689	0.12102779
yEnv.total land use	1	0.268778	0.61013808
yEnv.total land use.agr	1	1.297844	0.26876724
yEnv.total land use.forest	1	0.264294	0.61311283
yEnv.total land use.hunting fishing	1	0.101039	0.75405329
yEnv.total land use.heavy environmental impact	1	0.101215	0.75384696
yEnv.total land use.service and residental	1	0.184695	0.67220334
yEnv.total land use.no visible use	1	0.05474	0.81751401
yEnv.total land use.service and residental.commerce	1	2.848212	0.10782351
yEnv.total land use.service and residental.community serive	1	2.138441	0.15999254
yEnv.total land use.service and residental.recreation leisure sport	1	0.760239	0.3941386
yEnv.total land use.service and residental.residental	1	1.329054	0.26327174
yEnv.total land use.service and residental.nature reserves	1	0.20637	0.6547743
yEnv.total land cover.artificial land	1	1.633154	0.21666063
yEnv.total land cover.cropland	1	0.769374	0.39136705
yEnv.total land cover.woodland	1	0.715247	0.4082324
yEnv.total land cover.shrubland	1	0.036747	0.85001398
yEnv.total land cover.bareland	1	0.348569	0.56188136
yEnv.total land cover.water	1	0.670799	0.42292769
yEnv.total land cover.wetland	1	0.505382	0.48578111
yEnv.coastal region.total	1	0.545257	0.46928578
yEnv.coastal region.with a sea border	1	0.412777	0.52824069
yEnv.coastal region.with no sea border	1	3.817765	0.06559346

yEnv.densely-populated area	1	0.703418	0.41206544
yEnv.Intermediate area	1	1.613921	0.21927828
yEnv.thinly-populated area	1	0.027611	0.8697832
yEnv.precipation	1	0.839287	0.37108283
yEnv.temp.summer	1	0.151645	0.70129844
yEnv.temp.winter.average	1	2.428457	0.13565133

Note: Terminology of parameters is described in **Annexe 1: Call Y – parameter candidates**

Source: Frontier/Sumicsid/Consentec

Annexe 5: Second-stage analysis

Annexe 6: Cost weights for NormalisedGrid

In order to obtain one output parameter to comprise all physical assets, it is necessary to transform the different units of assets into a uniform number. This is done by multiplying all assets with respective cost weights and adding up the cost weighted assets (see **Section 2.1.5**). In the following we document the values of these weights. We follow the structure of the Call X in the documentation of the cost weights.

Lines

The Opex weight for lines (expressed as share of respective Capex weight) is 1.67%/a.

The Capex weights are illustrated in **Table 33**. We note that these weights are adjusted by a TSO specific factor in order to account for differences in ambient temperatures (see **Section 2.1.5**).

Table 33. Capex weights for lines

Capex weights of AC lines in € per km and per circuit									
Classes Current	1	2	3	4	5	6	7	8	9
Voltage 1 Circuit									
1	41	56	70	82	96	115	138	160	180
2	57	78	98	114	134	161	193	224	251
3	79	109	137	159	187	224	269	312	350
4	100	137	172	200	235	282	338	393	440
5	111	151	190	221	260	312	374	435	487
6	131	179	225	262	307	369	443	515	576
2 circuits									
1	32	44	55	64	75	90	109	126	141
2	45	61	77	90	105	126	152	176	197
3	62	85	107	125	147	176	211	246	275
4	79	107	135	157	185	222	266	309	346
5	87	119	150	174	204	245	294	342	383
6	103	141	177	206	242	290	348	405	453
3 circuits									
1	28	38	48	55	65	78	94	109	122
2	39	53	67	78	91	109	131	152	171
3	54	74	93	108	127	152	183	213	238
4	68	93	117	136	160	192	230	268	300
5	75	103	129	150	177	212	254	296	331
6	89	122	153	178	209	251	301	350	392
4 circuits									
1	25	34	43	50	59	71	85	98	110
2	35	48	60	70	82	99	118	138	154
3	49	67	84	98	115	138	165	192	215
4	61	84	106	123	144	173	208	241	270
5	68	93	117	136	159	191	230	267	299
6	80	110	138	161	189	226	272	316	354
5 & 6 circuits									
1	22	31	39	45	53	63	76	88	99
2	31	43	54	63	73	88	106	123	138
3	44	60	75	87	103	123	148	172	192
4	55	75	94	110	129	155	186	216	242
5	61	83	104	121	143	171	205	239	267
6	72	98	124	144	169	203	243	283	317
7&8 circuits									
1	20	27	35	40	47	57	68	79	88
2	28	38	48	56	66	79	95	110	124
3	39	53	67	78	92	110	132	154	172
4	49	67	85	99	116	139	167	194	217
5	54	74	94	109	128	154	184	214	240
6	64	88	111	129	151	182	218	254	284

Capex weights of DC lines in € per km and per circuit									
Classes Current / Voltage 1 Circuit	1	2	3	4	5	6	7	8	9
1	27	37	47	54	64	77	92	107	120
2	38	52	65	76	89	107	128	149	167
3	53	72	91	106	124	149	179	208	233
4	67	91	115	133	157	188	225	262	294
5	74	101	127	147	173	208	249	290	325
6	87	119	150	174	205	246	295	343	384
2 circuits									
1	21	29	37	43	50	60	72	84	94
2	30	41	51	60	70	84	101	117	132
3	42	57	72	83	98	117	141	164	184
4	52	72	90	105	123	148	177	206	231
5	58	79	100	116	136	163	196	228	255
6	69	94	118	137	161	193	232	270	302
3 circuits									
1	18	25	32	37	43	52	63	73	81
2	26	35	44	52	61	73	87	102	114
3	36	49	62	72	85	102	122	142	159
4	45	62	78	91	107	128	153	178	200
5	50	68	86	100	118	141	170	197	221
6	59	81	102	119	139	167	201	233	261
4 circuits									
1	17	23	29	33	39	47	56	66	74
2	23	32	40	47	55	66	79	92	103
3	33	44	56	65	76	92	110	128	143
4	41	56	70	82	96	115	138	161	180
5	45	62	78	91	106	128	153	178	199
6	54	73	92	107	126	151	181	211	236
5 & 6 circuits									
1	15	20	26	30	35	42	51	59	66
2	21	28	36	42	49	59	71	82	92
3	29	40	50	58	68	82	98	114	128
4	37	50	63	73	86	103	124	144	161
5	40	55	70	81	95	114	137	159	178
6	48	65	82	96	113	135	162	189	211
7&8 circuits									
1	13	18	23	27	31	38	45	53	59
2	19	26	32	37	44	53	63	74	82
3	26	36	45	52	61	74	88	103	115
4	33	45	56	66	77	93	111	129	145
5	36	50	62	73	85	102	123	143	160
6	43	59	74	86	101	121	145	169	189

Source: Frontier/Sumicsid/Consentec

Cables

The Opex weight for cables (expressed as share of respective Capex weight) is 0.35%/a.

The Capex weights for land cables are illustrated in **Table 34**. Capex weights for sea cables are 120% of the weights for the respective land cables.

Table 34. Capex weights for cables

Capex weights of AC land cables in € per km									
Classes Voltage / Current	1	2	3	4	5	6	7	8	9
1	738	751	769	787	815	864	943		
2	752	780	820	861	927	1048	1074		
3	783	846	938	1039	1043	1273	1719		
4	824	938	1113	1114	1361	1900	2498	3133	3767
5	851	1000	1060	1252	1608	2440	3468	4558	5649
6	916	1005	1281	1633	2349	4307	7405	10691	13978

Capex weights of DC land cables in € per km							
Classes Voltage / Current	1	2	3	4	5	6	7
1	492	501	512	525	543	576	629
2	501	520	546	574	618	699	716
3	522	564	625	693	695	849	1146
4	550	625	742	743	907	1267	2088
5	568	667	707	835	1072	1626	3039
6	611	670	854	1088	1566	2871	7128

Source: Frontier/Sumicsid/Consentec

Circuit ends

The Opex weight for circuit ends (expressed as share of respective Capex weight) is 0.85%/a.

Capex weights are illustrated in **Table 35**.

Table 35. Capex weights for circuit ends

Capex weights in k€ per circuit end																						
Voltage ranges [kV]			Outdoor - air insulated																			
			Single				Double				Triple				Special (1,5)				Quadruple			
			Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]			
			≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70
1		<=30	167	209	251	301	211	264	317	381	256	320	384	461	252	315	378	453	300	360	432	519
2	>30	<=70	252	315	378	453	319	398	478	573	385	482	578	694	379	474	569	682	452	543	651	782
3	>70	<=150	429	536	643	771	543	678	814	977	656	821	985	1182	646	807	968	1162	770	924	1109	1331
4	>150	<=220	654	818	981	1178	828	1035	1242	1491	1002	1253	1503	1804	985	1232	1478	1774	1176	1411	1693	2032
5	>220	<=350	795	994	1193	1431	1007	1258	1510	1812	1218	1522	1827	2192	1198	1497	1797	2156	1429	1715	2058	2470
6	>350		1116	1395	1674	2008	1412	1765	2118	2542	1709	2136	2563	3076	1681	2101	2521	3025	2005	2407	2888	3465
			Indoor - air insulated																			
			Single				Double				Triple				Special (1,5)				Quadruple			
			Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]			
			≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70
1		<=30	177	221	265	319	224	280	336	403	271	339	407	488	267	333	400	480	318	382	458	550
2	>30	<=70	281	351	421	505	355	444	533	639	430	537	645	774	423	528	634	761	504	605	726	872
3	>70	<=150	503	629	754	905	636	796	955	1146	770	963	1155	1386	757	947	1136	1363	904	1085	1301	1562
4	>150	<=220	795	994	1192	1431	1006	1258	1509	1811	1218	1522	1826	2192	1197	1497	1796	2155	1429	1715	2058	2469
5	>220	<=350	981	1227	1472	1766	1242	1553	1863	2236	1503	1879	2255	2705	1478	1848	2217	2661	1764	2117	2540	3048
6	>350		1413	1766	2119	2543	1788	2235	2682	3219	2164	2705	3246	3895	2128	2660	3192	3831	2539	3047	3657	4388
			GIS																			
			Single				Double				Triple				Special (1,5)				Quadruple			
			Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]				Short circuit breaking current range [kA]			
			≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70	≤30	≤50 >30	≤70 >50	>70
1		<=30	171	213	256	307	216	270	324	389	261	327	392	470	257	321	385	463	307	368	442	530
2	>30	<=70	539	674	809	971	683	853	1024	1229	826	1033	1239	1487	812	1015	1219	1462	969	1163	1396	1675
3	>70	<=150	832	1040	1248	1497	1053	1316	1579	1895	1274	1593	1911	2293	1253	1566	1880	2255	1495	1794	2153	2584
4	>150	<=220	1366	1707	2049	2458	1729	2161	2593	3112	2092	2615	3138	3765	2057	2572	3086	3703	2455	2946	3535	4242
5	>220	<=350	1699	2124	2549	3059	2151	2689	3227	3872	2603	3254	3904	4685	2560	3200	3840	4608	3055	3666	4399	5279
6	>350		2458	3072	3687	4424	3111	3889	4667	5600	3765	4706	5647	6776	3702	4628	5554	6664	4418	5302	6362	7634

Source: Frontier/Sumicsid/Consentec

Transformers

The Opex weight for transformers (expressed as share of respective Capex weight) is 0.5%/a.

Capex weights are illustrated in **Table 36**.

Annexe 6: Cost weights for NormalisedGrid

Table 36. Capex weights for transformers

Capex weights of transformers in k€ per piece										
			Power classes [MVA]							
			≤50	≤125 >50	≤350 >125	≤700 >350	≤1500 >700	≤1750 >1500	≤2250 >1750	>2250
Voltage classes			Transformer, No OLTC, No Phase Shift							
1		<=30	772	1332	2534	4224	6801	10782	12753	18697
2	>30	<=70	839	1448	2755	4592	7394	11723	13866	20329
3	>70	<=150	912	1574	2995	4992	8038	12743	15076	22103
4	>150	<=220	966	1668	3173	5288	8515	13499	16388	24026
5	>220	<=350	991	1710	3254	5423	8732	13843	17360	25451
6	>350		1034	1784	3394	5657	9109	14441	17803	26100
			Transformer, No OLTC, Phase Shift							
1		<=30	865	1492	2838	4730	7617	12076	14283	20940
2	>30	<=70	940	1622	3086	5143	8282	13130	15530	22768
3	>70	<=150	1022	1763	3355	5591	9002	14273	16885	24755
4	>150	<=220	1082	1868	3553	5923	9536	15119	18355	26910
5	>220	<=350	1110	1916	3644	6074	9779	15505	19443	28506
6	>350		1158	1998	3801	6336	10202	16174	19939	29232
			Transformer, OLTC, No Phase Shift							
1		<=30	908	1567	2981	4969	8001	12685	15003	21996
2	>30	<=70	987	1704	3242	5403	8699	13792	16313	23916
3	>70	<=150	1073	1852	3524	5873	9456	14992	17737	26004
4	>150	<=220	1137	1962	3733	6221	10017	15882	19280	28266
5	>220	<=350	1166	2012	3828	6380	10273	16286	20424	29943
6	>350		1216	2099	3993	6655	10716	16990	20944	30706
			Transformer, OLTC, Phase Shift							
1		<=30	1017	1755	3339	5565	8961	14207	16804	24635
2	>30	<=70	1106	1909	3631	6051	9743	15447	18270	26786
3	>70	<=150	1202	2075	3946	6578	10591	16791	19865	29124
4	>150	<=220	1273	2198	4181	6968	11219	17787	21594	31658
5	>220	<=350	1306	2254	4287	7145	11505	18241	22875	33536
6	>350		1362	2351	4472	7454	12002	19028	23458	34391
			Autotransformer, No OLTC, No Phase Shift							
1		<=30	695	1199	2281	3801	6121	9704	11477	16827
2	>30	<=70	755	1304	2480	4133	6655	10551	12479	18296
3	>70	<=150	821	1417	2696	4493	7234	11469	13569	19893
4	>150	<=220	870	1501	2855	4759	7663	12149	14749	21624
5	>220	<=350	892	1539	2928	4880	7858	12459	15624	22906
6	>350		930	1606	3055	5091	8198	12997	16022	23490
			Autotransformer, No OLTC, Phase Shift							
1		<=30	778	1343	2554	4257	6855	10868	12855	18846
2	>30	<=70	846	1460	2777	4629	7454	11817	13977	20491
3	>70	<=150	920	1587	3019	5032	8102	12845	15197	22280
4	>150	<=220	974	1681	3198	5330	8583	13607	16519	24219
5	>220	<=350	999	1724	3280	5466	8801	13954	17499	25655
6	>350		1042	1798	3421	5702	9181	14557	17945	26309
			Autotransformer, OLTC, No Phase Shift							
1		<=30	817	1411	2683	4472	7201	11416	13503	19796
2	>30	<=70	889	1534	2917	4862	7829	12413	14682	21524
3	>70	<=150	966	1667	3171	5286	8511	13493	15963	23403
4	>150	<=220	1023	1766	3359	5599	9015	14293	17352	25440
5	>220	<=350	1049	1811	3445	5742	9245	14658	18381	26949
6	>350		1095	1889	3594	5990	9644	15291	18850	27636
			Autotransformer, OLTC, Phase Shift							
1		<=30	915	1580	3005	5009	8065	12786	15123	22172
2	>30	<=70	995	1718	3268	5446	8769	13903	16443	24107
3	>70	<=150	1082	1867	3552	5920	9532	15112	17879	26212
4	>150	<=220	1146	1978	3763	6271	10097	16009	19434	28492
5	>220	<=350	1175	2028	3858	6431	10355	16417	20587	30182
6	>350		1226	2116	4025	6708	10802	17125	21112	30952

Source: Frontier/Sumicsid/Consentec

Compensating devices

The Opex weight for compensating devices (expressed as share of respective Capex weight) is 0.5%/a.

Annexe 6: Cost weights for NormalisedGrid

Capex weights are illustrated in **Table 37**.

Table 37. Capex weights for compensating devices

Capex weights in €/kVAr		
Capacitive	fixed	5
	adjustable	15
Inductive		15
Capacitive & inductive		15
SVC		65
STATCOM		90
Synchronous		65
Series compensation		15

Source: Frontier/Sumicsid/Consentec

Dispatching centres

The Opex weight for dispatching centres (expressed as share of respective Capex weight) is 12.8%/a.

The capex weight is € 4.5 Mio per dispatching centre.

AC/DC converter stations

The Opex weight for AC/DC converter stations (expressed as share of respective Capex weight) is 0.56%/a.

The capex weights are individual for each converter station (see **Section 2.1.5**).

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