TCB18 – PROJ 37803

Response to the Oxera Report on TenneT TSO in TCB18-ETSO

FINAL

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1. Overview

1.1 Context

1.01 This note is a comment to the Oxera report "*Analysis of TenneT's estimated efficiency under TCB18*", called Oxera (2020) below, released 14/08/2020 on behalf of TenneT TSO BV participating in the electricity benchmarking TCB18-ETSO. The note Oxera (2020) draws on a general report, Oxera (2020b) *A critical assessment of TCB18 electricity*, issued 30/04/2020, which will be cited when relevant.

1.02 The format of the note is brief as most documentation is provided in the following documents, released during the project:

1) Sumicsid (2019) *Norm Grid Development, Technical* Report V1.3, 2019-02-27.
2) Sumicsid and CEER (2019a) *Pan-European cost-efficiency benchmark for electricity transmission system operators*, Main report V1.2, 2019-07-12.
3) Sumicsid and CEER (2019b) *Project TCB18 Individual Benchmarking Report*, V1.0, 2019-07-25. (Released for several TSO).
4) Sumicsid and CEER (2020) *Dynamic efficiency and productivity changes for electricity transmission system operators*, Main report V1.2, 2020-09-11.
5) Sumicsid (2020b) *Response to the Oxera Report on TCB18 ETSO*, Report V1.0, 2020-10-30.

1.03 The outline of the response restates the main arguments of Oxera (2020) in an orange shaded paragraph. In some cases, the original statements have been summarized and reformulated without intention of changing the contents and bearing of the argument.

1.04 The response provides an open discussion in a normal paragraph, concluding in a shaded grey paragraph as to our assessment of the impact of the argument on the viability of the TCB18 benchmarking results.

1.2 Outline

1.05 In the next Chapter we respond in more detail on the main critique raised by chapter in Oxera (2020). Responses to the general points also raised in Oxera (2020b) are provided in Sumicsid (2020b) and not repeated in this note.

2. Oxera critique

2.1 Oxera previous issues

2.01 Oxera (2020) repeats a number of remarks concerning the TCB18 study from Oxera(2020b) already responded in Sumicsid (2020b), omitted here. The new points in Oxera (2020) concern the capacity provision proxy (transformer power), asset age and density effects. We thus limit our attention to these points.

2.2 Capacity provision proxy [Oxera, ch 2]

2.02 Oxera (2020, Chapter 3) makes the argument that the TCB18 should include transformers in underlying grids for TenneT rather than those owned by the operator.

[Oxera, section 2.1-2.3]

2.03 Using a transformer power variable on owned assets underestimates the efficiency of TenneT since they own a lower proportion of transformers at the HV/MV level. [Section 2.1]

2.04 The methods used in TCB18 do not account for ownership differences among countries. [Section 2.2]

2.05 Adding 'missing' transformer power for TenneT would increase the efficiency to 84% or 84.6% when adding a proxy for Totex of the added transformers. [Section 2.3]

2.06 TenneT is responsible for the extra high voltage (EHV) grid in the Netherlands, but it also operates a high voltage (HV) network operating at the 110kV-150kV level. The inclusion of activities at this level is not unique to TenneT. The European electricity system is vertically constituted in several levels, sometimes called transmission, subtransmission and distribution. The organization of subtransmission can be either in form of a TSO, a DSO or a third level entity, the Regional Transmission Operator (RTO).

Distribution, Subtransmission and Transmission

2.07 The transport service is derived from elementary power system economics where the length of transport of electric energy generates losses that are inversely proportional to the voltage level. Thus, for a specific range of distances and energy volumes, it is optimal to transport energy at medium (MV) or high (HV) voltage rather than low (LV) or extra-high (EHV). For this reason, sub-transmission networks are technically present in all modern power systems, usually in the range 60-130 kV. However, the systems differ in operation substantially from the transmission systems in that they operate mainly unidirectional flows and are subject to central control over the substations that link them to the transmission system. Another particularity is the multiple voltage levels present in typical RTO systems (20, 30, 40, 50, 66, 110 and 132 kV), whereas TSO normally strive for harmonized systems in one to three levels, including 300kV to 420 kV. In other reports, we have treated the problem of RTO networks and their benchmarking in e.g., Norway and Germany.

2.08 In TCB18 the TSOs reported 179 172 circuitkm of overhead line, only 170 km (<0. 1%) of this was at less than 110kV. We can therefore safely conclude that the reporting TSOs did not include assets related to subordinate levels in the benchmarking.

Transmission System Operator

2.09 From an economic perspective, the issue is not only the voltage level but also the way the network is operated. We may distinguish between DSO networks that are radial, passive nets serving transportation purposes only, and TSO networks that are meshed network subject to active control and serving also supply security tasks.

2.10 For a transportation network, flow and capacity measures (correlated to tariffs) may be correlated with investments and therefore work well as cost drivers and the basis for income cap regulation. For an active network, this is not necessarily the case. Lower flow may result if a bottleneck is relieved via a social welfare-increasing investment.

2.11 The key criteria distinguishing the TSO from the subordinate levels when it comes to transformation, i.e., the interface between the network levels, is the aspect of *control*. In TCB18, a necessary condition this aspect is also a contractual relationship of ownership or leasing, reported for all assets. For instance, the Opex related to maintaining an active transformer capacity across a power system involves cost for updating, installing and maintain control systems for the assets. Offering the capacity to the power system is a responsibility that is carried by the owner, not the underlying or connecting client. Note that the responsibility for the interface in voltage levels could be carried by a neighboring TSO for interconnections, the focal TSO, RTOs (as in German, Norway or Sweden), or a DSO (as in UK), depending on voltage level. This distinction is not unique to HV, the same principle applies to EHV as well between TSOs.

2.12 The TSO as responsible for the energy balance on the grid in real time is using the substations to regulate the flow. In the unlikely case of a temporal imbalance leading to a shortage, the rationing (load shaving) is made through the transformers (substations) operated and owned by the TSOs. For this reason, these stations are tightly integrated in the grid management system of the TSO, monitored and operated remotely.

2.13 The DSOs, on the other hand, are passively receiving the power from the substations on their site of the station, transforming it down in voltage to reach low voltage at the level of the client. Their stations are dependent on the feed-in from the TSO layer, but lack the infrastructure and control systems necessary for real time control. This arrangement is natural as the DSO has no base power fed directly into the grid, it needs the TSO to provide a stable supply.

Claim 2.03

2.14 The claim of TenneT that the underlying transformers, owned by the DSOs, should be integrated in the output for the TSO is technically incorrect. The DSO transformers are not substitutes for the TSO substations, but subordinate assets that are necessary and omnipresent in all national power systems. These assets are not under the control of the TSO and adding their total installed power is technically redundant since they are all connected to the higher grid for feed-in.

2.15 Another claim of TenneT concerns an alleged 'injustice' in that the operator would have a different, lower transformer basis than its comparators. Below we refute this by some simple ratios. First, note that the most TSOs have some HV lines in their asset base as illustrated in Figure 1 below with TenneT (187) and the mean operator (ave) are marked.

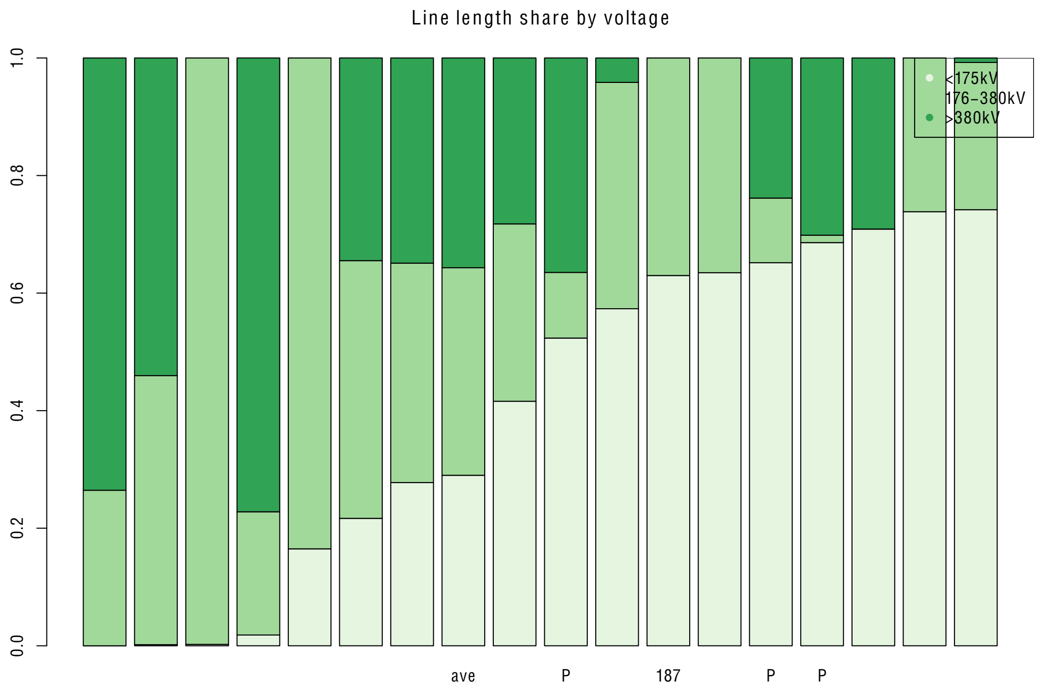


Figure 1 Share of overhead lines (circuit length, corrected for usage) by voltage class.

Peer analysis

2.16 The relative efficiency of TenneT is ultimately determined by the operators that constitute the best practice frontier.

2.17 The confidentiality agreements governing the TCB18 benchmarking does not allow the identification of individual units, their data or efficiency scores. In consequence, we cannot publish or reveal information that would lead to the disclosure of the peer units for TenneT.

2.18 Nevertheless, below we provide the following information regarding the position of the peers in two relevant dimensions: transformer power per circuitkm, and transformer power vs density.

Transformer power per circuitkm

2.19 In the sorted list in below, two of three peer units for TenneT are placed to the left (i.e. below) TenneT in terms of transformer power per EHV grid size. This means that the peers are not radically different from TenneT as regards to the installed transformer base. Indeed, the figure suggests that TenneT with the current data is very close to the mean transformer power for its size (dashed red line). With the added DSO transformers, TenneT would exhibit an unusual transformer capacity for its size measured as circuitkm EHV. This is to say that in the actual benchmarking, TenneT is indeed compared to units that have comparable transformer basis seen from the core task in EHV, and that the position of TenneT in that regard is not particular.

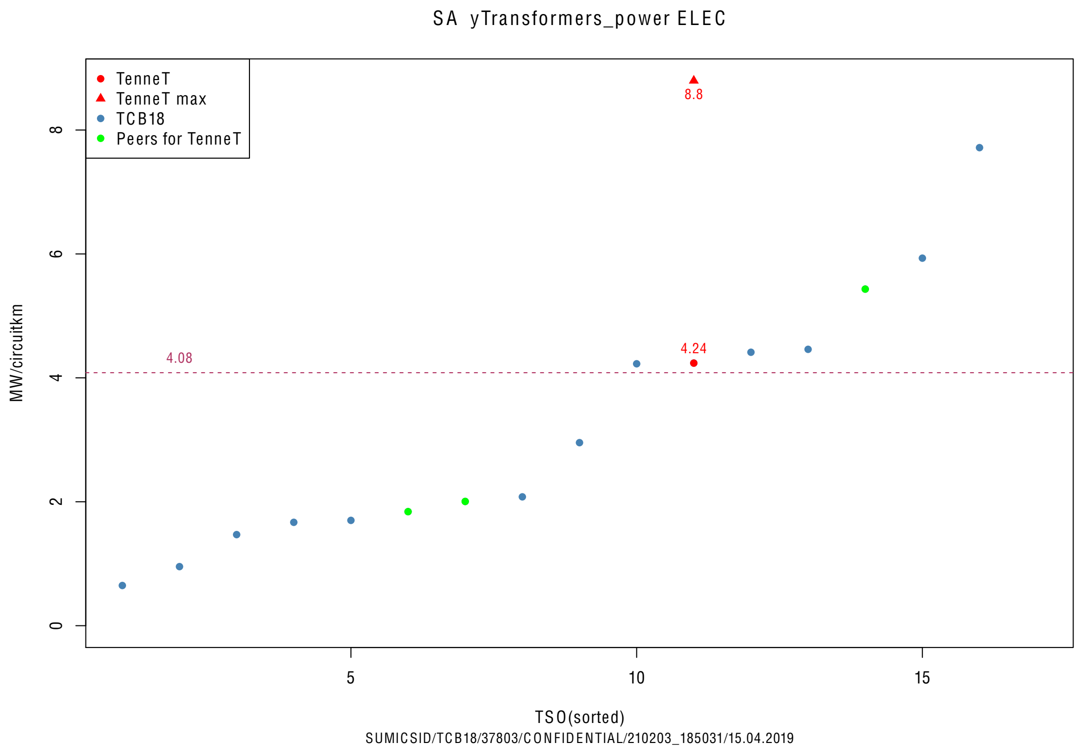


Figure 2 Transformer power (MVA) per circuitkm, TCB18-ELEC.

Transformer power per surface area

2.20 Concerning the intensity with respect to urban area in Figure 3 below, the peer units are also less “dense” in the meaning that they have a lower transformer power per dense urban area than TenneT. This means that their transformation need corresponds to the expected intensity in terms of residential and population load. As in the previous dimension, the transformer intensity for TenneT is normal, close to the mean with the current data. Adding extra transformer capacity to some units would distort the graph in an unexpected manner.

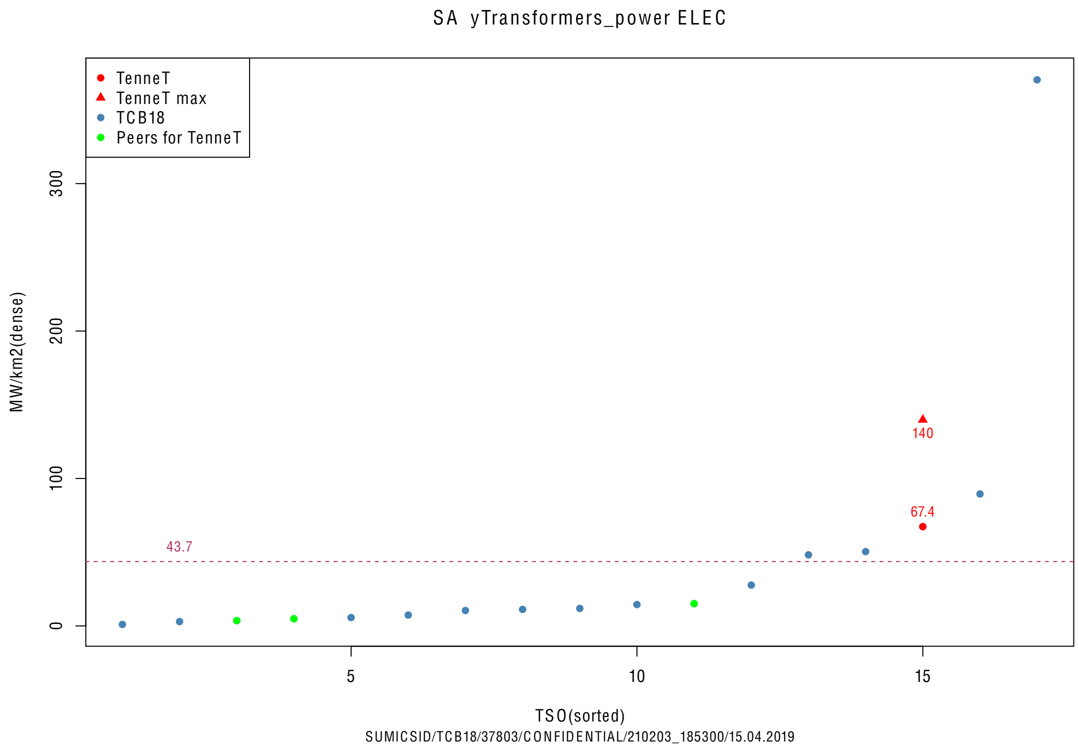


Figure 3 Transformer power (MVA) per km2 of dense urban and infrastructure landuse area, TCB18-ELEC, 2017.

Claim 2.04

2.21 The principle for inclusion of transformer power in the benchmarking is as a proxy for the overall transformation capacity offered to the underlying grid under the active control of the system operator. These assets are integrated technically and economically as fully owned and operated assets in the TSO power system.

2.22 All TSOs in Europe have also underlying grids with potentially several layers of transformation until the final client, generator or industry load. These assets are not TSO assets and not included in the benchmarking.

2.23 As seen, TenneT has a normal and consistent transformer capacity for its size and configuration. Increasing this artificially by including DSO-type assets is contrary to the idea for the transformer power as output and distorts the benchmarking.

2.24 The peers have a lower transformer capacity per EHV grid and urban area unit, meaning that they are not unusually endowed with transformer power compared to TenneT in relation to grid size and urban density.

2.25 All peers in the sample own and operate all transformers that are included in the benchmarking. The data in TCB18 does not include assets for underlying grids, but given the existence of DSOs for each peer and the indicators above, the units do not exhibit an incidence of transformer power that perturbs the evaluation and the assessment. TenneT is not disadvantaged in the benchmarking compared to the transformer capacity of their peers.

2.26 TenneT TSO participates in the international benchmarking on the same conditions as all other participants, using the same instructions for data collection and data definitions. The power system of TenneT TSO, including its transformers, is not radically different from the average TSO and the those of the immediate peers. The treatment of TenneT data is in no way different or biased. Thus, there is no support for the claim that TenneT would be subject to an unfair process. The suggestion to include assets that are not owned by the operator would lead to a major distortion of the results in direct violation with the principles for the benchmarking.

Claim 2.05

2.27 We now turn to the proposal in Oxera (2020) to add DSO-transformers to the capacity provision output for TenneT in order to calculate a new efficiency score. There is an obvious flaw in the benchmarking logic by *ad hoc* changing the output definitions retroactively for some operators with respect to some ratio, then using the selectively collected data to "prove" convergence. A second fundamental error is made in collecting selectively unvalidated information regarding assets from DSOs without relevant costs. We will show that the procedure is not only contradictory to the principles of benchmarking, but also creating an absurd data point for TenneT that cannot be compared with the actual reference set.

2.28 First, we construct a set of predictors for the transformer power in a power system. In the robust regression in Table 2-1 the lines and cables are considered as independent variables. As seen, the EHV part of the line length for a TSO is significant for predicting the transformer power, which is expected given the discussion above about the cascading effects in power systems.

Table 2-1 Robust regression results, n=81, TCB18-ELEC.

	Dependent variable:
	yTransformers_power
yLines_ehv	3.332***
	(0.383)
yLines_hv	−0.397
	(0.481)
yCables_tot	14.323***
	(2.909)
Constant	8,452.185***
	(2,494.794)
Observations	81
R^2	0.695
Adjusted R^2	0.683
Residual Std. Error	12,389.260 (df = 77)
Note:	*p<0.1; **p<0.05; ***p<0.01

2.29 We calculate the ratio of transformer power (MW) to the predictor: overall circuit length (EHV lines and cables). As transformers are necessary for transport over larger distances, this ratio should show a natural pattern. If a TSO had a particular structure with a higher part of transformers linked to DSO-type assets and HV-assets, this would show up as a higher ratio.

2.30 As seen in **Error! Reference source not found.** below, TenneT is already well above average with respect to transformer power per circuit length, with about 133% of the intensity of the mean operator in TCB18. Following the proposal in Oxera (2020) and adding the subtransmission would make the Dutch TSO an extreme case in the European setting, as seen from the triangle in the Figure. Besides the lack of techno-economic relevance for a TSO, the simulation in Oxera (2020) introduces a completely new element ("missing border transformers") that lacks clear definition and for which the technical data have not been validated and the cost data do not even exist. Oxera(2020) uses a unit cost ratio to estimate the investment cost, noting that this does not radically change the score for TenneT. This result follows directly from construction, projecting current unit cost to a different scale keeps relative NormGrid equal although the investment basis is changed with respect to composition (types, ages and dimensions of transformers). The entire calculation is therefore highly speculative, and the approach, data and assumptions cannot be used in regulatory applications.

2.31 An alternative denominator could be the dense urban area, with the argument that even relatively limited geographical areas (such as the Netherlands) justify a higher incidence of transformer power since the population density (proportional to the demand load) is higher than elsewhere. To examine this idea, we present **Error! Reference source not found.** with the transformer power per km2 of densely built-up area (cf. TCB18 main report). The surface area is slightly adjusted compared to TCB18 to exclude the proportion of non-identified land, rescaling the identified landuse categories proportionally. As seen in the Figure, the findings are analogous: TenneT is the third most transformer dense operator with the current data. A single operator stands out, this is a rural operator with long lines and very few large cities. Besides this extreme point, increasing the transformer power to 83,000 MW would make TenneT to the highest power continental operator with more than three times higher transformer intensity than the mean TCB18 operator (including the extreme case mentioned).

2.32 The transformer power of TenneT as reported and included in TCB18 is the third most dense transformer power operations in the data. Including other transformers would obviously distort the performance assessment, transforming TenneT to a dominating operator without any techno-economic sense.

2.33 Using a ratio to selectively add some undefined assets without cost in an unvalidated manner as in Oxera (2020) could be proving any relationship and is contrary to sound benchmarking. Neither the data, nor the process with the definitions are described in Oxera (2020), likely an indication of a summary and biased post-construction.

2.34 Principally, all outputs in the model should emanate from the assets used as inputs. Thus, adding output from foreign assets without validated cost is clearly contrary to the consistency principle in activity analysis. Even if all TSOs had such transformer power added to their output, the techno-economic relevance is lost since the capacity provision is driven by the interface between TSO and DSO, not DSO-controlled passive substations.

2.3 Asset age and investment timing [Oxera, ch 3]

[Oxera, section 3.1-3.3]

2.35 Oxera (2020, Chapter 3) argues that high asset age for TenneT drives OPEX which should be accounted for in the model. In particular, [Table 3.1] argues that all investments since 2013 have been inefficient for TenneT .

2.36 TenneT has older grid assets (besides transformers) than its peers. Maintenance cost increases sharply at the end of life. [Section 2.1]

2.37 OPEX unit cost increases with overall asset age, it should be corrected for. A measure of asset health or condition should be considered in Totex benchmarking. [Section 3.1.2]

2.38 A model with an extra output variable consisting of overage assets will make TenneT 89.6% efficient in 2017. [Section 3.1.3].

2.39 SFA for a logarithmic four-parameter model in [Section 3.1.3] confirms that expenditure increases with age. [Table 3.4]

2.40 The calculations in Table 3.1 (Oxera (2020)) are incorrect both for the operator and the use of the frontier estimates in the dynamic model (that are not valid for ad hoc changes in the transformer output for some operators). The results when comparing the 2017 performance in the 2013 frontier are given in Table 2-2 below. It is correct that TenneT increased its Totex by 30% in real terms during 2013-2017 with an increase of the grid at about 13%, transformers 6% and line length 3%. In 2013, TenneT had an efficiency score similar to that of 2017 (69.9% vs. 71.5%) and consequently the performance for the operator degraded during the period.

Table 2-2 Efficiency scores 2017 data in 2013 frontier, Base model.

	Frontier (2017|2013)	Frontier (2013|2013)	Change 2017/2013
Totex (real, 2017)	321,242,361	246,639,367	+30.2%
Score (DEA)	0.591	0.699	-10.9%
Efficient Totex	189,749,220	172,371,493	
Change in Efficient Totex	17,377,727		
Share of change in Totex	23.2%		
NormGridArea	338,973,131	298,865,831	+13.4%
TransformerPower	39,990	37,789	+5.8%
Lines.share.steel.angle	1966.593	1909.053	+3.0%

2.41 Oxera (2020) makes generally the claim that TenneT would be erroneously classified as inefficient due to high recent investments. However, this can be refuted just considering a comparative analysis of the major peer for TenneT in Table 2-3 below. The operator has a real growth in all outputs that is higher than that of TenneT, implying substantial investments, yet the increase in Totex over the period is well contained to less than 20%. The score for the peer increases during the period in recognition of this performance. Contrary to the perceptions in Oxera (2020) it was demonstrably possible to invest and expand the grid assets of different types during the specific period without incurring abnormal increases in Totex. Naturally, it is beyond the TCB18 study to exactly determine how the various operators achieved these results, the processes deployed and the detailed type of assets procured.

Table 2-3 Comparative data 2013-2017 for a TenneT peer, Base model.

	Change 2017/2013
Change in Totex	+19.7%
Score (DEA)	+7.9%
NormGridArea	+14.9%
TransformerPower	+19.1%
Lines.share.steel.angle	+12.6%

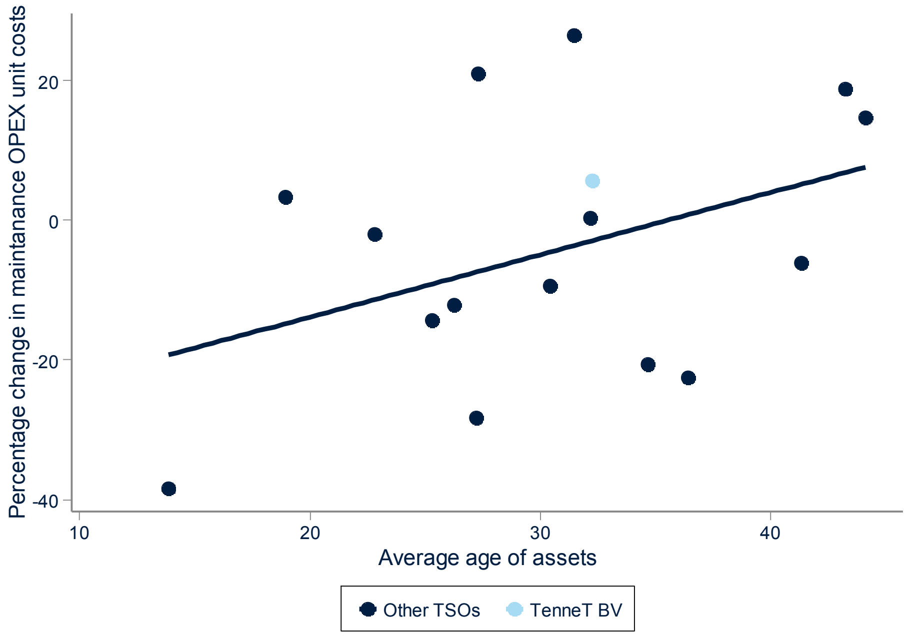
2.42 Another hypothesis in Oxera (2020) points out an exceptionally old grid as the reason for the high cost increases in 2013-2017. However, the asset ages for TenneT's assets are outside of the confidence interval only for lines and cables, cf. Figure 8 below. For other assets, such as transformers, control rooms, circuit ends and other components of substations, the ages are in the 25% confidence interval for TCB18. For special installations, TenneT has a significantly lower age than the sample.

2.43 Even considering the older assets, the generalization in the claim does not take into account the share of capital or Normgrid that is allocated to the different assets. E.g., relatively young substation equipment (transformers and circuit ends) may have a compensatory effect on any alleged age effects. It should also be noted that the acquisition of the older assets, primarily HV overhead lines, occurred relatively recently. As seen from the asset ages in 2006-2009, Figure 9 the situation of TenneT in the e3GRID benchmarking was the opposite, a young network in all asset categories. Nevertheless, the score for Opex-efficiency in the e3GRID 2009 model was 76%, indicating an endemic inefficiency independent of asset age. The hypothesis that TenneT suddenly would be inefficient only due to ageing assets must therefore be questioned on two grounds: (i) the incumbent inefficiency prior to the acquisition is similar to the one estimated in TCB18 with a far younger network, (ii) capex inefficiency for recently acquired used assets would suppose a changed asset management policy exceeding the expected Totex annuity, i.e., the replacement cost. The former observation speaks in favor of rather investigating organizational costs than asset features, the latter would contradict a prudent asset management and investment behavior.

2.44 Additionally, the unsupported claim for the rapid increase in Opex is not substantiated by any clear tendency in the highly volatile costs for maintenance and operating expenditure in general, see Figure 6 and Figure 7 below.

2.45 The regression in Figure 3.1 (Oxera (2020), reproduced below) is not based on significant parameters,. Although no data is included in Oxera (2020), our reproduced regression results in Table 2-4 confirm the analyses in TCB18 that the age effect indeed was insignificant in the sample. The dependent variable in the model is the unit cost development between years per operator, explained by average asset age and an intercept. The age parameter is not significant and close to zero. These results (also valid for asset classes lines, cables and transformers, both under normal and robust regression) were indeed shown and explained during W3 of TCB18. We illustrate the effect by coloring the confidence interval for the regression line in grey in Figure 5 below. The direction of the slope is not decided, although visually it looks like in the Oxera (2020) illustration.

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



Source: Oxera analysis of TCB18 data.

Figure 4 From Oxera (2020: Fig 3.1) age vs maintenance cost changes.

Table 2-4 Regression results, unit cost vs asset age for lines, TCB18-ELEC, n =16.

	Dependent variable:
	uc_m_dev
agem	0.004
	(0.007)
Constant	1.044***
	(0.237)
Observations	16
R^2	0.023
Adjusted R^2	−0.047
Residual Std. Error	0.198 (df = 14)
F Statistic	0.322 (df = 1; 14)
Note:	*p<0.1; **p<0.05; ***p<0.01

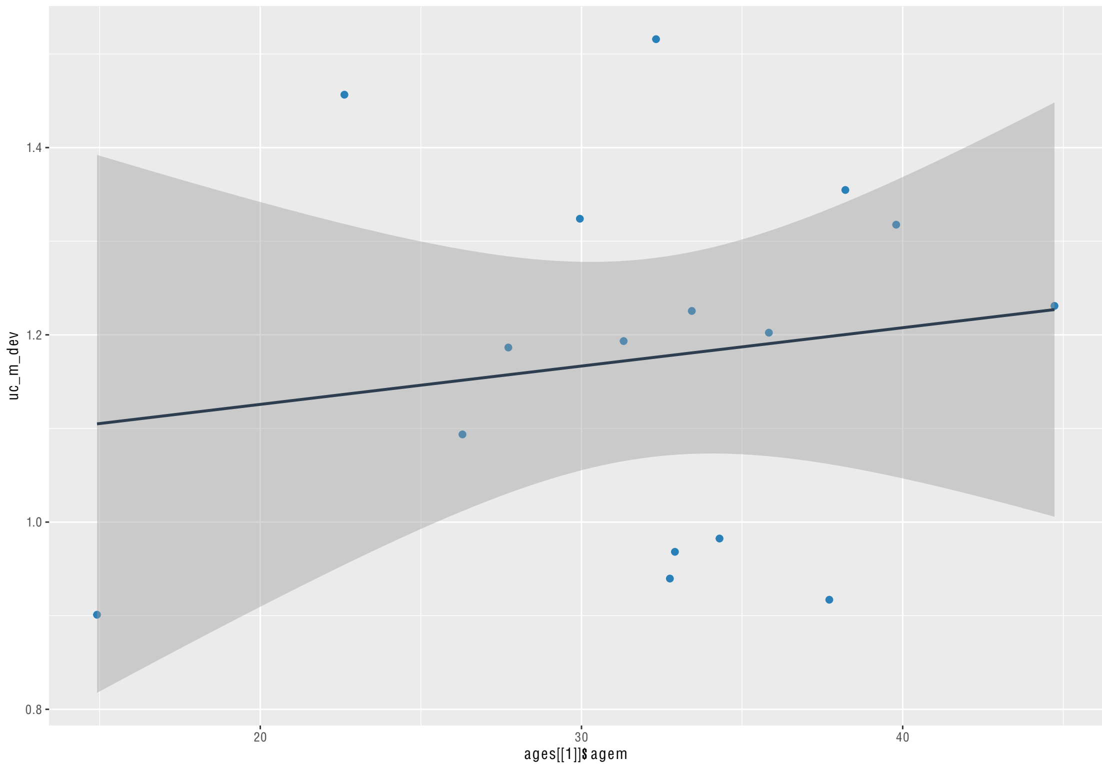
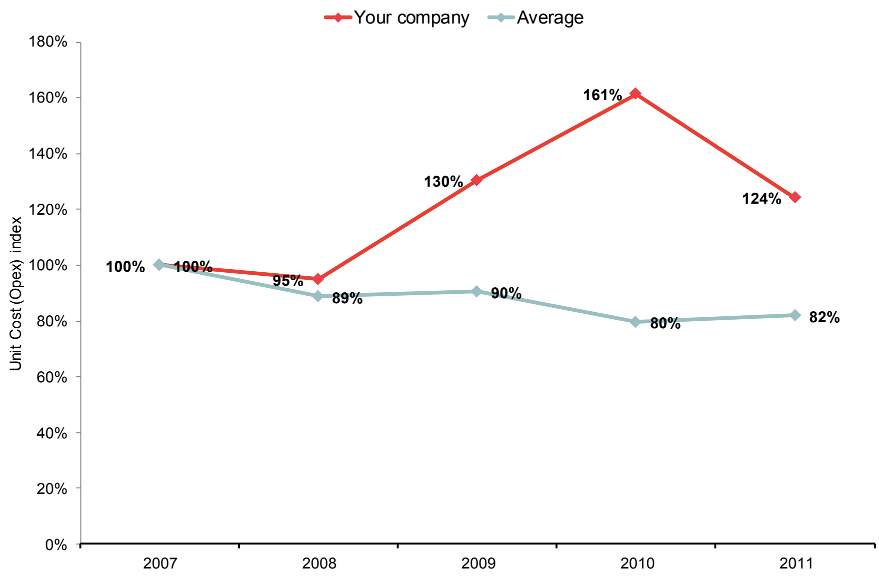


Figure 5 Change in Maintenace cost vs mean asset age, TCB18-ELEC.

2.46 The idea of a validated exogenous asset health indicator is hypothetical, such data does not exist. Besides, the idea of Totex and annuities is also to indicate that the rational TSO should replace the asset at the time when the Totex annuity exceeds the annuity for a replacement investment. Driving assets beyond a level with a "sharply increasing maintenance cost" cannot be representative of good asset management. Consequently, the model should not artificially correct for investment patterns that are not rational.



Source: Frontier/Sumicsid/Consentec

Figure 6 Opex development 2007-2011 for TenneT and average TSO in e3GRID 2012.

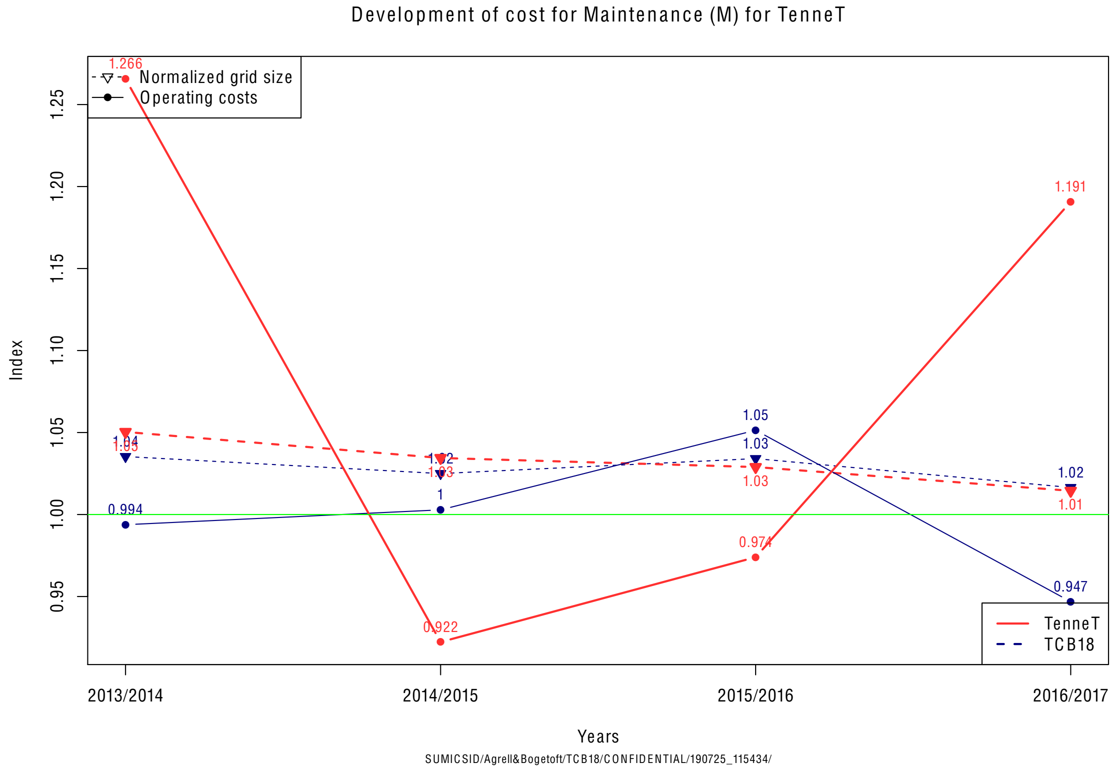


Figure 7 Maintenance cost development, TenneT 2013-2017, TCB18.

2.47 The Oxera (2020) proposal is boosting the efficiency for TenneT, not by correcting the asset age cost function, but by introducing an additional variable for which a number of TSOs have a lower output. In DEA, the weights for the virtual output in the calculation are set individually for each operator such that they maximize the score. It is therefore expectedly a bias in favor of TenneT in this simulation. An analogous result aiming for an arbitrarily high efficiency can be obtained by introducing any additional variable defined as to exclude all comparators. However, it is hardly considered an admissible practice in benchmarking.

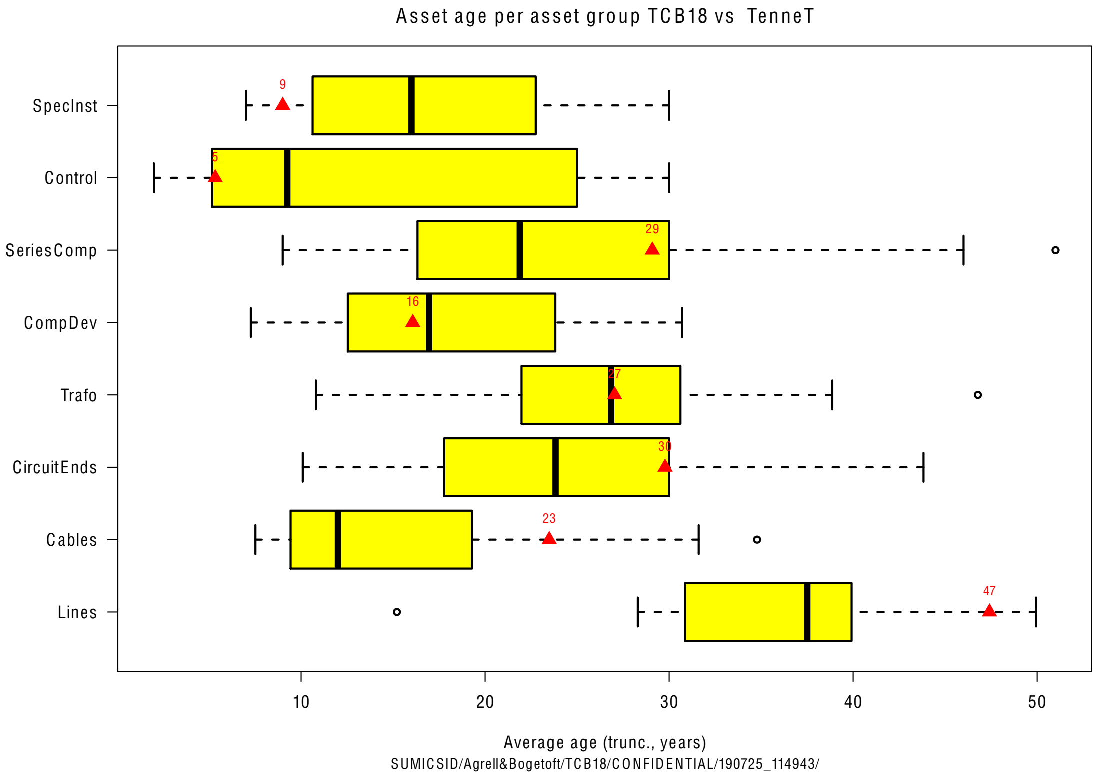


Figure 8 Asset age per asset group in 2017, TCB18-ETSO vs TenneT.

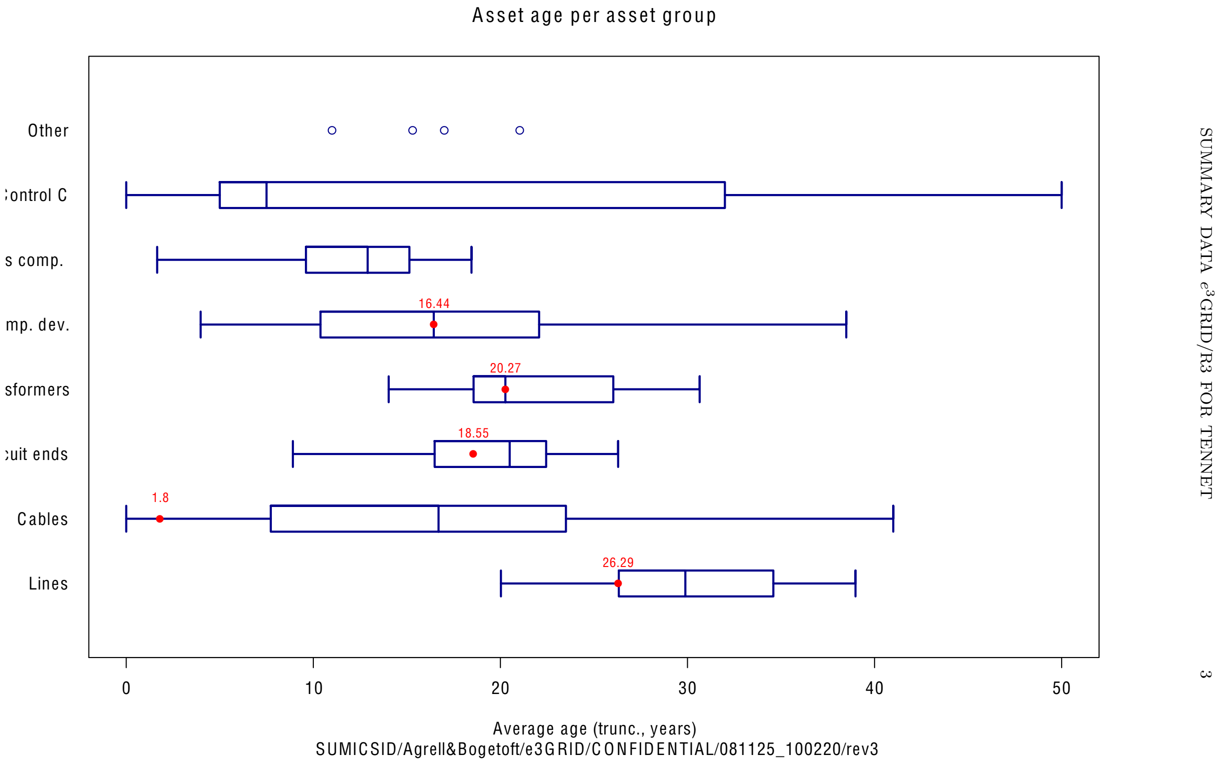


Figure 9 Asset ages for TenneT TSO in 2006, e3GRID 2009.

2.48 Unit cost for Capex is increasing over time in TCB18, this is due to an incorrect inflation adjustment factor. [Section 3.2]

2.49 TenneT has invested 30% more than an average TSO 2007-2017 (CAPEX change). This penalizes TenneT since new investments are more expensive than in the past, not corrected for in the TCB18 model. [Section 3.2.1]

2.50 If a four-parameter model is used, DSO-transformers are added to TenneT and average Unit cost is used as deflator rather than inflation, then the score for TenneT is 93.6%-97.5%. [Section 3.2.3]

2.51 It is generally established practice to use an exogenous price index for inflation control, rather than using the actual prices or investment volumes for the units included. The investment costs experienced by the units, in particular prior to incentive regulation, are likely to include inefficient expenditure. If the cost development or level are derived directly from this data, the purpose and method of the benchmarking are seriously void. In selecting the best possible inflation index, attention should be paid to the quality, availability and fit of the index. The methodological quality of the HICP indexes from EUROSTAT compared to general CPI-indexes from World Bank of OECD is well established. The sensitivity for the inflation adjustment method has been investigated in the Agrell and Bogetoft (2020), showing great stability for most operators using the 35 different combinations of the publicly existing inflation indexes. The average static efficiency score ranges from 83.7% to 91.5%, whereas HICPOG yields 89.8%.

2.52 TenneT has recorded high Capex even in earlier benchmarking (ECOM, e3GRID 2009, 2012) seen as Unit Cost. It is therefore a repeated observation that TenneT has shown proof of cost inefficiency in international benchmarking under several different inflation adjustment methods, the finding in TCB18 is not unique.

2.53 Concerning the investments, Fig 3.2 in Oxera (2020) shows a larger investment ratio than the average TSO for 2007-2017. However, the same conclusion is not valid if the horizon is opened to a longer perspective (Figure 10 for 1973-2017) or to physical measures of investments (growth of line length or transformer power) where TenneT is below average. As shown from the small example in Table 2-3 for a peer, TenneT has had higher costs but lower capacity growth than comparable operators: the illustration in Fig 3.2 is merely the amounts paid, not the actual outcome. As seen above, TenneT has not invested more globally, nor in real terms, but they have invested in a more expensive way than best practice. Ad hoc corrections to increase the unit cost over time would not change the conclusion for TenneT if it was done consistently for all, since peers in that case would appear even stronger. However, a biased ad hoc correction to explain the cost increases by an operator by the very same cost increases disguised as 'inflation adjustments' is incorrect.

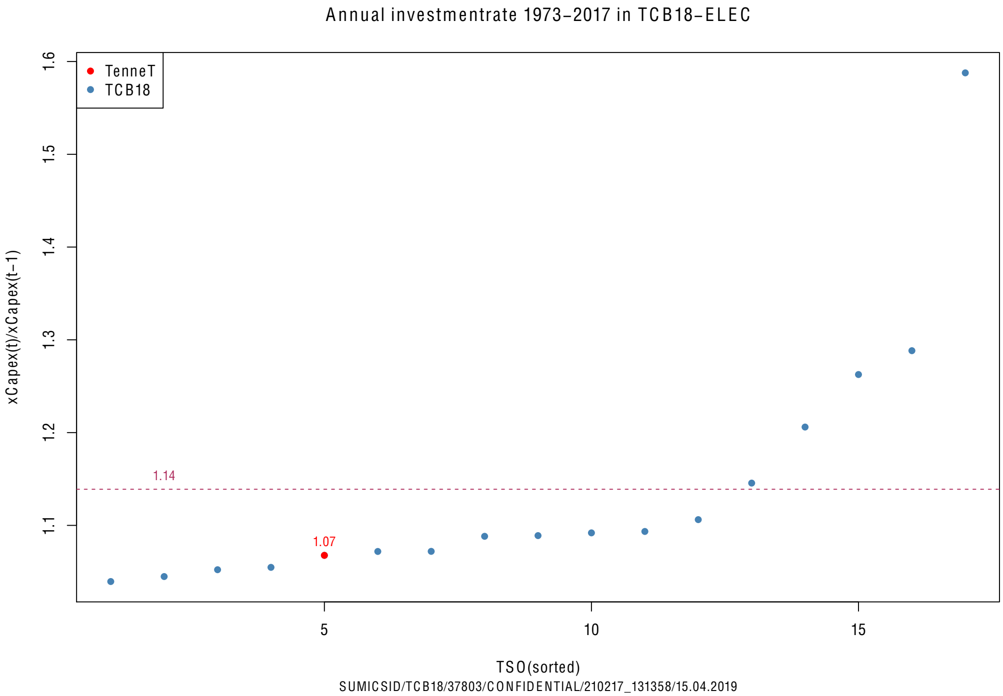


Figure 10 Investment rate, real terms (Capex ratio), 1973-2017.

2.54 Oxera (2020) makes a simulation using average Unit cost per year as index. As mentioned above, this cancels the detection of dynamic inefficiency as the cost increases are interpreted as inflationary. In addition, it introduces random noise as all TSOs do not invest in all types of assets every year. Before 1990, 3-7 TSOs record annual investments in any given year, meaning that the average unit cost will be heavily dependent on the operators investing. The procedure therefore introduces a clear bias in favor of TSO with long investment streams and large incumbent investment efficiency, since these are heavily reduced or considered as fully efficient. Their hypothesis would give a completely different cost development estimate than any known and validated inflation series, leaving no empirical correspondence in cost development or in applied benchmarking.

2.55 The numeric estimates for the efficiency are grossly inflated with (i) changing the dimension of the model, (ii) adding extra DSO transformers and (iii) the capex readjustment. It is not clear how this change alone would affect the average score and its distribution, also given the uncertainty for the selective data and the approximative cost estimations.

2.4 Population density [Oxera, ch 4]

2.56 Oxera (2020, Chapter 4) is iterating the claim that density should be included in the model as a valid cost driver.

[Oxera, section 4.1-4.3]

2.57 The environmental adjustment in TCB18 correlates with lower unit cost [Section 4.2]

2.58 Forest is the primary driver of environmental complexity in TCB18. [Fig 4.2]

2.59 TenneT is benchmarked against peers with lower density [Table 4.2]

2.60 A model with DSO-transformers added and density will make TenneT 94.3%-100% efficient in 2017, including 97.5% with a 10% weight restriction like in e3GRID [Table 4.4].

2.61 The regression on environmental adjustments (unit cost against the factor) is invalid. None of the regression coefficients shown are significant, the demonstration has no statistical support. The result is likely due to the fact that the simple relationship ignores the other parameters that have an effect on Totex. DEA is used specifically since the other variables also affect cost, including the level of efficiency.

2.62 Oxera (2020) argues implicitly that density is the only valid cost driver, ignoring the Normgrid engineering report documenting the cost impact from various environmental factors. The support for the environmental factors is defined prior to the data collection in TCB18, based on exogenous sources. Thus, the established factors for other conditions remain valid although not applicable to TenneT. The environmental multipliers are validated by several studies, as also noted in Sumicsid (2018). Naturally, the numerical estimates for the factors depend on the data and circumstances for the observations which is also why the engineers suggested median values rather than point estimates.

2.63 The discussion on density is missing a number of important facts. First, density measured as population per area is not a cost driver for electricity transmission as such. Density is a proxy for the cost increasing impact of physical obstacles; infrastructure, buildings, roads and rail, industry and parks that force underground cables, by-passes or specific installations to be constructed. Compared to most published studies merely using circuitlength as grid measure, TCB18 is already largely addressing these elements explicitly through the NormGrid, where additional or overdimensioned assets are recognized as output, and through the angular-line output, correcting for routing complexity occurring due to densely constructed area.

2.64 However, the same impediments are also occurring when facing other obstacles outside of cities; waterways, forests, hills, wetlands, infrastructure (airport, ports, et c). In TCB18 all these environmental complexities are considered equally based on the detailed GIS data, directly going to the source rather than using a proxy. The Area measure is both cost relevant and neutral in that a specific terrain (say, infrastructure land) is considered equally difficult for any TSO, irrespective of how many residents live in the area. The same logic applies to the other environmental factors for slope, wetness and subsoil structure as well.

2.65 The impact of specific factors is also much more limited than alluded to in Oxera (2020). The claims that "[i]t is unclear why Sumicsid determined forests to be the primary driver of environmental complexity" is incorrect, forest conditions are not considered to be the most severe by the engineers. The complexity factors are given in Table 2-5 below. It shows that the highest weight is given to infrastructure (3.5), whereas forests are given 1.55. The determination of the exact weights by the engineering team is explained in Sumicsid (2019, section 5.2). In the underlying report from Black and Vetch for the Western Electricity Coordination Council, four different engineering studies are compared and the paper states: "*Black & Veatch identified nine different terrain types and then reviewed available data to locate terrain multipliers for difficulty of construction. From a construction difficulty perspective, the easiest was identified as scrub or flat terrain, and the most difficult was forested areas.*" Our engineers have no original data to confirm or refute the US research with respect to forest construction. However, the sensitivity with respect to the complexity factors is very low. For instance, even if the forest factor were to be set to base level (1.0) meaning that constructing lines in a forest would give the same cost impact as wasteland, the efficiency of TenneT only shifts to 77.2%. Oxera (2020) obtains more extreme values by compounding their radical increase of transformer power with other minor changes.

Table 2-5 Complexity factors for Landuse, TCB18-ELEC.

Variable	Definition	Factor
yShare.area.urban.tot	City areas	1.50
yShare.area.infrastructure.tot	Road, rail, port, airports	3.50
yShare.area.cropland.tot	Agricultural area, cultivated	1.00
yShare.area.woodland.tot	Forest	1.55
yShare.area.grassland.tot	Grass and meadows	1.00
yShare.area.shrubland.tot	Shrubs and bushland	1.10
yShare.area.wasteland.tot	Land without use	1.00
yShare.area.wetland.tot	Lakes, rivers, ponds	1.20
yShare.area.otherw.tot	Other land	1.00

Table 2-6 Complexity factors for Slope, TCB18-ELEC.

Variable	Terrain (slope) feature	Factor
Flat land	Flat	1.00
Undulating	Undulating (slopes < 10 %)	1.20
Hilly terrain	Hilly (10 % < slopes < 30 %)	1.40
Mountains	Mountainous (slopes > 30%)	1.75

2.66 A regulatory benchmarking must also by an equitable and fair exercise for all operators. As TenneT has the highest density in the sample, it is obvious that the peers have lower density. However, this is not to say that they do not have other significant environmental challenges, relevant to TenneT and to operating cost. In e3GRID, a density measure was chosen as only environmental proxy, in line with some academic papers, to capture heterogenous operating conditions. For TCB18, the ambition was higher involving an ambitious collection of detailed GIS-data for topography (slope, ruggedness, coastal position), vegetation, landuse (including urban, infrastructure, agricultural, forest, mountains, etc), soil conditions, subsoil structure and humidity conditions (wetness and water). The general impact of indicators was first evaluated by the engineering team, without using the TCB18 data, then fitted to the actual data. The TCB18 process and data considerably enhanced the environmental modelling in the project in comparison to e3GRID and the single density factor. The proposal by Oxera (2020) is entirely driven by the technical conditions in DEA, leading to a higher score for a single operator, ignoring the fact that dense area is already included as such in the landuse parameters. The constructive approach chosen in TCB18, developed from e2GAS, is clearly the most comprehensive environmental modelling used in regulatory benchmarking. Resorting to an operator-driven "cherry-picking" of specific indicators for which one or several operators score highly is not conducive to robust and informative benchmarking.

2.67 The simulation in Oxera (2020) for the density model includes the DSO-transformers which likely, in combination with the density, transforms TenneT to an extreme operator. It is therefore possible that TenneT becomes an outlier for most formulations. Density is used in the model as a proxy for a number of cost impacts, *in relation to actual grid assets*. Per se, a higher density does not change the cost of already installed and operating assets. However, the individual weights in DEA for an extreme case like TenneT would be completely allocated to density, as if the only valid cost driver for TenneT would be its location. Combining this extreme effect with the earlier dubious ad hoc addition of DSO data makes the efficiency score anecdotical.

2.68 Including density as a separate parameter in the TCB18-model is a deterioration of the quality of the model, and useless without weight restrictions. The real costincreasing effects of landuse, slope, subsoil and wetness are addressed by including the relevant data for the area affected by the condition, not the proxy of population per square that only considers one type of complexity. The problems related to urban constructions are covered through the NormGrid and the angular-lines output parameters, compensating for longer lines, more cables, more difficult routing and more substations. Methodologically, the landuse parameter in itself dominates any partial solution such as population density.

2.69 Density is ultimately a dummy-variable for TenneT, as such it will always provoke high scores for itself and little effects on other operators. The data for DSO used in Oxera (2020) are not representative of TSO operations.

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