Analysis of TenneT's estimated efficiency under TCB18

Prepared for
TenneT TSO B.V.

14 August 2020

Strictly confidential

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Contents

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Boxes, figures and tables

Executive summary

The TCB18 electricity study[1] is an international comparison of 17 electricity transmission system operators (TSOs) based in 15 European countries. The consultant that conducted the project, Sumicsid, used cost and asset data provided by the TSOs, in addition to environmental and price-level data from external sources, to assess the TSOs' relative efficiency.

Specifically, Sumicsid assessed total expenditure (TOTEX), which is constructed as the sum of operating expenditure (OPEX) and capital expenditure (CAPEX). OPEX is measured on an annual basis, with an adjustment to direct manpower costs to account for labour cost differentials between the TSOs, while CAPEX is distributed over time by using annuities and an assumed interest rate on investments. The benchmarking model uses three cost drivers to explain differences in TOTEX across TSOs, namely: the overall asset base, represented by normalised grid (NormGrid) adjusted by environmental complexity; capacity provision, represented by transformer power; and routing complexity, represented by weighted lines.

As in previous benchmarking exercises,[2] Sumicsid used data envelopment analysis (DEA) to assess the efficiency of the participating electricity TSOs.

Sumicsid's analysis concluded that TenneT B.V. ('TenneT') is 71.5% efficient in 2017, implying that TenneT can reduce its expenditure by 28.5% (€92m) while maintaining its current level of service.[3]

If the results from TCB18 are to be used in a regulatory context (or indeed in any context), it is essential that the limitations of Sumicsid's analysis are fully understood, and that appropriate adjustments are made to ensure that the resulting efficiency targets are robust and achievable. Therefore, all TSOs that participated in TCB18, including TenneT, commissioned Oxera to validate and review the results from TCB18, and to recommend robust solutions to any issues that emerged.

In our assessment of TCB18 electricity, which is detailed in our main report,[4] we found that the study suffers from a number of significant flaws, some of which are fundamental. A summary of our key findings include the following.

- The transparency of TCB18 falls significantly short of what would be considered good regulatory practice. Sumicsid's published materials do not contain necessary information for third parties to clearly follow its analysis, validate its analysis, or offer recommendations without considerable effort.
- The data underlying the assessment contains significant errors that have a material impact on the estimated efficiency of the TSOs.
- The data collection and construction process did not result in a sufficiently harmonised dataset on which robust cost benchmarking can be performed.
- Sumicsid's approach to model development was arbitrary, restrictive and inconsistent with the scientific literature.

[1] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators main report', July.
[2] For example, see Sumicsid, Frontier Economics, Consentec (2013), 'E3GRID2012 – European TSO Benchmarking Study A REPORT FOR EUROPEAN REGULATORS', July.
[3] Sumicsid (2019), 'Project TCB18 Individual Benchmarking Report TenneT – 187', July, p. 3.
[4] Oxera (2020), 'A critical assessment of TCB18 electricity', April.

- The assumptions made in the estimation of the model specification are not well justified.
- Sumicsid's approach to model validation was incapable of detecting flaws or omissions in the model.
- The efficiency results from DEA remain unvalidated, with the limitations with respect to data and model specification manifesting as efficiency gaps.

The overall assessment of our main report was that the estimated efficiency scores cannot be used for regulatory, operational or valuation purposes in their current form. To remedy the issues identified, we provided a total of 15 recommendations on the study's procedural and methodological issues. We also suggested that it could be helpful to consider debriefs involving all parties to help future studies.

We understand that the Netherlands Authority for Consumers and Markets (ACM) nevertheless plans to use TCB18 as evidence to set an individual efficiency target, and thus regulatory revenues, for TenneT for the coming regulatory period (2022–26).

It is also our understanding that the ACM has already acknowledged some of the less material issues with TCB18 and is aiming to correct for them.[5] Correcting for these issues results in an increase in TenneT's estimated efficiency from the 71.5% to 74.5%.

However, these adjustments are not sufficient to address the material flaws in TCB18 that result in a significant bias against TenneT. In this report, we examine some of the specific issues that result in a material underestimation of TenneT's efficiency in Sumicsid's analysis.

As the issues we examine in this report are fundamental and significant in nature, one should ideally repeat the model development procedure after suitable adjustments to the data and model specification on each issue. However, there are several fundamental issues with Sumicsid's analysis (as detailed in our main report), which severely limits this option. Hence, we focus on quantifying the impact of the specific issues under Sumicsid's model specification and estimation procedure (including following its flawed outlier procedure) after suitable adjustment.

1. The output used to proxy capacity provision materially underestimates the capacity that TenneT provides.

In its study, Sumicsid recognised capacity provision as a key cost driver, and used the sum of the power of all transformers **owned** by a TSO (the 'transformer power' variable) as a proxy for this output.[6]

However, some TSOs do not own all of the transformers connected to their networks. These TSOs provide the capacity associated with these transformers, which is unaccounted for in Sumicsid's transformer power variable. This especially occurs if the electricity distribution system operators

[5] Specifically, there was an error in how the 'other' category was treated in Sumicsid's calculation of the environmental adjustment. Authority for Consumers and Markets (2020), 'Beoordeling en implementatie TCB18 - Issues TenneT', March.
[6] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators main report', July, p. 32.

(DSOs) own many of the transformers connected to a TSO's grid, which is the case in the Netherlands.

Statistical analysis of the TCB18 data and correspondence with participating TSOs show that for five of the TSOs (including TenneT), the capacity proxy does not include a significant proportion (up to 50%) of transformers connected to the TSO grid.

To correct for this bias, we construct two alternative capacity proxies that do not suffer from the issue. One proxy involves adjusting Sumicsid's transformer power variable based on estimates of 'missing' transformer power in the TCB18 sample provided to Oxera by the affected TSOs.[7] The other adjustment involves replacing Sumicsid's transformer power variable with the power of circuit ends, a category of assets in the TCB18 data that is more consistently associated with the other assets managed by TSOs.

These adjustments indicate that **TenneT's estimated efficiency is *understated* by 10–17% based on the capacity issue alone**. In other words, the adjustments show TenneT's estimated efficiency to be 84–91% in 2017. The failure to account for asset ownership is a fundamental data issue. As such, adjustments for subsequent issues are considered on an incremental basis to it.

2. The impact of asset age and investment timing on TenneT's level of expenditure is not accounted for.

Sumicsid's benchmarking model with the 'adjusted transformer power' capacity provision shows that TenneT's estimated efficiency decreased from 96.5% in 2013 to 84.0% in 2017. If the change in *estimated* efficiency was driven by a *genuine deterioration* in TenneT's efficiency, this would imply that TenneT's investments since 2013 were procured at a cost nearly ten times the efficient price and that the observed increase in OPEX was driven wholly by inefficiency.[8]

One reason for the observed deterioration in TenneT's estimated efficiency is that Sumicsid's model specification in TCB18 does not account for TenneT's asset-age profile. Namely, TenneT is affected by two (related) conditions.

- TenneT operates a significantly older grid than its peers, and many of its assets reached the end of their economic life in 2013–17.[9] Both operational rationale and statistical evidence on the TCB18 data suggest that maintenance costs (and thus OPEX)[10] increase with increased asset age, yet no cost driver in Sumicsid's model accounts for this (NormGrid decreases with asset age, while transformer power and weighted lines are invariant to asset age) and no cost normalisation was considered to account for this. Thus, the benchmarking model could bias efficiency estimates against TSOs with relatively older grids. This issue is particularly relevant for TenneT as its peers operate significantly younger assets (and therefore do not suffer from this issue compared with TenneT). To account for this issue,

[7] There is a risk that increasing the transformer power variable without adjusting TOTEX for the increased costs associated with these assets could lead to a bias in the opposite direction. To account for this, we also consider increasing the affected TSOs' TOTEX based on this issue. This additional adjustment has no material impact on TenneT's estimated efficiency relative to adjusting the transformer power variable alone.
[8] See section 3 for details of this calculation.
[9] Oxera analysis of TCB18 data.
[10] Based on analysis of TCB18 data, maintenance costs account for approximately 66% of TenneT's benchmarked OPEX, compared with 41–60% for its peers.

we include an additional cost driver representing the NormGrid value of overage assets (i.e. assets that are older than their 'techno-economic lifetimes').

- Average investment costs (defined as real CAPEX per unit of NormGrid) have been increasing at a rate of approximately 1.5% p.a. since 1973. This is driven by many factors, including new regulatory requirements on assets, increased routing complexity due to infrastructure density, and increased input prices. As Sumicsid did not undertake any normalisations to account for these cost pressures,[11] the benchmarking model is biased against TSOs (such as TenneT) that undertook significant investments in recent years. We apply a correction to CAPEX for all TSOs to account for this trend in investment costs.[12]

Although the two issues outlined above relate to the age of a TSO's network, they are independent of each other. The former accounts for age effects on maintenance expenditure (OPEX) for specific assets, while the latter addresses the observed increased cost of investment (CAPEX), which relates to the overall profile of investments.

We find that the observed drop in TenneT's estimated efficiency under Sumicsid's model is largely accounted for after applying adjustments for asset age and investment costs.[13] **TenneT is estimated to be 100% efficient in 2013–15 and 93.6–97.5% efficient in 2017**. Sensitivity analysis suggests that this result is robust to small changes to how overage assets are defined, and to adjustments accounting for rising investment costs.

3. TCB18 does not appropriately capture the impact of population density on TSOs' expenditure.

As a TSO's main task consists of transporting energy across its service area, the features of the service area environment, such as land use, climate and topography, can be a significant driver of its costs. Population density is one of the most important and commonly considered manifestations of this topographical dimension. That population density drives up costs is recognised by many regulators and was also recognised by Sumicsid in the predecessor study, e3grid,[14] where a measure of density was included as a separate cost driver in the DEA model.

In contrast, the environmental adjustment in TCB18 is restrictive and unsubstantiated.[15] The cost impact of density forms a small proportion of the overall environmental complexity weight; the weight is largely based on the share of a TSO's service area covered with forests. We are not aware of any claims submitted as part of TCB18 or e3grid or any other literature that

[11] The annuity approach to measuring CAPEX is intended to account for the impact of investment timing. However, for the annuity approach to truly account for investment timing, the real price of assets needs to be constant through time. As Sumicsid has only deflated CAPEX based on a measure of consumer prices (rather than investment prices), its approach does not guarantee that real investment costs are constant.
[12] See section 3.2 for details of this adjustment.
[13] Note that this is incremental to the transformer power adjustment outlined above.
[14] Sumicsid, Frontier Economics, Consentec (2013), 'E3GRID2012 – European TSO Benchmarking Study A REPORT FOR EUROPEAN REGULATORS', July.
[15] As noted in our main report, NormGrid was either ignored or given a small weight in determining most TSOs' efficiency scores (see Oxera (2020), 'A critical assessment of TCB18 electricity', April, figure 5.4), thereby attenuating the cost impact of Sumicsid's environmental complexity adjustment (even ignoring the general inappropriateness of this adjustment).

supports the assumption that forests are the main driver of environmental complexity for European electricity TSOs.

Moreover, statistical analysis on the data indicates that the composite complexity weight used by Sumicsid is a poor reflection of overall environmental complexity. TSOs with lower costs per NormGrid receive higher environmental adjustments on average. This is unintuitive, as we would expect TSOs operating in more difficult environments to have to spend more to overcome these difficulties, and therefore to have higher unit costs.

Not only is the environmental complexity factor inappropriate, it is also biased against densely populated TSOs such as TenneT, as the share of area covered in forest is negatively correlated with population density in the sample.

We consider two approaches to appropriately capture the impact of density on efficient TOTEX. In the first approach, we include the density variable that Sumicsid used in e3grid2012[16] (i.e. the total area with population density at 500 people/km^2 or above) as a separate cost driver. We also test sensitivities regarding the exact threshold use to ensure that the result is robust. In the second approach, we include a version of the density variable that Sumicsid used in TCB18, defined as the total area service by a TSO that is 'urban' or 'infrastructure', as a separate cost driver. Controlling for environmental complexity as a cost driver is more aligned with regulatory precedent and academic literature than making adjustments to other outputs, as Sumicsid has done.[17]

If the cost impact of population density is effectively captured in the model, TenneT is consistently estimated to be 94.3–100% efficient in 2017 and in earlier years. We also observe that TenneT is estimated to be operating close to 100% efficient even if the cost impact of density is restricted in line with the approach used in e3grid (i.e. if weight restrictions are considered).[18] If the asset age and investment timing issues are also accounted for in the data/model, TenneT is consistently estimated to be 100% efficient in all years.

Accounting for data uncertainty

As highlighted in our main report, there is a significant amount of uncertainty arising from data and modelling errors, and this uncertainty is not accounted for in Sumicsid's deterministic application of DEA. Therefore, in line with the recommendations of our main report, we validate the DEA results using stochastic frontier analysis (SFA) and a Monte Carlo simulation for each adjustment described above. These methods indicate that **significant data uncertainty persists** even after these adjustments to the data and model specification, and a large upward adjustment to the estimated efficiency scores is needed to account for this.

[16] Sumicsid (2013), 'E3GRID2012 – European TSO Benchmarking Study', July, p. 4.
[17] Note that the adjustment for environmental factors is incremental to the transformer power adjustment, but does *not* include adjustments for asset age or investment costs.
[18] Specifically, TenneT is estimated to be 97.5% efficient when the weight on density is restricted to be 10% of the weight on other outputs *without* making adjustments for asset age or investment costs. The restriction is always imposed with respect to a single output; all three other outputs were tested and the maximum score obtained was assigned to a TSO. Restricting the weight on density to be 10% of the weight on other variables is slightly more stringent than the weight restrictions in e3grid2012, where the weight on NormGrid was allowed to vary between 8.5 times and 25.4 times the weight on density. See Sumicsid, Frontier Economics, Consentec (2013), 'E3GRID2012 – European TSO Benchmarking Study A REPORT FOR EUROPEAN REGULATORS', July, p. 93.

Summary of our assessment

If the bias in the capacity proxy, the impact of investment timing and asset age and population density are sufficiently addressed on the TCB18 data, following Sumicsid's benchmarking procedure leads to the conclusion that **TenneT is consistently estimated to be 100% efficient over the assessment period of 2013–17**. Given the considerable uncertainty in the data, there is insufficient evidence to conclude that TenneT is not 100% efficient, even in the models where TenneT's is estimated to be less than 100% efficient.

This suggests that the highlighted issues resulted in a significant underestimation of TenneT's efficiency by Sumicsid (71.5%) and the ACM (74.5%).

It is important to note that we have not explicitly addressed many of the issues highlighted in our main report, which led us to conclude that the estimated efficiency scores and suggested cost savings calculated in TCB18 are not robust. Analysis presented in this report supports the conclusion in our main report, that the estimated efficiency scores in TCB18 cannot be interpreted as 'true' differences in efficiency. We consider that even if the improvements suggested in this report were taken into account, further research is required to address the fundamental issues with Sumicsid's analysis.

1 Introduction

1.1 Summary of TCB18

The transmission cost benchmarking project (TCB18) was a study undertaken by the Council of European Energy Regulators (CEER), participating national regulatory authorities (NRAs) and a consultancy, Sumicsid, to assess the cost performance of European transmission system operators (TSOs). The electricity study covered 17 TSOs from 15 countries, including TenneT.

Sumicsid uses data envelopment analysis (DEA) to estimate the efficiency of the TSOs. DEA uses linear programming to estimate the minimum level of inputs needed for a unit (e.g. a TSO) to produce its outputs given the inputs and outputs for all other units. Efficient units would be those for which no better performing unit (actual or composite of efficient units) could be identified in the dataset. Naïve applications of DEA are deterministic, meaning they do not account for statistical noise (e.g. certain types of data or modelling uncertainties) explicitly when estimating the efficiency frontier and the inefficiency with respect to this.

A robust DEA application involves (i) defining appropriate input variables; (ii) developing a set of output variables (i.e. cost drivers) that explain differences in efficient inputs in the sample; (iii) ensuring potential outlier units do not have an undue influence on the efficient frontier; (iv) testing whether the assumptions that feed into the model are appropriate; and (v) robustly validating the final model and the DEA results.

Cost construction

Sumicsid constructs its input variable (total expenditure, TOTEX) as the sum of operating expenditure (OPEX) and capital expenditure (CAPEX) that are subject to different normalisations. OPEX is calculated on an annual basis and direct manpower costs are adjusted using a price level index (PLI) for civil engineering to account for different labour costs across the TSOs. Some cost items within OPEX are not part of the assessment.[19]

CAPEX, meanwhile, is calculated using the annuity approach, whereby the cost of an investment in an asset is spread over the asset's economic life. Sumicsid makes no adjustment to the investment data to account for differences in input prices.

All costs are converted to 2017 prices using country-specific consumer price inflation (CPI) and into euros using the average exchange rate in 2017.

Cost driver construction

Sumicsid uses three variables ('cost drivers') to account for differences in scale and operating environments across TSOs. These are defined as follows.[20]

- **Normalised grid (NormGrid).** This variable is a measure of the assets deployed by TSOs to meet their service obligations. Sumicsid describes it as 'Totex relevant proxy for the total power system'.[21] It is calculated as the

[19] The cost items include costs that are uncontrollable or out-of-scope and include energy costs, landowner compensation, right-of-way and easement fees, taxes and levies, depreciation, research and development and the rent of the main office building.
[20] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators MAIN REPORT', July, p. 32.
[21] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators MAIN REPORT', July, p. 33.

weighted sum of assets, where the weights are derived through operational and statistical analysis.

Environmental adjustment for Land-use complexity. This is a measure of the environmental complexity of a TSO's service area. It is intended to capture topographical features of environmental complexity. It is not included as a separate driver of expenditure in the model but is instead used to adjust the NormGrid variable.

- **Transformer power.** This is defined as the sum of the power of all transformers owned by a TSO, and is intended to be a proxy for the capacity of a TSO's network.
- **Weighted lines.** This is the total length of lines owned by a TSO multiplied by the share of angular towers and share of steel towers. It is intended to be a proxy for routing complexity.

While it is unclear from the main report how these drivers and the environmental adjustments were selected, Sumicsid notes in some workshop slides that it has used econometric analysis to inform them.

Returns to scale

'Returns to scale' relates to how changes in outputs (e.g. NormGrid) are linked to associated changes in inputs (e.g. TOTEX) for efficient companies, and the returns-to-scale assumption is one of the key steps in applications of DEA. In this respect, there are typically two assumptions that are made: constant returns to scale (CRS) and variable returns to scale (VRS). Under CRS technology, an increase in output of, say, 5% is associated with a 5% increase in efficient TOTEX. Under VRS technology, a 5% increase in output can be associated with a greater than, equal to, or less than 5% increase in TOTEX, depending on whether decreasing, constant, or increasing returns to scale prevail.

Sumicsid assumes a non-decreasing returns to scale (NDRS) technology in TCB18, whereby increasing returns to scale prevail when scale size is small, but constant returns to scale prevail beyond a certain scale. Sumicsid states that this assumption is supported by statistical evidence, but does not provide this evidence in the final outputs.

Outlier detection

Sumicsid's application of DEA is deterministic. That is, it takes no account of statistical noise when estimating the efficient frontier or individual efficiency scores. To mitigate the impact of outliers, Sumicsid follows the same approach as the Bundesnetzagentur (in the second regulatory period) as outlined in the German Incentive Ordinance (ARegV). Specifically, it conducts a dominance and super-efficiency test to detect outliers. These tests are defined as follows.

- The aim of the **dominance test** is to identify TSOs that exert a substantial influence on the efficiencies of other TSOs. The test conducted by Sumicsid compares the average estimated efficiency in the full sample with the average efficiency calculated after excluding the potential outlier from the sample. The test relies on a number of assumptions, including a half-normal distribution of inefficiencies and independent samples, but Sumicsid does not provide evidence to suggest that these assumptions are met.[22]

[22] Indeed, the samples are not independent by construction.

- The aim of the **super-efficiency test** is to identify companies that are significantly more efficient than the rest of the sample. Sumicsid identifies a TSO as an outlier if its efficiency score assessed relative to the rest of the companies exceeds the third-quartile efficiency value by more than 1.5 times the interquartile range of efficiency values.

Second-stage validation

Sumicsid carries out second-stage analysis to test whether any relevant cost drivers have been omitted in the first-stage model used for efficiency estimation. Our understanding is that Sumicsid regresses the estimated efficiency scores from its DEA model against potentially omitted variables (such as asset age), although the exact method of estimation is not clear from its final outputs.[23] If the estimated coefficient on the omitted variable is statistically insignificant, Sumicsid states that it is 'already considered in the model and do[es] not merit specific post-run corrections'.[24]

Empirical results

The TCB18 study concludes that European TSOs have significant scope to improve their relative efficiency and operate at lower overall costs. Sumicsid estimates the average inefficiency in the sample to be 10.2%, and TenneT's inefficiency to be 28.5%. This implies that TenneT can reduce its expenditure by €92m while maintaining its level of service.

Subsequent to the publication of TCB18, TenneT highlighted several issues to the ACM, including an error in Sumicsid's construction of the environmental complexity factor that reduced TenneT's estimated efficiency score.[25] Based on Oxera analysis, we understand that a correction of this error would improve TenneT's estimated efficiency from 71.5% to 74.5%, and the implied cost reduction target from €92m to €82m.

1.2 Oxera assessment of TCB18 electricity

All TSOs that participated in TCB18 electricity, including TenneT, commissioned Oxera to validate and review the results from TCB18, and to recommend robust solutions to issues that emerged. This multi-year process resulted in our assessment of TCB18, which was published in April.[26] We presented the findings to the ACM on 5 June 2020.[27]

In this review we identified a number of significant issues with Sumicsid's analysis. Here, we summarise these under four themes, as follows.

Transparency

- An overarching theme in the TCB18 study is Sumicsid's lack of transparency, which falls significantly short of what would be considered good practice. Sumicsid's outputs do not contain the necessary information for third parties to clearly follow its analysis, replicate its analysis, or offer constructive solutions without considerable effort. We proposed several mechanisms through which Sumicsid could have aided better transparency

[23] We understand that Sumicsid stated in a workshop that ordinary least squares (OLS) was used.
[24] Sumicsid (2019), 'Project TCB18 Individual Benchmarking Report TenneT – 187', July, p. 35.
[25] Specifically, the ACM acknowledged that Sumicsid's treatment of the 'other land-use' category was inappropriate and underestimated the environmental complexity faced by TenneT.
[26] Oxera (2020), 'A critical assessment of TCB18 electricity', April.
[27] Oxera (2020), 'A critical assessment of TCB18 electricity – presentation to ACM', June.

while maintaining data confidentiality, such as the sharing of anonymised modelling codes and describing its analysis in more detail.

Data collection and construction

- The dataset from which the cost model was derived contains multiple data errors and inconsistencies that have a material impact on the shape of the efficient frontier and the estimated efficiency of all TSOs. For example, some the TOTEX data for one company was overestimated by approximately 30%. Based on these errors alone, four TSOs that are classed as inefficient by Sumicsid may be peers.
- Sumicsid's decision to model total expenditure (TOTEX) as a single input assumes a strict, one-to-one trade-off between operating expenditure (OPEX) and capital expenditure (CAPEX). This is inappropriate as OPEX and CAPEX are subject to different normalisations and adjustments, which implies that a one-to-one trade-off is unlikely to be realistic. Modelling OPEX and CAPEX as separate inputs can increase the efficiency of some TSOs by up to 17 percentage points.
- Sumicsid only normalises 5.9% of the total cost base for differences in price levels, and thus risks conflating uncontrollable differences in macroeconomic environments with inefficiency.

Model development

- Sumicsid's approach to model development is not clearly explained in its final report. Moreover, its sole reliance on asset data as cost drivers rather than the outputs that TSOs produce, its limited statistical analysis and non-validation of outputs and modelling assumptions, and the sensitivity of its model to small changes in the modelling result in an insufficiently validated model.
- The estimated relationship between costs and cost drivers is highly sensitive to the sample on which the model is estimated, as are the resulting efficiency scores. For instance, depending on the exact sample, two of Sumicsid's three cost drivers can exhibit a negative relationship with costs in econometric modelling. This is inconsistent with DEA, where cost drivers are assumed to increase costs.
- Sumicsid completely relies on three asset-based measures without any validation with pure outputs (such as peak load per grid level) or alternative asset-based measures. Our analysis shows that TSOs estimated efficiencies are highly sensitive to which asset-based measure is used. For instance, if assets are not aggregated into a single NormGrid variable, but considered as separate outputs, TenneT would be estimated as fully efficient (i.e. its estimated efficiency would be increased by 28.5%).

Application and validation

- The assumptions that feed into the model estimation are not well-justified or robustly tested. Sumicsid's reliance on the outlier procedure used in German energy regulation is unsubstantiated, as that procedure is not sufficient in an international benchmarking context. The outlier procedure is also subject to flaws and unlikely to be able to detect potential outliers. Where alternative and scientifically appropriate outlier tests are applied, we find that some TSOs' estimated efficiencies can increase by up to 17%.

- Sumicsid's reliance on second-stage validation (which is a flawed procedure) and lack of validation of the DEA outputs shows that the TSOs' estimated efficiencies remain unvalidated. For example, Sumicsid states that NormGrid is the primary driver of expenditure, yet most TSOs' efficiency scores are not primarily driven by NormGrid.
- Importantly, Sumicsid has not cross-checked the results of its analysis using well-established alternative methods such as stochastic frontier analysis (SFA),[28] despite having a panel of data available.[29] When applied to Sumicsid's model and dataset, SFA suggests that there is no statistically significant inefficiency among the TSOs.

Conclusion of our review of TCB18

Our review of TCB18 concludes that although international benchmarking **can be a powerful tool** for companies and regulators to assess the efficiency of network operators (especially in the context of electricity transmission, where the sector is often characterised by national monopolies), the TCB18 study itself suffers from a **number of significant flaws**, some of which are **fundamental**.

Therefore, while we welcome projects such as TCB18, which have attempted to develop a framework for periodic assessment of TSOs, the flaws in TCB18 highlighted in our review and throughout this report mean that the estimated efficiency scores and suggested cost savings are not robust—and, in some cases, are biased. They can **thus not be used for regulatory, operational or valuations purposes in their current form.**

1.3 Context of this report

From our assessment summarised above, it is clear that many of the issues that Oxera has highlighted—such as the data errors, the ex-ante focus on asset-based cost drivers, the lack of iterative model development procedures, and lack of transparency—will continue to affect all results derived from TCB18, including the analysis presented in this report. While these issues can be remedied in a future benchmarking exercise, they cannot be robustly solved without significant additional research. If the ACM were to consider it to be appropriate to use results from TCB18 for TenneT, given regulatory timelines, we do not consider that would be feasible to undertake an entirely new benchmarking analysis. Thus, we do not elaborate on many of the issues that we identified in the main report.[30]

Instead, we focus on a subset of specific issues that systematically bias TenneT's estimated efficiency. We tackle these in the subsequent sections as follows.

[28] SFA is an econometric approach to benchmarking regulated companies. For a more detailed discussion on SFA, see Kumbhakar, S. and Knox Lovell, C.A. (2000), *Stochastic Frontier Analysis*, Cambridge University Press, Kumbhakar, S.C, Wang, H-J and Horncastle, A. P. (2015), *A Practitioner's Guide to Stochastic Frontier Analysis Using STATA*, Cambridge University Press, and Deuchert, E. and Parthasarathy, S. (2018–19), five-part series of articles on the German energy regulator's benchmarking framework covering efficiency methods (DEA and SFA), functional form assumptions, cost driver analysis, outlier analysis and model validation, *ew–Magazin für die Energiewirtschaft*.
[29] A panel dataset contains data over time across TSOs and thus contains more information than a single year of data.
[30] These issues include (but are not limited to): (i) Sumicsid's handling of data errors; (ii) Sumicsid's arbitrary restriction of cost driver candidates to asset-based measures; (iii) Sumicsid's returns-to-scale assumption; and (iv) Sumicsid's outlier procedure.

- The capacity proxy in TCB18 is based on TSOs ownership of transformers. Due to different ownership structures, a significant bias is introduced in this proxy (section 2).

The failure to account for asset ownership is a fundamental data issue. As such, adjustments for subsequent issues are considered on an incremental basis to it.

- The construction of costs and cost drivers make the results sensitive to the age of network (section 3.1) and the timing of investments (section 3.2).
- The way in which Sumicsid accounts for environmental complexity is unjustified, insufficient and unintuitive (section 4).

As the issues we examine in this report are fundamental and significant in nature, one should ideally repeat the model development procedure after suitable adjustments to the data and model specification on each issue. However, there are several fundamental issues with Sumicsid's analysis (as detailed in our main report), which severely limits this option. Hence, we focus on quantifying the impact of these specific issues under Sumicsid's model specification and estimation procedure (including following its flawed outlier procedure) after suitable adjustment.

We also implement some of our recommendations on validation of the outputs to account for data and modelling uncertainties. Building on our main report, we use two established statistical methods to inform an appropriate 'margin of error' adjustment for the uncertainties, including the following.

- **Monte Carlo simulations** for statistical noise. As per the recommendations outlined in our main report,[31] we add a 10% random error component to all costs and cost drivers and re-estimate the model a sufficiently large number of times (in our case, 1,000 times) to derive a distribution of efficiency scores for TenneT. This will demonstrate the impact of small[32] data/modelling errors on TenneT's performance, and therefore the sensitivity of the analysis to these apparent uncertainties.
- We cross-check the results using **SFA**. Not only can this give an indication of the amount of statistical noise in the sample, SFA can also be used to assess whether cost drivers have an operationally intuitive relationship with expenditure.

[31] Oxera (2020), 'A critical assessment of TCB18 electricity', April, section 3.1.3.
[32] We consider the 10% random error to be small relative to the known data errors in the sample. For example, a data error in a TSO's CAPEX overstated its TOTEX by 32%; for another TSO, the value of weighed lines is overstated by 27%. See Oxera (2020), 'A critical assessment of TCB18', April, p. 35.

2 The capacity provision proxy

2.1 Issues with Sumicsid's approach

Sumicsid used asset-based measures as cost drivers in TCB18. For the NormGrid variable, the assets themselves are considered the output.

For the remaining outputs, capacity provision and routing complexity, Sumicsid also restricts itself to the use of asset-based cost drivers (transformer power and weighted lines, respectively) and does not consider the actual outputs delivered or services provided to consumers. Sumicsid states that transformer power and weighted lines are highly correlated with outputs.[33]

The use of asset-based measures in benchmarking can have certain advantages over 'pure' outputs that TSOs are responsible for. For example, outputs such as 'peak energy demand' can be volatile, while asset characteristics are relatively constant (and as such, the year of assessment should make less of an impact). Nevertheless, the specific asset-based measures must be robustly justified using both operational reasoning and empirical evidence, or a situation may arise in which the benchmark is biased towards a particular asset-based solution, regardless of the true efficiency of the solution.

For example, a TSO facing increasingly volatile energy supply due to increased generation from renewable sources of energy may consider two solutions with similar levels of investment: one that involves investment in assets to increase network capacity, and one that involves investment in software to manage energy supply and demand. The former solution will materially increase the size of the asset base, while the latter will not. A TSO choosing the latter solution will therefore be disadvantaged in a model that controls for assets.

A similar issue may arise with regards to ownership structure—asset-based measures will always benefit those TSOs that own the assets that are used as outputs. Others who still face similar levels of an output but chose other solutions (e.g. non asset-based or assets owned by third parties) will thus be put at a disadvantage.

Therefore, when asset-based measures are used, in addition to statistical evidence on the overall validity of the correlation claim, it needs to be ensured that the construction of the proxy variable makes the TSOs structurally comparable and does not bias the analysis in favour of some TSOs at the expense of others. In the present case, Sumicsid did not present any such analysis to validate its approach.

2.2 Critique

The transformer power variable is calculated as the sum of the power capacity of all transformers owned by the TSO. Therefore, it underestimates the capacity provided by TSOs that do not own all the transformers connected to their network. This issue arises especially if the DSOs own some of the transformers connected to the TSO's network.[34] If the share of connected transformers owned by a TSO is not (approximately) equal among the TSOs in the sample, the capacity proxy would be a biased measure of capacity

[33] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators main report', July, section 5.05.
[34] A similar issue may arise if large customers own a disproportionate share of transformers.

provision. Box 2.1 explores the different grid ownership structures in the TCB18 sample in more detail.

Box 2.1 Different ownership structures present in the sample

In general, the electricity grid can be sub-divided into three 'levels': the ultra-high voltage grid (UHV-grid), high voltage grid (HV-grid) and the medium-low voltage grid (MLV-grid). These three levels are connected through transformers.

While all TSOs operate UHV-grids and independent DSOs generally own the majority of MLV-grids, there is some heterogeneity in the sample regarding the ownership of the HV-grids and the bordering transformers between the HV-grid and the MLV-grid.

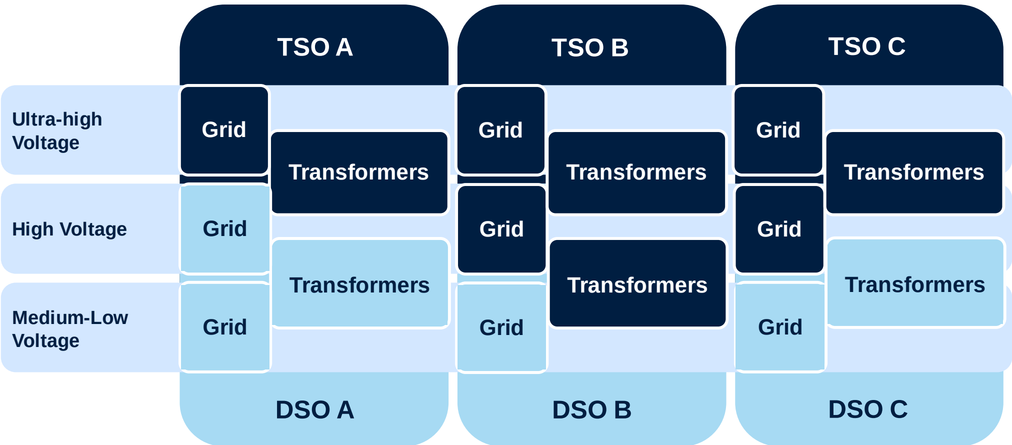
Broadly, the sample can be sub-divided into three groups based on the ownership of these transformers, as illustrated in Figure 2.1.

- **TSO A:** Four TSOs own only the UHV-grid and the bordering transformers to the DSO-owned HV-grid.
- **TSO B:** eight TSOs own both UHV-grids, HV-grids as well as bordering transformers between the HV-grid and MLV-grid.
- **TSO C:** Five TSOs (including TenneT) own both the UHV-grid and the HV-grid but not the bordering transformers between the HV-grid and MLV-grid.

The TSOs in the latter group provide capacity (and thus incur costs) for HV-grid assets, but this is not captured by Sumicsid's 'transformer power' variable. This omission creates a disconnect between the costs a company incurs and the cost drivers it is credited for, and therefore biases the efficiency score estimated in Sumicsid's model.

Source: Oxera analysis.

Figure 2.1 Asset ownership structure of TSOs

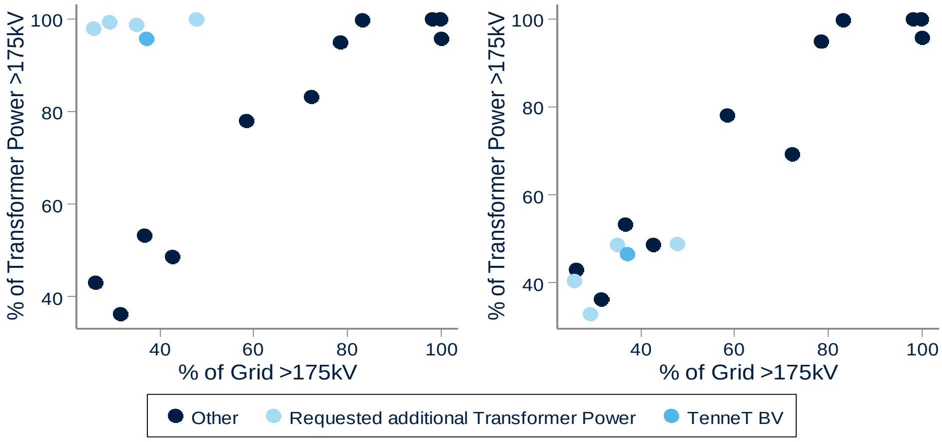


Note: TenneT is included in the TSO C category.

Source: Oxera analysis.

The empirical issue in the TCB18 dataset is demonstrated in Figure 2.2 below.

Figure 2.2 Share of assets in UHV-grid



Source: Oxera analysis of TCB18 data.

Figure 2.2 shows that the share of the grid (measured by line length) at the UHV level varies between 25.8% and 100% in the TCB18 sample. The chart on the left shows that with the exception of the five TSOs affected by the bias, there is a strong correlation between the proportion of UHV lines and the proportion of transformers with a primary voltage of more than 175kV. These five unusual TSOs are in the third category of TSOs that do not own the bordering transformers.[35] For instance, TenneT's HV-grid is substantially longer than its UHV grid, yet only 4% of transformer power owned by TenneT is at the HV level.

The chart on the right shows the relationship between the proportion of UHV lines and the proportion of transformers with a primary voltage of more than 175kV when the transformers' data is corrected to account for the ownership structure. All five affected TSOs are now broadly in line with the rest of the sample.[36] After applying the adjustment, TenneT's share of transformers at the UHV level decreases to 47%. This demonstrates that although this is not an issue that is unique to a single TSO, the differences between TSOs due to this obvious ownership structure and data issue can bias the results. Since the transformer power of these TSOs will always be lower than expected, it is unlikely that any comparison based on transformer power will be favourable.

The presence of significant data issues such as these reinforces the general data issues identified in our assessment of TCB18,[37] and demonstrates that these data issues can have a significant impact on the efficiency scores of individual TSOs.

The issue of differing ownership structure of grid levels is not unique to TCB18. For example, a similar issue occurs in the benchmarking of German electricity DSOs. Benchmarked DSOs may own a HV grid a MLV grid or both. Therefore, the German Energy regulator, Bundesnetzagentur, uses two measures of peak load (a pure output measuring capacity provision) in its assessment of DSOs relative efficiency: one for the peak load at the MLV-level and one for the peak

[35] This was confirmed through correspondence with the TSOs. All 17 TSOs were contacted for comment, and five (including TenneT) indicated that the relevant transformer output was indeed missing from the data.
[36] The predictive power is illustrated by the R-squared. Adjusting transformer power for the affected TSOs increases R-squared from 0.19 to 0.92.
[37] See Oxera (2020), 'A critical assessment of TCB18 electricity', April, section 3.1.

load at the HV-level. Such an approach should also have been considered by Sumicsid to account for this ownership structure.

Beyond the specific issue of asset ownership, transformer power is only one measure of capacity provision. There is no evidence in the outputs of TCB18 that this variable has been validated against alternative asset-based measures of capacity, or appropriate non-asset-based measures of capacity.[38]

2.3 Quantification of the bias and proposed adjustment

In our correspondence with TSOs we requested an estimate as to how much transformer power in bordering transformers is owned by DSOs and thus 'missing' from Sumicsid's capacity variable.[39] We then adjust the transformer power variable by adding the TSOs' estimates of 'missing' capacity. Accounting for this, TenneT is estimated to be 84.0% efficient in 2017.[40]

While this approach addresses the obvious data inconsistencies in the sample, it is itself subject to limitations. Ideally we would like to add the additional expenses associated with these transformers. However, as these assets are not owned by the TSOs, the cost associated with them (incurred by the DSOs) is not necessarily equal to the expenditure that a TSO would incur by owning these assets. To identify the potential impact of additional expenditure, we calculated two adjustments to TOTEX: one based on the additional capacity indicated and one based on the additional capacity indicated, as well as the costs per NormGrid of the TSOs.[41] These sensitivities suggest that TenneT's estimated efficiency is robust to the changes in TOTEX for the affected companies.[42]

We present the full results of these sensitivities for all years in Table 2.1.

Table 2.1 DEA efficiency estimates—adjusted transformer power

Adjustment to account for ownership of transformers	2013	2014	2015	2016	2017
No adjustment to TOTEX	96.5%	85.2%	88.4%	88.8%	84.0%
Added TOTEX based on incremental transformer power	97.3%	89.5%	89.2%	90.8%	84.6%
Added TOTEX based on incremental transformer power and TSO's overall 'unit costs'	97.0%	89.1%	88.6%	90.5%	84.1%

Source: Oxera analysis of TCB18 data.

[38] To account for limitations of using peak load as a cost driver (e.g. potential volatility), adjustments to the data will be required (such as taking a long-term average of peak load).
[39] We cannot independently verify the estimate of missing transformer power given by the TSOs. However, we note that the adjusted transfer power data is more aligned with operational expectations than the transformer power data used by Sumicsid (see Figure 2.2).
[40] Note that TenneT's estimated efficiency score steadily reduces from 96.5% in 2013 to 84.0% in 2017. The causes of this deterioration in estimated efficiency are related to maintenance activity and rising investment costs. This is discussed in detail in section 3.
[41] Specifically, we multiply TOTEX by a factor of $1 + \frac{Additional\ Transformer\ Power}{Owned\ Transformer\ Power} * \frac{NormGrid\ (Transformers)}{NormGrid\ (overall)}$ and $1 + \frac{Additional\ Transformer\ Power}{Owned\ Transformer\ Power} * \frac{NormGrid\ (Transformers)}{NormGrid\ (overall)} * \frac{TOTEX}{NormGrid}$
[42] In fact, TenneT's efficiency increases slightly if these costs are added to the TOTEX variable. This is because TenneT's peers in this model are also affected by this issue, and therefore also receive an upward adjustment to TOTEX. Note that in adjusting the TOTEX variable we did not add the equivalent amount of NormGrid, thus this is a conservative estimate of TenneT's efficiency under additional TOTEX.

To address the uncertainties surrounding this adjustment, we also constructed an alternative measure of capacity provision based on the sum of the power of circuit ends owned by TSOs. This variable is more consistently associated with grid assets than Sumicsid's transformer power variable, and does not suffer from the same issues regarding ownership structure as transformers.[43] Based on this proxy of capacity, TenneT is estimated at 99.7% efficient in 2013 and 91.2% efficient in 2017, indicating that the analysis based on adjustment to the transformer power variable may underestimate TenneT's efficiency score. That is, the adjustments to transformer power data present a conservative estimate of the bias in the capacity provision proxy in TCB18.

Table 2.2 DEA efficiency estimates—power of circuit ends

Adjustment to account for ownership of transformers	2013	2014	2015	2016	2017
Using circuit end power as an alternative output	99.7%	95.7%	97.6%	100%	91.2%

Note: The results presented here are slightly different than those presented in the main report (Oxera (2020), 'A critical assessment of TCB18 electricity', April, Figure 4.3), due to an issue in the calculation of circuit ends data that was discovered as part of our quality assurance.

Source: Oxera analysis of TCB18 data.

A Monte Carlo simulation indicates that we cannot say with 95% confidence that TenneT is less than 99% efficient using the adjusted transformer power measure or less than 100% using the power of circuit ends in 2017.[44] This suggests that **almost the entire efficiency gap opening up in 2013–17 could be due to statistical noise**.

We also estimated SFA models for the model specifications outlined above. These are presented in Table 2.3 below.

[43] TCB18 Circuit Ends data suffers from data errors with respect to the amounts of identical circuit ends installed. We correct for these errors as part of this sensitivity.
[44] Note that this statement assumes that once network capacity is adequately accounted for, there are no remaining features of the modelling that systematically bias the results against TenneT. As we demonstrate in sections 3 and 4, this assumption is incorrect.

Table 2.3 SFA results

	Sumicsid's model	Adjusted transformer power	Circuit end power
NormGrid (area)	0.609***	0.545***	0.717***
Weighted lines	-0.0186**	-0.0200***	0.0133**
Transformer power	0.584***		
Transformer power (adjusted)		0.733***	
Power of circuit ends			0.239***
Constant	1.140	0.498***	1.138
Observations	81	81	81
Adjusted R-squared (OLS)	0.882	0.897	0.885
Statistically significant inefficiency	No	Yes	No
Converged	Yes	Yes	Yes
Chi-bar test statistic	1.111	35.91	1.267

Note: All data is in logarithms.

Source: Oxera analysis of TCB18 data.

In line with the results in our main report,[45] we do not detect any statistically significant inefficiency using Sumicsid's transformer power variable or the circuit end power variable, which means that the model cannot distinguish between statistical noise and inefficiency. However, we observe statistically significant inefficiency in the model specification with adjusted transformer power as a capacity proxy (the second column). Importantly, the coefficient on weighted lines has a negative sign and is statistically significant. There is no operational explanation for this, and the efficiency scores derived from this model are therefore not informative in their current state.[46]

The SFA model not finding statistically significant inefficiency or exhibiting unintuitive coefficients is not a reason to simply use DEA efficiency scores, thereby ignoring the problems of model specification and data uncertainty. Rather, it suggests that caution is warranted against interpreting any estimated inefficiency in the DEA model as actual inefficiency rather than statistical noise, and/or that the model's specification should be reconsidered. This also supports the results of the Monte Carlo simulations, indicating that there is significant uncertainty with respect to TenneT's estimated efficiency.

The failure to appropriately account for asset ownership when constructing the proxy variable for capacity provision is a basic data issue and, as such, all of the analysis presented in the rest of this report is incremental to this adjustment. Specifically, we use the adjusted transformer power data with no adjustments to TOTEX as this appears to be the most conservative estimate of the bias induced by this issue. That is, it gives TenneT the lowest efficiency score when compared with the other adjustments to account for this issue.

[45] Oxera (2020), 'A critical assessment of TCB18 electricity', April, section 5.3.3.
[46] A negative coefficient indicates that, all else equal, a TSO with a higher value of weighted lines is expected to have less TOTEX. We note that Sumicsid does not appear to consider whether the results of its econometric analyses are operationally valid. For example, in the TCB18 gas study, the estimated coefficients on two of the four cost drivers are negative (see Sumicsid (2019), 'Project TCB18: Individual Benchmarking Report Energinet.dk - 214 ', July, Table 3.1).

3 Maintenance and investment activity

After addressing the bias in the capacity provision proxy, TenneT is estimated to be nearly 100% efficient in 2013. However, an estimated efficiency gap of 15–16% opens up for TenneT from 2013 to 2017. In addition to this, the technical change or frontier shift in the TCB18 sample for the same time period is estimated at -3.9%, meaning that *efficient* costs *increased* at 3.9% p.a. in real terms over the period.[47] In combination, this implies that TenneT's individual productivity has decreased at 5.9% p.a. from 2013 to 2017.[48] While the Monte Carlo simulations indicate that this gap could be a result of statistical noise unaccounted for in Sumicsid's analysis, it is also clear from the data that TenneT's expenditure increased during this period.

Specifically, according to TCB18 data, in-scope (i.e. costs subject to benchmark) OPEX increased by 13%, while in-scope CAPEX increased by 46%. As outlined in Table 3.1 below, the estimated regress of 5.9% suggests that 91.2% of the increase in TOTEX was due to inefficiency. This would mean that the entire increase in OPEX and nearly 90% of TenneT's CAPEX since 2013 have been inefficient.[49]

Table 3.1 Efficiency of TOTEX increases

	2017 data	2013 data	Difference
TOTEX (A)	321,242,361	246,639,367	74,602,994
Estimated TOTEX efficiency relative to 2013 frontier (B)[1]	76.1%	96.5%	
Efficient TOTEX (A*B)	244,593,934	238,006,990	6,586,944
Share of increase deemed efficient			**8.8%**

Note: All efficiency scores presented here include an adjustment to the transformer power data. [1] The numbers presented here show TenneT's efficiency score when the efficient frontier is estimated using data from 2013 only.

Source: Oxera analysis of TCB18 data.

The results are likely related to two additional issues in the TCB18 benchmarking data.

1. TenneT operates a significantly older grid than any of its peers, with an average age of 32 years in 2017 compared to 22–27 years for its peers. As assets age, they typically require more frequent maintenance, and therefore the OPEX associated with these assets increases. This effect is not captured in the present benchmarking model.[50] We address this issue in section 3.1.

[47] Sumicsid (2020), 'PROJECT CEER-TCB18 - Dynamic efficiency and productivity changes for electricity transmission system operators - MAIN REPORT', section 3.08, April.
[48] This is calculated by comparing the data for TenneT in year t and estimating the efficiency against the frontier in year t-1. This score is then compared to TenneT's efficiency in year t. Afterwards we take the average. Alternatively, we can compare TenneT's 2017 values against the 2013 frontier. This suggests that TenneT's efficiency declined at 5.1% p.a. Importantly, the analysis shows an implausibly large deterioration in TenneT's estimated productivity, no matter how that deterioration is calculated.
[49] TenneT's OPEX and CAPEX increased by €15.5m and €59.1m, respectively, leading to a TOTEX increase of €74.6m. As TenneT's 'efficient' TOTEX (as estimated by Sumicsid) only increased by €6.6m over the period, this means that €68.0m of TenneT's increase in expenditure is deemed to be inefficient. This is equivalent to all of TenneT's increase in OPEX (€15.5m) plus 89% of TenneT's increase in CAPEX (0.89x€59.1m). Equivalently, one could argue that all of TenneT's increase in CAPEX is inefficient, as is 58% of its increase in OPEX, or that about 91% of the expenditure in both is inefficient.
[50] Age is one of the variables used in Sumicsid's second stage analysis (for example, see Sumicsid (2019), 'Project TCB18: Individual Benchmarking Report Fingrid – 131', July, Table 5.1). Sumicsid therefore concludes that age is not a material driver of expenditure that is omitted from its model specification.

2. TenneT also performed significant (re-)investments in recent years—on average, TenneT invested over 32% more than other TSOs. CAPEX per NormGrid has risen substantially throughout the industry, and recent investments are incorrectly assessed to be inefficient in Sumicsid's framework. We address this in section 3.2.

3.1 Asset age

3.1.1 Issues with Sumicsid's approach

When grid assets are connected to the network for a significant amount of time, the wear and tear of day-to-day operations results in a higher likelihood of more frequent faults, thus requiring more regular inspections and repairs.[51] This results in an increase in OPEX associated with ageing assets. The impact and timing of this varies by asset type, but typically increases sharply around the time an asset reaches the 'end of its life'.[52] For example, in a report for the UK energy regulator (Ofgem), UK DSOs set out that asset health decreases exponentially, as 'it is assumed that the processes involved as the asset deteriorates (e.g. corrosion, oil oxidation, insulation breakdown, etc.) are accelerated by the products of the deterioration process'.[53] The impact of asset age on benchmarked maintenance costs is a frequent point of consideration in regulatory benchmarking.[54]

As can be seen in Table 3.2, TenneT operates a relatively old grid, with an average age of 32 years, while TenneT's peers operate younger grids between 23 and 27 years old. Thus, when compared to its peers, a larger proportion of TenneT's assets will have reached an age where maintenance costs increase sharply, increasing benchmarked OPEX. This difference is even more pronounced for some types of assets, such as Circuit Ends, which form a large part of TenneT's asset base. 'Transformers' is the only asset category where TenneT's assets' age is broadly in line with its peers'.

Table 3.2 Average asset age in years by asset category

	Overall	Lines	Cables	Circuit ends	Transformers
TenneT B.V.	32	51	23	27	27
Peers	23–27	32–38	8–14	8–21	21–31

Source: Oxera analysis of TCB18 data.

The increased OPEX associated with aging assets is not matched by an equivalent increase in any of the cost drivers used in TCB18, as Sumicsid's benchmarking model does not control for asset age or increasing maintenance requirements with its cost drivers. All cost drivers are either invariant to asset age (transformer power and weighted lines) or decrease (adjusted NormGrid)[55] with asset age.

However, as we explained in our main report, this type of second-stage analysis has no theoretical validity and cannot be used to support the statements that Sumicsid has made in TCB18. See Oxera (2020), 'A critical assessment of TCB18 electricity', April, section 5.4.

[51] For instance, in the UK asset age is a key component in the calculation of the forecasting of asset risk. See DNO working group (2017), 'DNO common network asset indices methodology', January.

[52] The causality runs the opposite way here, as OPEX increases due to age, assets are replaced with new assets (CAPEX), hence this is considered the end of their life.

[53] DNO working group (2017), 'DNO common network asset indices methodology', January p.32

[54] For example, age was a key issue in the Bristol Water appeal. See Competition and Markets Authority (2015), 'Bristol Water plc A reference under section 12(3)(a) of the Water Industry Act 1991', October

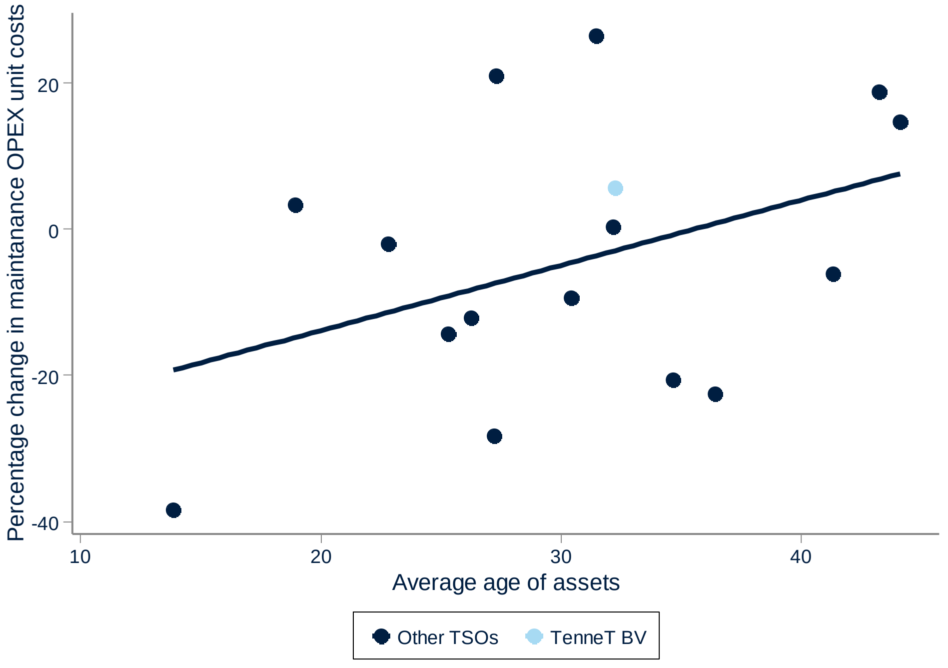
[55] NormGrid contains an OPEX and a CAPEX component. While the OPEX component is invariant with asset age (i.e. there is still an OPEX weight for overage assets), the CAPEX component is set to zero after an asset exceeds the end of its designed life. Thus, NormGrid is weakly decreasing in asset age.

Thus, the age effect will lead to a negative bias for TSOs that operate a relatively old grid, such as TenneT. That is, when TenneT is compared to peers with relatively young networks, it is incorrectly identified as inefficient, irrespective of the optimality of its asset age profile and the efficiency of its expenditure. The fact that this is happening is evidenced by the issue that (almost) the entire increase in OPEX expenditure that TenneT has realised over the period is considered to be inefficient.

3.1.2 Critique

As outlined above, the impact of asset age on maintenance expenditure is well-founded in operational analysis. In addition it can also be seen in the TCB18 data. As shown in Figure 3.1, the increase in (real) maintenance costs per unit of NormGrid over the sample period is positively associated with overall asset age (defined as the age of all assets, weighted by their NormGrid value). Sumicsid's model makes no adjustment for this effect. To account for this, measures of asset health or condition should be considered in TOTEX benchmarking.

Figure 3.1 Change in maintenance costs over the sample period per NormGrid and asset age



Source: Oxera analysis of TCB18 data.

That such an important and well-known issue is not addressed or discussed in TCB18 illustrates the weakness of Sumicsid's model development procedure. In a regulatory setting, it is considered best practice to define a set of cost activities, suggest cost factors to capture each activity, and invite participating companies to comment on these and to suggest alternatives. This process of iterative consultations limits the risk that significant outputs are insufficiently considered. It also gives regulators an opportunity to respond to the comments from the industry and justify their choices with empirical evidence. We consider that a robust process to validate Sumicsid's modelling assumptions (as well as claims of the industry) was not followed in TCB18.

3.1.3 Quantification of the bias and proposed adjustment

A simple approach to account for the impact of asset age on TOTEX would be to include a (scaled) measure of overall asset age as a cost driver. However, from our correspondence with TSOs and in reviewing the existing operational evidence,[56] it became clear that the increase in maintenance cost was not linear and only became significant once an asset was close to reaching the end of its life.

An alternative approach could be to reduce TSOs' modelled TOTEX by an estimate of the impact of asset age on costs. However, the precise cost impact of asset age on TOTEX is unknown and not measurable without detailed engineering knowledge of TSOs' assets.

Therefore, in the current case, we include the NormGrid value of assets that exceeded their 'techno-economic life' as defined by Sumicsid[57] as a separate cost driver.[58] This allows the DEA to determine the importance of old assets directly.

The cut-off at the end of an asset's 'techno-economic life' was chosen as we understand that maintenance costs increase sharply as assets reach the end of their lives. However, as the definition of 'techno-economic lifetime' is not clearly explained in TCB18, we also conducted sensitivity analysis to this threshold. For these, we defined the threshold as 90% or 110% of the techno-economic lifetimes defined by Sumicsid.

As can be seen in Table 3.3, the increasing OPEX impact of ageing assets has a material impact on TenneT's estimated efficiency. The estimated efficiency gap that opens up in 2013–17 is reduced from 16% in the base case to 11% when the age of assets is accounted for.

Table 3.3 Estimated DEA efficiencies—controlling for asset age

	2013	2014	2015	2016	2017
Including overage assets as a driver	98.4%	89.2%	88.6%	93.6%	89.6%
Including assets exceeding 90% of standard life as a driver	99.9%	92.0%	91.9%	93.2%	87.9%
Including assets exceeding 110% of standard life as a driver	98.4%	88.2%	99.3%	100.0%	88.7%

Note: The transformer power variable has been adjusted for ownership structure, as outlined in section 2.3.

Source: Oxera analysis of TCB18 data.

The Monte Carlo simulations for noise in the data further support the conclusion that the remaining efficiency gap may be driven by noise or the inclusion of TSOs that are super-efficient outliers. In the present case, the **simulations indicate that we cannot say with 95% confidence that TenneT is not fully efficient** using any of the sensitivities listed in Table 3.3.

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[56] Ofgem (2017), 'DNO common network asset indices methodology', January p. 32.
[57] Sumicsid (2020), 'PROJECT CEER-TCB18 - Dynamic efficiency and productivity changes for electricity transmission system operators - MAIN REPORT', Table 4-02, April
[58] More specifically, our approach proceeds in two steps. First, we remove the assets that exceeded their 'techno-economic life', as defined by Sumicsid in table 4-2 of the calculation of Sumicsid's NormGrid measure. Subsequently, we add those assets back in as a separate driver.

The SFA results are presented in Table 3.4 below. On all the specifications tested, the SFA model was able to identify statistically significant inefficiency. Note that the coefficient on overage assets is positive and statistically significant in all specifications tested, which provide indicative statistical evidence that efficient expenditure increases as assets age. The coefficient on weighted lines is not in line with operational expectations, and efficiencies derived from these models would not be informative.

Table 3.4 SFA results—controlling for asset age

	Overage assets (90%)	Overage assets	Overage assets (110%)
NormGrid (area)	0.442***	0.361***	0.668***
Weighted lines	-0.012***	-0.011***	-0.019***
Transformer power (adjusted)	0.646***	0.730***	0.630***
Overage assets (90%)	0.080***		
Overage assets (100%)		0.0737***	
Overage assets (110%)			0.018***
Constant	2.626***	3.415***	-0.912***
Observations	81	81	81
Statistically significant inefficiency detected?	Yes	Yes	Yes
Converged?	Yes	Yes	Yes
Chi-bar test statistic	44.77	33.42	34.81

Note: The transformer power variable has been adjusted for ownership structure, as outlined in section 2.3. All data is in logarithms.

Source: Oxera analysis of TCB18 data.

The analysis presented in this section demonstrates that much of the increase in TenneT's expenditure in the modelling period can be explained by the increased maintenance activity that could be associated with older assets. Sumicsid's current model assumes that (almost) all of this activity is inefficient, yet it has not presented evidence to support this assumption, nor has it commented on the feasibility of such a large deterioration in TenneT's estimated efficiency score.

3.2 Investment timing

3.2.1 Description of the issue

Several of the TSOs that participated in TCB18 (including TenneT) indicated that the cost of more recent investment projects is higher than historical investment projects. Sumicsid's main report documents that apart from TenneT, Statnett and Energinet also submitted claims on this issue. The TSOs, as part of the study, note that the increased costs were associated with new regulatory requirements on assets, or more complex routing due to increasing infrastructure density.[59]

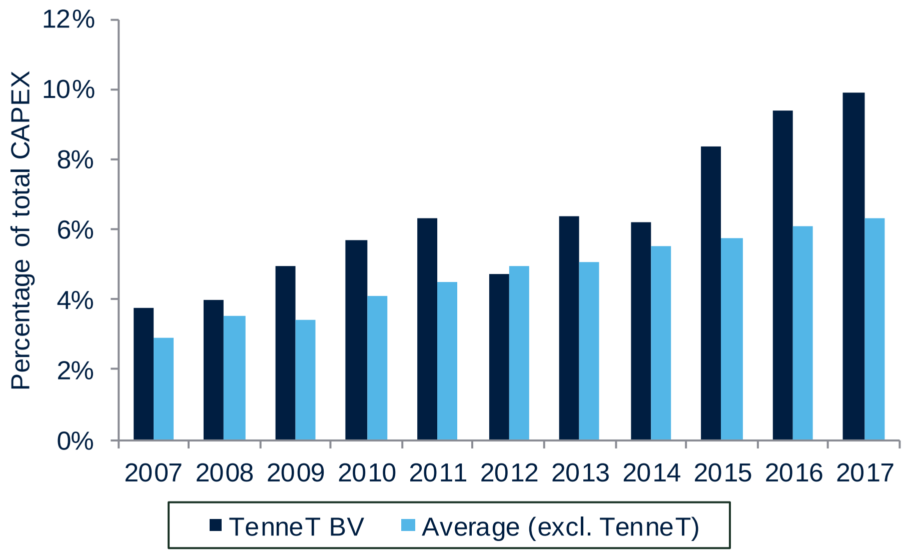
Sumicsid dismissed the claims relating to increasing costs as 'not unique'. While the rising investment costs associated with new projects may be common across the TSOs (although Sumicsid presents no evidence to support this assertion), it does not naturally follow that all TSOs are impacted in the same way. Indeed, if the cost of new projects is increasing, TSOs that have

[59] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators main report', July, Tables 3-2 and 3-3.

built assets more recently will have higher costs than TSOs that have not, regardless of the efficiency of the investment.

As discussed, TenneT operates a relatively old grid. Moreover we understand that TenneT undertook significant additional investments in upgrading capacity in recent years. Figure 3.2 illustrates this point—since 2007, TenneT has invested significantly more than the average TSO in the sample, with TenneT's CAPEX[60] outpacing the other TSOs' investment by an average of 30%. Because of this, TenneT is disproportionately affected by the issue of rising investment costs described by the TSOs.

Figure 3.2 Investment over time



Note: CAPEX is smoothed over a five-year rolling window.

Source: Oxera analysis of TCB18 data.

3.2.2 Critique

If the index of inflation used in TCB18 is not an accurate representation of the changes in investment costs that TSOs face (either because prices of inputs are increasing at a different rate to inflation or the complexity of outputs is increasing), then the CAPEX measure used in TCB18 is sensitive to the timing of the investment. For example, if costs rise faster than the general inflation index used, earlier investments will seem to be more efficient, irrespective of whether the later projects were conducted efficiently.

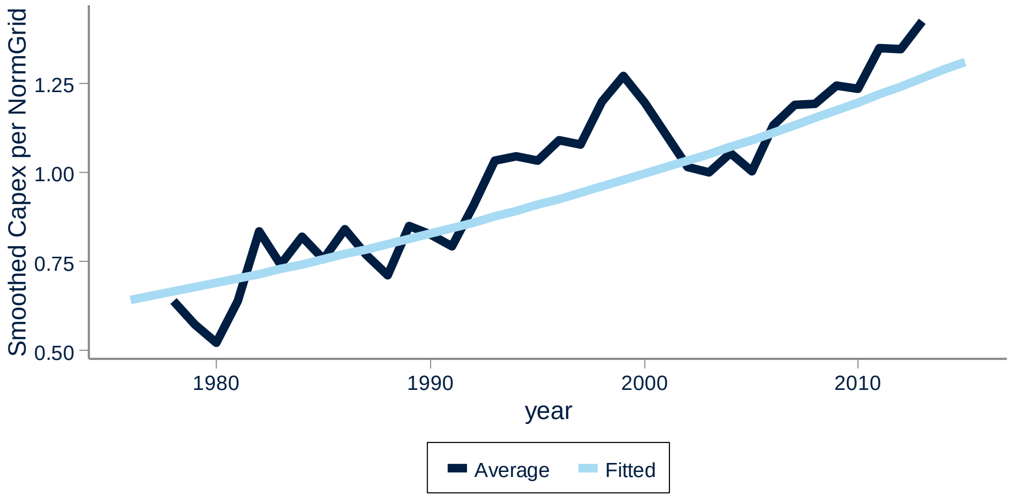
It can be difficult to determine the appropriate inflation index, as long-run data on investments and associated assets is not generally available. In the current case, however, we *do* have both long-running expenditure data for many TSOs and extensive information about the associated assets. As the NormGrid variable is *intended* to be 'a Totex-relevant proxy for the total power system',[61,]

[60] This is relative to overall CAPEX—i.e. as a percentage of total CAPEX.
[61] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators main report', July, Section 5.04.

[62] we would expect the annuitized CAPEX required for an additional unit of NormGrid to be constant over time.[63]

In contrast to this, we observe that there has been a consistent increase in the cost per additional unit of NormGrid over time, as illustrated in Figure 3.3.

Figure 3.3 Costs per NormGrid over time



Note: All prices are corrected for inflation using the Eurostat HICPOG index used by Sumicsid.

Source: Oxera analysis of TCB18 data.

This demonstrates that Sumicsid did not capture the rise in input prices for TSOs in the modelling. The benchmarking results are thus sensitive to the timing of investments. Specifically, TSOs that have invested significantly as TenneT has in recent years (and significantly more than others) will be disadvantaged, as new investments in recent years are implicitly benchmarked against existing investments that faced lower input costs per NormGrid. This results in large, recent investments being deemed particularly inefficient; this could help to explain the observation that 90% of TenneT's increase in CAPEX in 2013–17 is deemed to be inefficient by Sumicsid's model.

In order to determine whether the observable trend in annuitized CAPEX per NormGrid is significant and not a random fluctuation, we conducted a regression analysis. Specifically, we have regressed the annuitized CAPEX per unit of additional NormGrid observed for the eight TSOs in the sample with a CAPEX stream of at least 10 years on a time trend.[64] We controlled for unobservable time-invariant differences between TSOs using a fixed-effects model.

The existence and significance of the trend is confirmed by regression analysis. The coefficient on the time trend is always positive and statistically

[62] Note that we have identified several issues with Sumicsid's NormGrid variable in our general review of TCB18 that are not tackled in this report (see Oxera (2020), 'A critical assessment of TCB18 electricity', April, section 4.4). Nonetheless, we consider that this analysis can demonstrate that (i) there is a bias induced by the inability of Sumicsid's model to account for investment timing; and (ii) this bias is highly material for TSOs that have made significant investments in recent years, such as TenneT.

[63] This assumes that the measure of inflation adequately captures the change in input prices and that there has been no productivity growth in the sample.

[64] Of the sixteen TSOs in the sample, six were excluded due to their CAPEX stream being less than 10 years long (meaning that inference on their CAPEX stream would not be informative). Two TSOs were removed due to clearly anomalous data.

significant. As shown in Table 3.5, the increase in costs per NormGrid is estimated to be approximately 1.5–1.8% p.a. both within and across TSOs.

Table 3.5 Results of the unit cost regression

	Fixed-effects	Pooled OLS
Intercept		-36.681**
Year	0.015**	0.018**
'Within' R-squared	0.067	0.119
Observations	248	248

Note: Standard errors clustered around TSOs used in both models. As the fixed-effects estimator includes a dummy for each TSO, no intercept is calculated.

Source: Oxera analysis of TCB18 data.

The inability of Sumicsid's model to account for rising investment costs is evidenced by its frontier shift analysis—a frontier regress of 3.9% p.a. is large in magnitude and directionally incongruous to what is typically estimated in regulatory applications, and could be driven in part by the fact that Sumicsid's inflation adjustment is based on changes in consumer prices rather than changes in investment costs of the TSOs.[65]

3.2.3 Quantification of the bias and proposed adjustment

To address the bias against recent investments, we adjust all TSO's investments to be consistent with 2017 prices based on the estimated increase in prices from the regression analysis. In addition we also account for the impact of age on maintenance activity (see section 3.1). Through this adjustment, we ensure that any investment, no matter the timing, is ex ante expected to cost approximately the same per unit of NormGrid. We consider two approaches, as follows.

- **Adjusting CAPEX for cost trend.** Here, we use the regression coefficients from Table 3.5 to inflate historical CAPEX by approximately 1.5% p.a. relative to Sumicsid's estimate of CAPEX. This assumes that costs per unit NormGrid have been steadily increasing, and that any observed volatility is caused by random statistical noise rather than genuine changes in input prices. This is represented by the light blue line in Figure 3.3.
- **Adjusting CAPEX for the average unit cost.** Here, we use average CAPEX per NormGrid to deflate CAPEX. This assumes that the year-to-year volatility is driven by genuine changes in input prices,[66] and is represented by the dark blue line in Figure 3.3.

Both approaches have their limitations. For example, it may be unrealistic to assume that real investment costs have increased at a constant rate in the period 1973–2017 given there has been significant macroeconomic volatility in that period. The evolution of real investment costs may also differ between nations, depending on macroeconomic environments. However, there is a clear and universal upward trend in investment costs in the sample that needs

[65] We understand that the ACM intends to dismiss Sumicsid's frontier shift estimates when setting TenneT's regulatory revenues, despite them being estimated using the same model, estimation approach and on a larger dataset than the static analysis. The ACM's dismissal of the dynamic efficiency analysis could be justified if it also dismissed the results from the static analysis when setting individual efficiency targets. It cannot be that one piece of evidence from TCB18 is deemed more robust than another.

[66] One challenge in calculating the precise adjustment is that several TSOs have large 'opening investments' that are recorded significantly later than 1973 and cannot be assigned to a specific year. For those TSOs we adjusted CAPEX to be consistent with a uniformly rising investment profile for the time before the start of their CAPEX stream.

to be accounted for to avoid biasing the analysis against TSOs with recent investments, and we consider the two adjustments outlined above to be a clear improvement on Sumicsid's approach of ignoring the issue in its entirety.

As shown in Table 3.6, accounting for steadily increasing CAPEX per NormGrid (in addition to the overage cost driver from section 3.1) results in TenneT's efficiency being estimated as 100% from 2013–15 and 93.6% in 2017. If, instead, the average unit cost is used as the deflator, TenneT's efficiency score is 97.5% in 2017.

Table 3.6 DEA results—rising costs adjustment

	2013	2014	2015	2016	2017
Adjusting CAPEX for cost trend	100.0%	100.0%	100.0%	96.8%	93.6%
Adjusting CAPEX for average costs per NormGrid	100.0%	100.0%	100.0%	100.0%	97.5%

Note: One TSO exhibited a clear disconnect between CAPEX timing and the addition of assets. This TSO was removed from the reference set for this analysis. The transformer power variable has been adjusted for ownership structure, as outlined in section 2.3. An asset-age variable is included in the model, as outlined in section 3.1.3..

Source: Oxera analysis of TCB18 data.

Monte Carlo simulations for noise indicate that we cannot say with any level of confidence that TenneT is not fully efficient in all years once these adjustments are made.

The results from SFA estimation are presented in Table 3.7. Both models estimate statistically significant inefficiency, while the coefficient on weighted lines has a negative sign which is not in line with operational expectations, and efficiencies derived from these models would not be informative.

Table 3.7 SFA results—rising costs adjustment

	Cost trend	Average cost adjustment
NormGrid (area)	0.609***	0.651***
Weighted lines	-0.017***	-0.017***
Transformer power (adjusted)	0.594***	0.538***
Old assets	0.061***	0.085***
Constant	0.220***	-0.056***
Observations	81	81
Statistically significant inefficiency	Yes	Yes
Converged	Yes	Yes
Chi-bar test statistic	47.23	48.08

Note: The transformer power variable has been adjusted for ownership structure, as outlined in section 2.3. All data is in logarithms.

Source: Oxera analysis of TCB18 data.

4 Population density

4.1 Description of the issue

We showed through previous analysis that the observed drop in TenneT's estimated efficiency in the period of analysis can be fully explained by the age of TenneT's network and the timing of its investments. Nevertheless, these estimates are still biased by the inappropriate nature of Sumicsid's environmental adjustment, specifically the low weight given to population density in the analysis.

As a TSO's main task consists of transporting energy across its service area, the features of that surface area's environment, such as land use, climate and topography, can be a significant driver of their costs. Population density is one of the most important manifestations of this topographical dimension. It is widely recognised that population density (as well as sparsity) will impact costs. Density can drive up the cost of access and planning costs, among others, and can increase the complexity of the network compared with service areas in 'ideal' locations (i.e. where the population is not extremely spread out).

Sumicsid recognised the need for a cost driver associated with population density in e3grid, stating:

> 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.[67]

In the same report, Sumicsid states:

> TSOs in densely populated areas are confronted with many additional requirements to construct the assets.[68]

The view that the density and distribution of populations is a key aspect of heterogeneity between regulated utilities is shared by many regulators and is reflected in their modelling. Table 4.1 provides examples from the most recent price controls in many European jurisdictions.

[67] Sumicsid (2013), 'E3GRID2012 – European TSO Benchmarking Study', July, p. 4.
[68] Sumicsid (2013), 'E3GRID2012 – European TSO Benchmarking Study', July, p. 22.

Table 4.1 Examples of density variables in regulatory benchmarking

Country	Sector	Regulator	Approach to density
Netherlands	Energy	ACM	In its decision for TenneT's estimated efficiency for the 2017–21 regulatory period, the ACM applied an efficiency score derived from the results of e3grid 2012, which controlled for population density as a separate output in the benchmarking model.
United Kingdom	Energy	Ofgem	Ofgem suggests there is merit in correcting for density in the modelling rather than controlling for regional wage differences or other symptoms of density.[1] Ofgem states: 'The introduction of density into econometric modelling has been considered or employed in a number of price controls and there is a range of possible explanatory variables that could be used to capture its effect on efficient costs.'
United Kingdom	Water	Ofwat	Ofwat considers that on the one hand, the density variable captures the potential for a water treatment business to treat water using larger and fewer treatment works incurring lower unit costs. On the other hand, dense areas may be associated with higher property, rental and access costs. It includes both density and sparsity measures in its models.[2]
United Kingdom	Water	CMA	The CMA allowed a cost adjustment based on relative population density and congestion in the Bristol Water appeal.[3]
Norway	Energy	NVE	NVE controls for the amount of substations in its DEA model as an indicator of whether the DSO operates in urban or rural areas.[4]
Sweden	Energy	EI	EI has chosen to use customer density, defined as the number of customers per km line, to be the primary representation of the conditions under which the DSOs operate.[5]
Austria	Energy	E-Control	E-Control uses the (transformed) density of connections as a cost driver.[6]
Germany	Energy	Bundesnetzagentur	The Bundesnetzagentur considers the area with more than 700 addresses as a cost driver. It recognises that the activity in densely populated areas can complicate the tasks of the DSOs and may lead to higher costs.[7]

Source: [1] Ofgem (2019), 'RIIO-2 tools for cost assessment', June, p. 58. [2] Ofwat (2019), 'PR19 final determinations: Securing cost efficiency technical appendix', December, p. 14. [3] Competition and Markets Authority (2015), 'Bristol Water plc A reference under section 12(3)(a) of the Water Industry Act 1991', November, A4(3)-29. [4] NVE (2017), 'Revenue cap calculation in R', December, p. 22. [5] EI (2016), 'The regulation of electricity network tariffs in Sweden from 2016', p. 5. [6] E-Control (2013), 'Regulierungssystematik für die dritte Regulierungsperiode der Stromverteilernetzbetreiber', November, p. 41. Frontier Economics and TU Berlin (2019), EFFIZIENZVERGLEICH VERTEILERNETZBETREIBER GAS (3. RP) Gutachten für die Bundesnetzagentur, May, p. 108.

Sumicsid controls for differences in operating environments in TCB18 by multiplying NormGrid with a single environmental factor based on land use. The weights used to construct the environmental adjustment are not discussed or presented in Sumicsid's final report or its appendices, but are presented in one of its workshops.[69]

The final report states:

> The most important factor for electricity was land use categories (area measures), relating to costs of construction (reinforcements, site access) and to operation (maintenance access). This is in fact consistent with the earlier results

[69] Sumicsid (2019), 'Model Specification Model Results', April, slide 55.

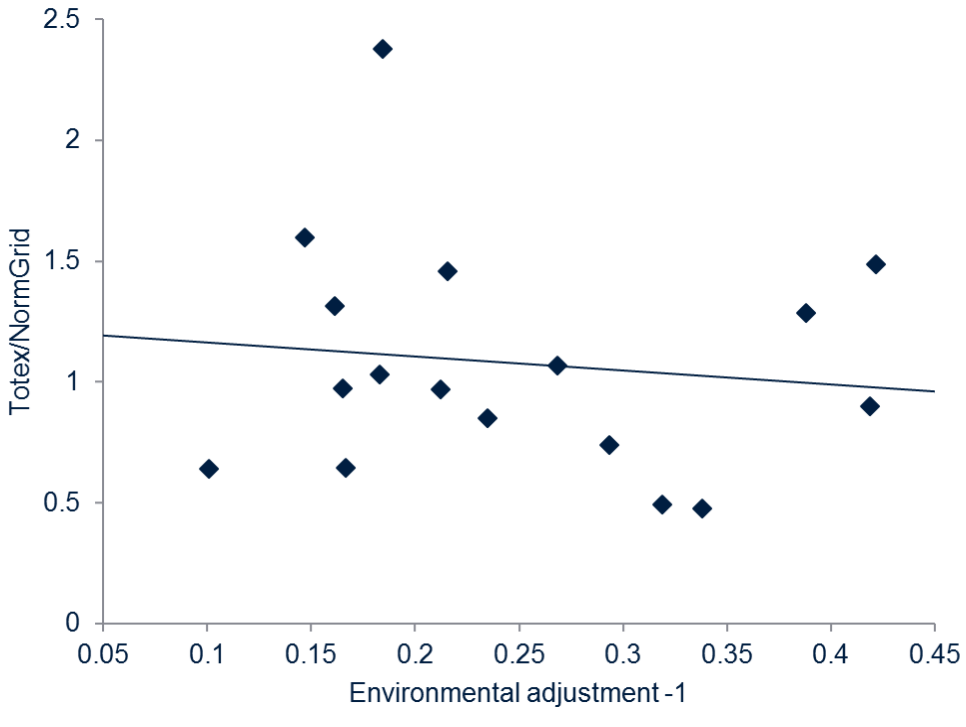
highlighting **infrastructure density as a major factor**, but in addition it addresses the costs incurred through other factors (slope, subsoil) when operating in specific terrain (forest, mountains).[70] [emphasis added]

4.2 Critique

Sumicsid does not reference the sources of its environmental weights in any of its outputs, and we have been unable to find an external source that validates these weights. Furthermore, it does not present any conceptual or empirical evidence to support the weights that it has used for its sample of TSOs.

Indeed, the environmental adjustment *is not* justified from a statistical perspective, such as a regression on costs per NormGrid. As illustrated in Figure 4.1, TSOs with higher costs per NormGrid based on unadjusted NormGrid receive slightly lower environmental adjustments on average. That is, TSOs that operate in complex regions (based on the land use factors applied by Sumicsid) have lower unit costs than TSOs that operate in less complex areas. This is inconsistent with operational rationale that it is more costly to operate in complex regions.

Figure 4.1 Relationship between environmental adjustment and TOTEX per NormGrid



Note: Environmental weights are corrected to exclude the 'other' category of land use in line with the ACM's suggestion and therefore differ to those presented in Oxera (2020), 'A critical assessment of TCB18 electricity', April.

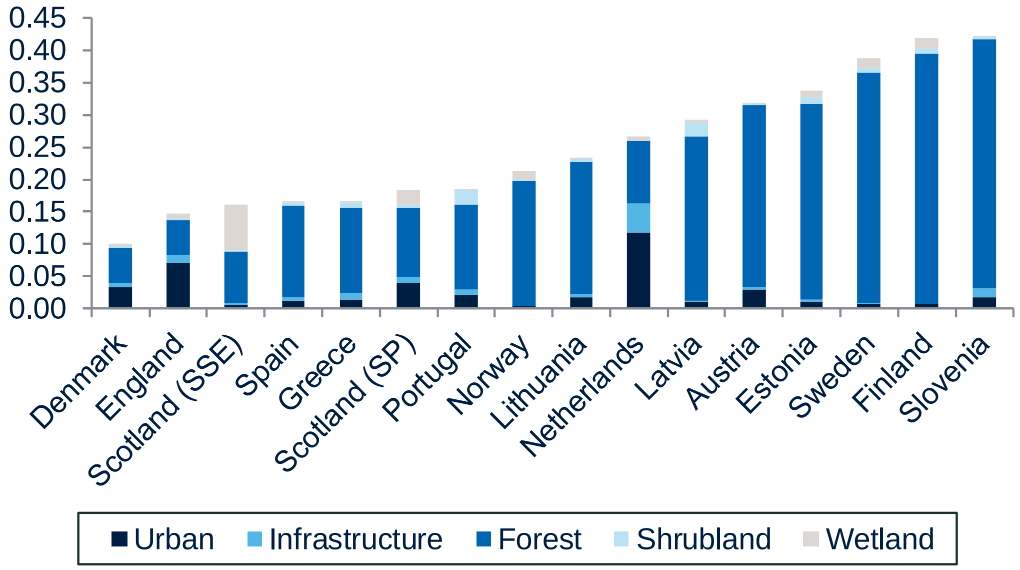
Source: Oxera analysis of TCB18 data.

This result likely stems from the fact that (as illustrated in Figure 4.2) the main driver of a TSO's environmental adjustment in TCB18 is the proportion of land covered in forests, and not population density (proxied by the level of urbanity)

[70] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators main report', July, section 5.04.

or the proportion of land used by infrastructure.[71] This explains why TenneT, despite having the highest population density and the largest share of land used by infrastructure in the sample, has an environmental adjustment that is broadly in line with the industry average. It is unclear why Sumicsid determined forests to be the primary driver of environmental complexity. We are not aware of any cost adjustment claims submitted as part of TCB18 or e3grid or any other literature that support this.

Figure 4.2 Impact of different land use categories on NormGrid weight



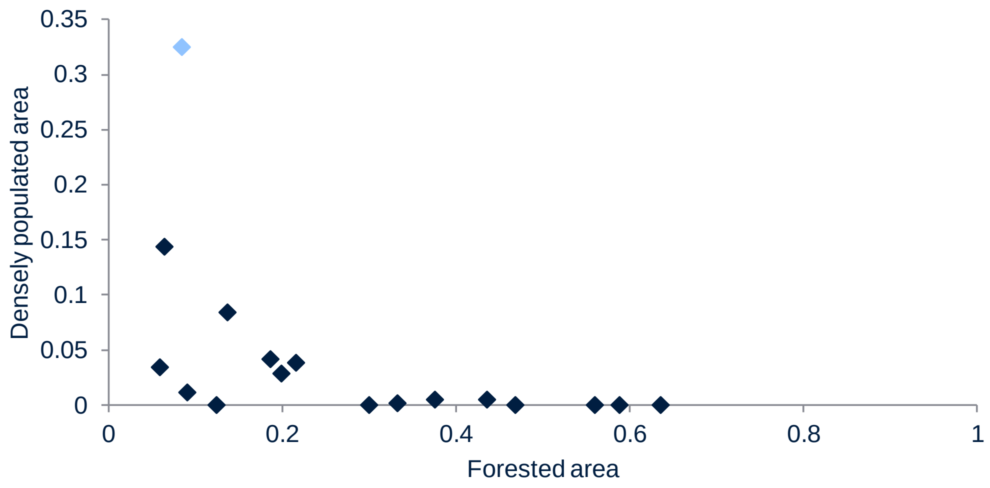
Note: Environmental weights are corrected to exclude the 'other' category of land use in line with the ACM's suggestion and therefore differ to those presented in Oxera (2020), 'A critical assessment of TCB18 electricity', April.

Source: Oxera analysis of TCB18 data.

Moreover, Figure 4.3 shows that the main component of the environmental adjustment, forest-covered area, is *negatively correlated* with population density—TSOs that operate in dense regions thus tend to have a smaller environmental adjustment than TSOs that operate in sparse regions. This negative correlation also holds when potential outlier TSOs (such as TenneT itself) are excluded from the sample.

[71] This is counter to Sumicsid's statement that population and infrastructure density are the major environmental factors that drive TSOs' expenditure.

Figure 4.3 Correlation analysis—population density and forested area



Note: TenneT is highlighted as light blue in the chart.

Source: Oxera analysis of TCB18 data.

Therefore, the adjustment for topography in TCB18 is not only generally a poor reflection of environmental complexity, but also biased against densely populated TSOs. This is particularly relevant for TenneT, as it is the most densely populated TSO in the sample—as can be seen in Table 4.2, 32% of TenneT's service area has a population density of at least 500 people per square kilometre, yet the equivalent share is less than 15% for all other TSOs in the sample and, importantly, less than 1.5% for TenneT's peers. TenneT is therefore benchmarked to peers that operate in significantly different environments and is disproportionately affected by the lack of a density cost driver.

Table 4.2 Population density in TCB18

	Share of area with >500p/km2
TenneT	32%
Second-highest value in TCB18	15%
TenneT's most-dense peer	2%
TenneT's peers (average)	0%
Average TSO	4%

Source: Oxera Analysis of EUROSTAT data.

Sumicsid's other statements regarding the correlation of its land use complexity weight with other environmental characteristics are also unsupported by empirical evidence. In particular, that the land use complexity weight accounts for a variety of factors, including infrastructure (urbanity), slope (mountainous) and subsoil (gravel) conditions is not backed up with empirical evidence.[72] At a high level, the correlation between the land use-complexity factor used by Sumicsid and other complexity drivers that were

[72] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators main report', July, section 5.04.

proposed by Sumicsid as part of TCB18 gas or e3grid is either negligible or negative.[73]

Finally, Sumicsid's approach of adjusting one output variable (NormGrid) may not adequately account for the environmental complexity of some TSOs. For example, in our review of TCB18 electricity, we found that most TSOs attach a small (or zero) weight to NormGrid in determining their overall efficiency score. These TSOs will not materially benefit from the environmental adjustment, even if they operate in a complex environment.

4.3 Quantification of the bias and proposed adjustment

As outlined above, Sumicsid's approach (combining all land use categories into a single factor using unjustified weights, and applying this weighting factor to only one of three cost drivers) leads to significant issues and ultimately biased estimates of TSOs' efficiency scores. To avoid such subjective judgement, we do not consider this type of environmental adjustment.

An approach to accounting for environmental factors that would be consistent with the nonparametric DEA would be to let the DEA choose the importance of this cost driver endogenously by including it as a separate cost driver. This approach is consistent with the treatment of population density in e3grid2012. In performing this analysis, we have defined 'densely populated area' as a region with population density of more than 500 people/km^2, in line with e3grid2012.

In this specification TenneT is 100% efficient and a peer to four other TSOs in 2017. This result is robust to changes in the threshold used to define densely populated areas (i.e. defining the threshold at 400 people/km^2 or 600 people/km^2).[74]

We also consider a measure based on the area covered by urban fabric or infrastructure according to TCB18 Environmental data. This specification also confirms that TenneT's score is significantly underestimated if density is not properly accounted for, estimating TenneT to be 94.3% efficient in 2017. These results are presented in Table 4.3 below.

Table 4.3 DEA results—density

	2013	2014	2015	2016	2017
500 people/km2 threshold	100%	100%	100%	100%	100%
400 people/km2 threshold	100%	100%	100%	100%	100%
600 people/km2 threshold	100%	100%	100%	100%	100%
'urban' and 'infrastructure' areas	100.0%	85.2%	93.9%	96.3%	94.3%

Note: The transformer power variable has been adjusted for ownership structure, as outlined in section 2.3.

Source: Oxera analysis of TCB18 data.

Monte Carlo simulations for noise in the models incorporating a density variable (i.e. the top three rows in Table 4.3) indicate that we can reject the hypothesis, that TenneT is not fully efficient. In other words, **TenneT is shown**

[73] The correlation with Sumicsid's slope factor is slightly positive, with a correlation coefficient of 0.01; the correlation coefficient with subsoil factors and urbanity is negative, at -0.18 and -0.45, respectively.
[74] Note that none of the analysis presented in this section makes adjustments for maintenance activity or investment timing. This is because TenneT is already estimated to be close to 100% efficient after these adjustments are made, so the estimated bias induced by Sumicsid's approach to accounting for environmental factors would appear to be immaterial if this analysis was incremental to the analysis presented in section 3, despite it being a significant issue for TenneT.

to be 100% efficient in at least 95% of simulations in these models. In the models controlling for the land-use variable (i.e. the bottom row in Table 4.3), we cannot reject the hypothesis that TenneT is 100% efficient. TenneT is also always estimated as 100% efficient in 2013-2017 if we apply the adjustments suggested in section 3 as well.

As TenneT is clearly the most densely populated TSO in the sample, TenneT might be assessed as 100% efficient due to a lack of comparable TSOs. Sumicsid believes that this is an issue for this output (but not for other outputs used in TCB18) as densely populated area is 'non-operation related'.[75] We consider that this is an inaccurate characterisation of the densely populated area output (which is a proxy for many operational challenges, like cost of access and grid complexity). However, in the context of a valid DEA model, the issue of 'inappropriate' weights may be remedied through the introduction of weight restrictions. These could set bounds for the maximum relative importance of outputs (as was done in e3grid). If weight restrictions are to be used in DEA, they should be robustly evidenced from an operational and economic perspective.

However, TenneT's estimated efficiency is robust to the introduction of certain weight restrictions. As shown in Table 4.4, when restricting the importance of the population density variable to 10% of the importance of other outputs,[76] TenneT is still estimated to be 97.5% efficient in 2017 (without adjusting for the timing of investments and asset age). Again, this result is robust to the exact threshold of population density chosen.[77]

Table 4.4 Restricted DEA results

	2013	2014	2015	2016	2017
500 people/km^2 threshold	100%	99.1%	100%	100%	97.5%
400 people/km^2 threshold	100%	100%	100%	100%	97.9%
600 people/km^2 threshold	100%	100%	100%	100%	97.1%

Note: The transformer power variable has been adjusted for ownership structure, as outlined in section 2.3.

Source: Oxera analysis.

The results of the SFA are presented in Table 4.5 below. Once again, we observe statistically significant inefficiency in some specifications, but the coefficient on weighted lines has a negative sign in those models. This is not consistent with, and efficiencies derived from these models would not be informative. The coefficient on 'densely populated area' tends to be small but significant. This is likely to be due to the fact that, as outlined above, not much variation exists with respect to densely populated area in most of the sample.

[75] Sumicsid (2019), 'Pan-European cost-efficiency benchmark for electricity transmission system operators main report', July, section 7.08.
[76] The restriction is always imposed with respect to a single output; all three other outputs were tested and the maximum score obtained was assigned to a TSO. Restricting the weight on density to be 10% of the weight on other variables compares to the weight restrictions in e3grid2012, where the weight on NormGrid was allowed to vary between 8.5 and 24.5 times the weight on density. See Sumicsid, Frontier Economics, Consentec (2013), 'E3GRID2012 – European TSO Benchmarking Study A REPORT FOR EUROPEAN REGULATORS', July, p. 93.
[77] TenneT is estimated to be inefficient when 'urban' and 'infrastructure' areas are used as a cost driver, indicating that the DEA model has found (a combination of) peers that are similar to TenneT. As such, TenneT cannot be considered an outlier according to this specification.

The specification using the urban and infrastructure covered areas in TCB18 did not converge[78] and is not presented here.

Table 4.5 SFA results—density

	400 people/km2	500 people/km2	600 people/km2
NormGrid (area)	0.545***	0.545***	0.545***
Weighted lines	-0.020***	-0.020***	-0.020***
Transformer power (adjusted)	0.733***	0.733***	0.733***
400 people/km^2	5.63e-06***		
500 people/km^2		5.55e-06***	
600 people/km^2			6.28e-06***
Constant	0.496***	0.496***	0.495***
Observations	81	81	81
Statistically significant inefficiency	Yes	Yes	Yes
Converged	Yes	Yes	Yes
Chi-bar test statistic	15.75	15.72	16.02

Note: The transformer power variable has been adjusted for ownership structure, as outlined in section 2.3. All data is in logarithms

Source: Oxera analysis of TCB18 data.

[78] If a model does not converge, it means that the iterative procedure used to estimate the model results in an endless loop. In this sense, the model cannot be estimated. This could be because of poor starting values, wrong distributional assumptions or general model misspecification.

5 Conclusion

In this report we have assessed the consistent downward bias in TCB18's estimated efficiency for TenneT resulting from four issues.

- **The biased capacity proxy—**different ownership structures between TSOs mean that Sumicsid's proxy significantly underestimates the capacity of TenneT's network.
- **Asset age**—Sumicsid did not consider that maintenance expenditure could increase with asset age, and as TenneT operates a significantly older network than its peers, this omission biases TenneT's estimated efficiency.
- **Investment timing**—investments have become more expensive for TSOs in recent years, biasing estimates against TSOs that recently conducted significant investments.
- **Population density—**Sumicsid's environmental adjustments are focused on forested areas and not well-established drivers of costs, such as population density. Sumicsid's adjustments are not intuitive and not supported by data or operational rationale.

The issues covered in this report demonstrate that Sumicsid failed to ensure structural comparability between TSOs, resulting in non-robust efficiency estimates. Our generic report outlined the main conceptual issues. This report builds on it and details some of the issues that were not appropriately addressed and their impact on TenneT's estimated efficiency. The impact of these adjustments, presented throughout this report, are summarised in Table 5.1.

Table 5.1 Summary of adjustments to TCB18

Adjustment	Estimated efficiency (%)	Impact relative to Sumicsid's assessment (%)
Correcting the network capacity proxy for ownership structure	84.0	12.5
Accounting for asset age in the cost driver specification[1]	87.9–89.6	16.4–18.1
Adjusting CAPEX to account for the increased costs of recent investments[1,2]	93.6–97.5	22.1–26.0
Appropriately accounting for population density[1]	94.3–100.0	22.8–28.5

Note: [1] The efficiency scores presented under these adjustments have also adjusted the transformer power data for ownership structure, and can be considered incremental to the first row. [2] The efficiency scores presented here are incremental to accounting for asset age in the cost driver specification.

Source: Oxera analysis of TCB18 data.

We also presented an alternative adjustment for the bias in the capacity proxy, which uses the power of circuit ends as an alternative cost driver. We confirmed that the results from using this proxy alongside the adjustments proposed in sections 3 and 4 are consistent with those based on the adjusted transformer power variable. These results are presented in Table 5.2.

Table 5.2 Summary of adjustments to TCB18 - circuit end power

Adjustment	Estimated efficiency (%)	Impact relative to Sumicsid's assessment (%)
Correcting the network capacity proxy for ownership structure	91.2	19.7
Accounting for asset age in the cost driver specification[1]	91.5–92.0	20.0–20.5
Adjusting CAPEX to account for the increased costs of recent investments[1,2]	97.3–98.9	25.8–27.4
Appropriately accounting for population density[1]	96.3–100.0	24.8–28.5

Note: [1] The efficiency scores presented under these adjustments have also replaced the transformer power data for ownership structure using the power of circuit ends variable, and can be considered incremental to the first row. [2] The efficiency scores presented here are incremental to accounting for asset age in the cost driver specification.

If all the proposed adjustments are applied simultaneously, TenneT is also estimated as 100% efficient in all years.

Note that once statistical noise is accounted for through either Monte Carlo simulations or SFA, TenneT is estimated to be nearly fully efficient when *any* of these adjustments are made.

The analysis presented in this report demonstrates that the TCB18 study is materially biased against TenneT. Indeed, if all of the issues covered in this report were to be addressed in the manner proposed, we find that the TCB18 data and benchmarking procedure lead to the conclusion that **TenneT is estimated to be 100% efficient**.

However, in this report, we explicitly *do not* address many of the issues highlighted in our main report. Importantly, our position on TCB18 remains unchanged. Even after adjustments for the issues covered in this report have been implemented, **TCB18 does not provide a robust evidence base for setting regulated revenues in its present form** and requires further research to address some of the fundamental issues with Sumicsid's analysis.

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