Project TCB21
Individual Benchmarking Report
TenneT - 349

ELECTRICITY TSO
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Executive Summary

In the CEER Transmission System Cost Benchmarking Project (TCB21) the efficiency for the electricity transmission system operators is estimated using two base models in Data Envelopment Analysis (DEA); E2388.V2.4 and E3395.V2.4 ; along with variants corrected for environmental factors; E2388.V2.4.env2 and E3395.V2.4.env2 . The models (see section 2.3) are solved in DEA using non-decreasing returns to scale, excluding outliers, primarily for 2020.

TenneT has been classified as cost inefficient in 4 models. The results show the scores 84.53, 72.65, 71.65, 71.65 percent , respectively, in model(s) E2388.V2.4, E2388.V2.4.env2, E3395.V2.4, E3395.V2.4.env2 . Compared to the average performance in the electricity panel, TenneT scores below the mean in all 4 models.

The support for the cost efficiency scores has been established using five analyses in this report: scale efficiency (section 3.2), partial opex-capex efficiency (section 3.3), peeling efficiency (section 3.4), robust efficiency (section 3.5), and cross efficiency (section 3.6).

The direct and indirect causes for the efficiency results for TenneT are naturally multiple and linked to the history and structure of the operator. Here, we briefly comment on the dynamic cost development compared other TSOs, see Chapter 5.

Over the period, TenneT has regressed in productivity (absolute) and in efficiency (relative to the sample). This negative development explains part of the efficiency results. The average productivity change for TenneT is -4.93 per cent per year and the average efficiency regress is 3.75 percent per year.

For, TenneT Totex has changed by 5.23 per cent per year whereas the mean grid output has changed with 1.49 percent per year over the period 2016-2020. The change in Totex is higher than the mean increase for the sector. The grid growth has been weaker than the mean output growth in the sector.

TenneT changed Opex by 4 per cent per year for the period, which is higher than the mean change in the sector at 2.85 percent per year. This has contributed to weaken the relative opex-efficiency for TenneT.

Capex surpassed grid growth for TenneT by 6.37 per cent per year compared to the sector with a mean excess of 10.88 percent per year. The relative position to the sector improved. This contributed positively to the efficiency score for TenneT in 2020.
More clues about probable sources of performance differences linked to the age structure (section 2.5), cost structure (section 2.6) and general profile TenneT are found within the indicators and KPIs in section (section 2.7).

Finally, there are also model-based factors that may have an impact on the result for TenneT such as the interest, inflation and salary indexes, age-limits, overhead allocation and the environmental factors used to control for operating complexity. The direct impact of changes in these on the score for TenneT are reported in the sensitivity analysis (see section 4) with details in Appendix.

Acronyms

Table 0.1: Acronyms in the report.

Acronym	Definition
CAPEX	CAPital EXpenditure
CEA	Cross Efficiency Analysis
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DRS	Decreasing Returns to Scale
ex.asep	excluding asset-separated operators
exo	excluding outliers
fte	full time equivalents
I	Indirect support services (activity)
L	LNG terminal services (GAS only, activity)
M	Maintenance services (activity)
NDRS	Non-Decreasing Returns to Scale
O	Other (out-of-scope) services (activity)
OPEX	OPerating EXpenditure
OS	Optimal scale of operations
P	Planning services (activity)
RDEA	Robust DEA
S	System operations (activity)
SE	Scale Efficiency
T	Transport services (activity)
TCB21	(CEER) Transmission Cost Benchmarking project 2021
TO	Offshore transport services (activity)
TOTEX	TOTal EXpenditure
UC	Unit cost (cost per NormGrid or physical unit)
UCC	Unit cost Capex
UCO	Unit cost Opex.
UCT	Unit cost Totex.
VRS	Variable Returns to Scale
X	Market facilitation services (activity)

Chapter 1

Outline

The following material is a summary of results, descriptive data and sensitivity analyses for TenneT with code number 349 in the TCB21 benchmarking based on data processed 15/08/2024. This release is exclusively made to the authorized NRA and the information contained in this release is not reproduced as such in any other project report for TCB21. All underlying information in this release is subject to the confidentiality agreement of TCB21. This report with associated data files is part of the final deliverables for the TCB21 project. The contents of this report is strictly confidential.

The benchmarking model of the TCB21 project uses a total expenditure measure as input and the costs drivers listed in section 2.3 below. In addition, it is a Data Envelopment Analysis (DEA) model which means that it determines the best practice among the TSOs and uses this as the standard for evaluating each of the firms in the sample. Indeed, one major advantage of DEA compared to e.g. statistical (parametric) benchmarking models is that the improvement targets are defined by one or several identifiable units in the sample that can be reviewed for comparability beyond the mere data specification.

DEA constructs a best practice frontier by departing from the actual observations and by imposing a *minimal set of additional assumptions*:

1. One assumption is that of *free disposability* which means that one can always provide the same services and use more costs and that one can always provide less services at given cost levels. In the base model, this is an entirely safe assumption, but it does allow us to identify more comparators for any given TSO.

2. Another assumption is that of *convexity*. It basically means that one can make weighted averages of the performance profiles of two or more TSOs. This is a more technical assumption widely used in economics.

3. The third assumption is that of *non-decreasing returns to scale* or as it is sometimes called, *(weakly) increasing returns to scale*. It means that if we increase the costs of any given TSO with some percent, we should also be able to increase the service output, the costs drivers, with at least the same percent. We can also formulate this as an assumption that it can be a disadvantage to be small, but not to be large. It is important that this assumption is not just imposed *ex ante*. The statistical analysis of alternative returns to scale models suggests that it actually is a reasonable assumption to make in the sample of electricity transmission operators in this study.

The best practice DEA model and the theory behind it are further explained in the main report and its accompanying appendices. Some useful common notation is listed in Table 0.1

1.1 Project documentation

The project has advanced through activity definitions, data collection, verification and validation, thereafter model analysis and specification, prior to the presentation of preliminary findings and possible models at WS3. The individual report is not reproducing material from the common documentation below, to which we refer for any general information about the process, data, models and methods. In particular, the following project reports/notes are essential to the project methods, analyses and findings:

1. Note on Aggregation for Transparency, V1.0, 2022-04-07.
2. Note on Comparability, V1.1, 2022-09-08.
3. Note on Environmental Modelling, V1.4, 2023-01-13.
4. Environmental Analysis Matrix Electricity, V1.1, 2023-03-15.
5. Environmental Analysis Matrix Gas, V1.1, 2023-03-15
6. NormGrid Weights, V1.2, 2024-04-16.
7. Method and Calculations, V1.2, 2024-06-30.
8. Special Conditions Response Note, V1.0, 2024-06-30.
9. Model Specification GAS, V1.0, 2024-06-30.
10. Model Specification ELEC, V1.0, 2020-07-30.

The documentation also includes project presentations for common models that are not reproduced in this report, see the list below.

1. WS2 Benchmarking Development TCB18-TCB21, X02, 2022-06-22.
2. WS3 Model specification ELEC/GAS, V02, 2023-04-12.
3. WS4 Model results ELEC/GAS, V02, 2023-06-26.
4. WS5 Final model results ELEC/GAS V11, 2023-11-23.

The presentation material has been distributed to the participants before (draft) and after the workshops (final with minutes from the workshop).

1.2 Reading guide

The remainder of the report is divided into four main chapters with the following main contents:

2 *Data*, a chapter providing an overview of TenneT data (section 2.1), model inputs and outputs (section 2.3), technical profile compared to the other TSOs (section 2.4), age profile (section 2.5), cost structure (section 2.6) and a large set of indicators and KPIs to characterize the dataset and the position of TenneT in section (section 2.7).

3 *Results*, providing for each model the individual scores for TenneT and mean scores for the electricity TSOs. Sections in the chapter provide support for the scores in terms of Scale efficiency (Section 3.2), Partial Opex/Capex efficiency (Section 3.3),peeling DEA for validation of the thickness of the frontier and grey units in section 3.4, robust DEA results with confidence intervals in section 3.5 and dual price analysis in Cross Efficiency in section 3.6.

4 *Sensitivity analyses*, documenting the sensitivity of the DEA results with respect to the real interest rate (section 4.1), assetlife assumptions (section 4.2), labour cost indexes LCI (section 4.3), inflation indexes (section 4.5), and allocation rules for indirect costs (section 4.6).

5 *Cost development analysis* documents for TenneT and the reference set the development of total and partial cost measures over time, relative to the base cost, grid growth for TenneT and the mean TSO in TCB21, respectively.

Documentation for used parameter values, notation with formulae for the indicators in section 2.7, graphs for unit-cost values for capex and opex, as well as graphs for labour cost indexes per country are relegated to an Appendix.

Chapter 2

Data

The data collected in the TCB21 project is extremely rich and cannot be fully represented in a short summary. Hence, the reporting for each individual operator includes the following documents in addition to this report:

1. Asset sheet with Normgrid values, XLSX asset dump. Cf. 2.1.
2. Cost data sheet (Capex and Opex), XLSX cost dump
3. Variable data sheet, XLSX list of environmental parameters

2.1 Assetdata

Below in Table 2.1, we provide an overview of the model data used and some descriptive statistics for TenneT. The definitions of the NormGrid parameters are given below:

1. NGa - Normgrid (totex, annuity)
2. NGa.noage - Normgrid (totex, annuity), no age-limit for assets
3. NGCa - Normgrid (capex, annuity)
4. NGOpex - Normgrid (opex, annual), no age-limit for assets
5. pc - piece-count, corrected for ownership-share

Table 2.1: Detailed asset summary (usage share included) 2020

	Code	pc 2020	NGOpex	NGCa	NGa	NGa.noage	Mean.age
lines_cables	10	1,333	31,601	181,570	213,171	220,584	31
transformers	20	135	2,272	14,402	16,674	23,371	29
circuitends	30	2,653	53,750	119,225	172,975	222,223	34
compdev	40	111	671	10,735	11,406	12,100	17
seriescomp	50	44	139	1,648	1,787	2,504	35
cc	60	3	2,803	3,533	6,336	6,336	8
NORMGRID TOTAL	0	4,279	91,236	331,114	422,350	487,119	30

2.2 Capex-break

In the elec benchmarking, 0 operators were subject to the capex-break method described in the main report. The application of Capexbreak was not made to prevent an infeasible target, but to avoid an absurd datapoint.

2.3 Model input and output

The single input (Totex) and the relevant outputs for the benchmarking models for TenneT are listed in Tables 2.2 to 2.5 below. The exact calculation of the inputs and outputs is documented in the separate confidential spreadsheets provided for each TSO in the project.

Table 2.2: Model data, E2388.V2.4, 2020

Type	Name	Value	Mean	TSO/mean
Input	dTotex	349,950,687	195,946,005	1.79
Output	yCables_tot	1,806	436	4.14
Output	yLines.share_totex_angle.vsum	296,823	429,252	0.69
Output	yNGop_20	2,272	2,421	0.94

Table 2.3: Model data, E2388.V2.4.env2, 2020

Type	Name	Value	Mean	TSO/mean
Input	dTotex	349,950,687	195,946,005	1.79
Output	yCables_tot.cLSGG	3,359	831	4.04
Output	yLines.share_totex_angle.vsum.LSGG	466,147	765,442	0.61
Output	yNGop_20	2,272	2,421	0.94

Table 2.4: Model data, E3395.V2.4, 2020

Type	Name	Value	Mean	TSO/mean
Input	dTotex	349,950,687	195,946,005	1.79
Output	yTransformers.power.ehv	40,899	26,060	1.57
Output	ySubstations.hv	277	116	2.38
Output	yNGOex.agecorr_trafo.subst	35,970	45,180	0.80

Table 2.5: Model data, E3395.V2.4.env2, 2020

Type	Name	Value	Mean	TSO/mean
Input	dTotex	349,950,687	195,946,005	1.79
Output	yTransformers.power.ehv	40,899	26,060	1.57
Output	ySubstations.hv	277	116	2.38
Output	yNGOex.agecorr_trafo.subst.LSGG	56,489	79,985	0.71

2.4 Profile

The specific profile of TenneT compared to the other operators in TCB21 is illustrated in Figs. 2.1 to 2.4 below. For each model, the level for TSO TenneT is indicated in red and in blue the median level for the TSOs in TCB21 for 2020.

The relative gridsize in Fig. 2.5 depicts the gridsize (measured in NormGrid)of the reference set, scaled such that the mean is set to 100, compared to the size of TenneT. This analysis gives an impression of the scale differences in the benchmarking.

The routing complexity is analyzed in 2.6 below. TenneT is marked with a red triangle, overhead line per tower and the share of angular towers on the horizontal axis.The figure graphs the circuit length tower on the vertical axis, potentially indicating either a technical choice of smaller towers or topographical challenges

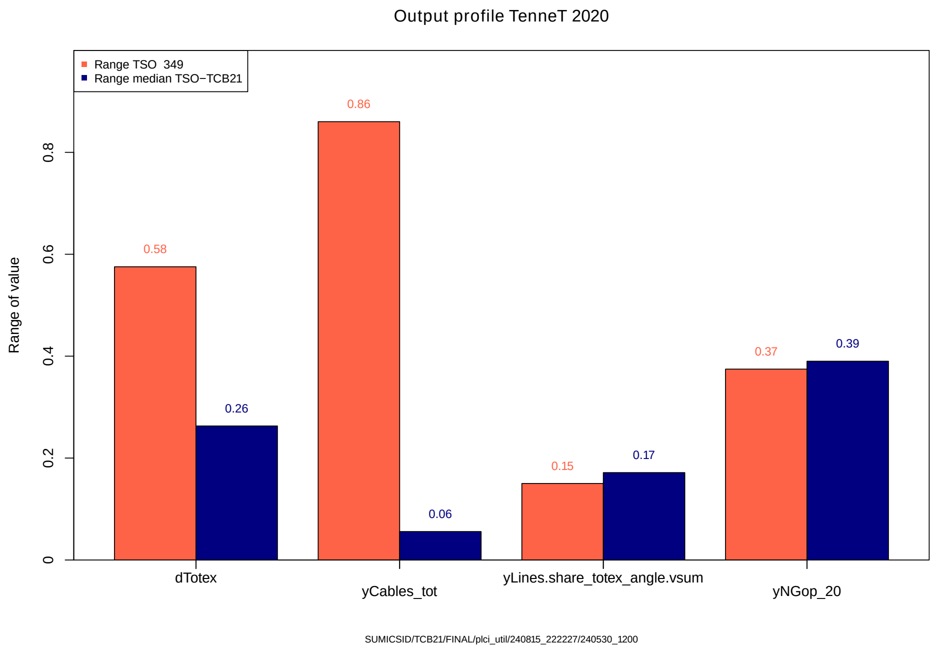

Figure 2.1: Inputs and outputs compared to median range in TCB21 (0.0 = minimum, 1.0 = maximum) for TenneT in model E2388.V2.4 , 2020 .

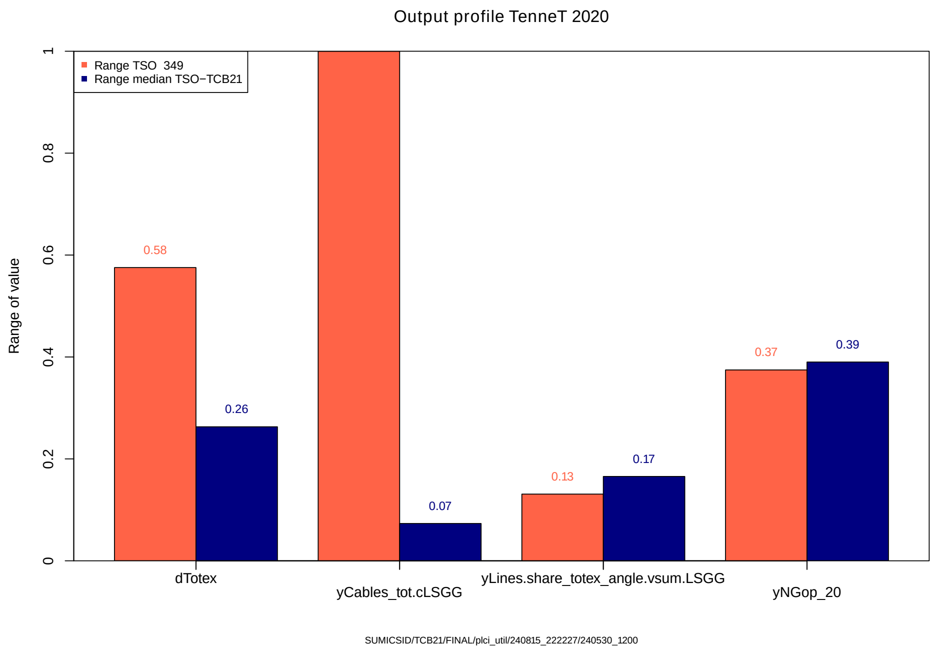

Figure 2.2: Inputs and outputs compared to median range in TCB21 (0.0 = minimum, 1.0 = maximum) for TenneT in model E2388.V2.4.env2 , 2020 .

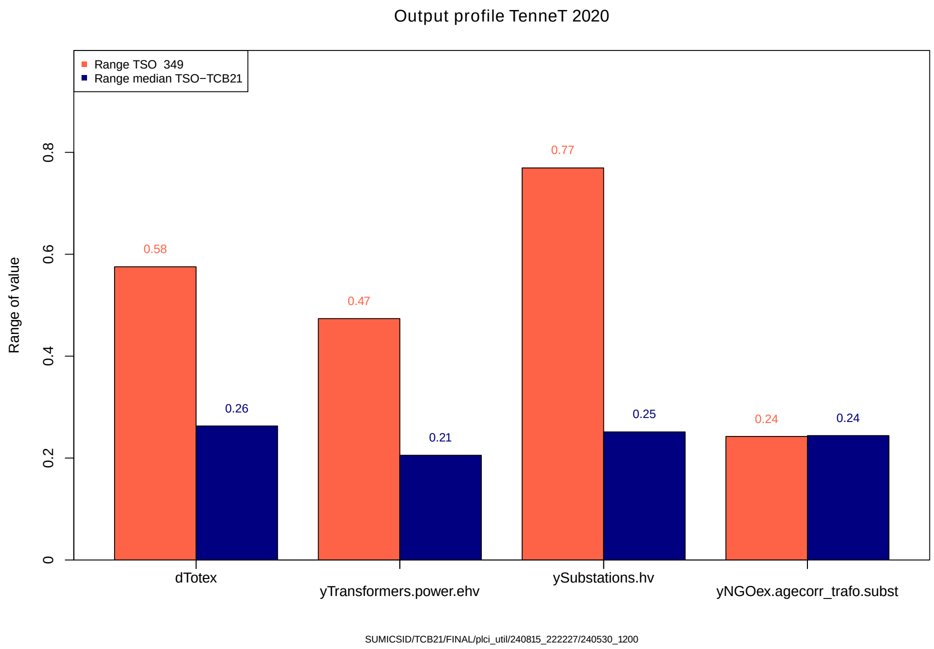

Figure 2.3: Inputs and outputs compared to median range in TCB21 (0.0 = minimum, 1.0 = maximum) for TenneT in model E3395.V2.4 , 2020 .

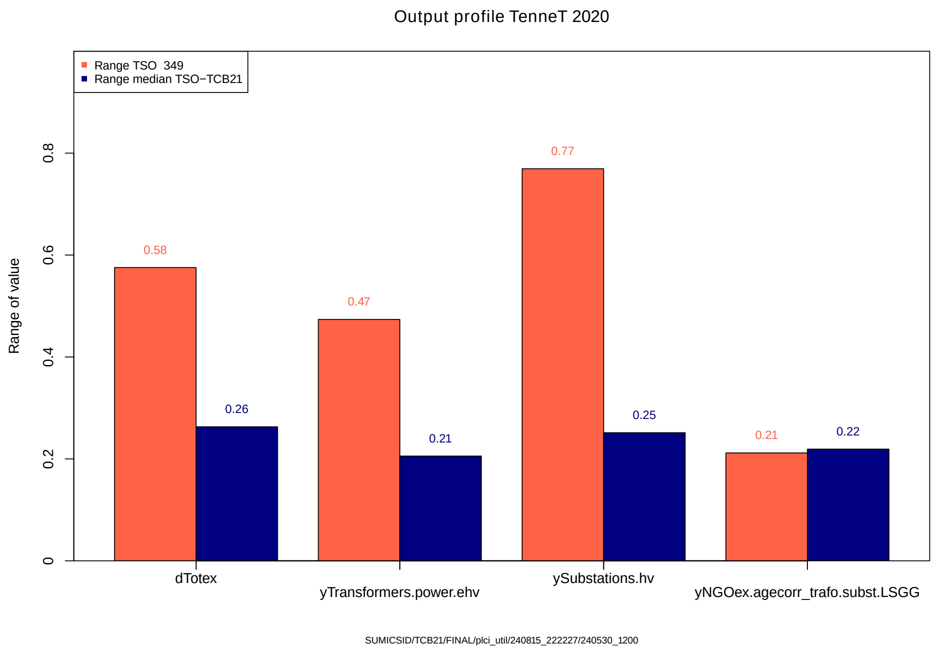

Figure 2.4: Inputs and outputs compared to median range in TCB21 (0.0 = minimum, 1.0 = maximum) for TenneT in model E3395.V2.4.env2 , 2020 .

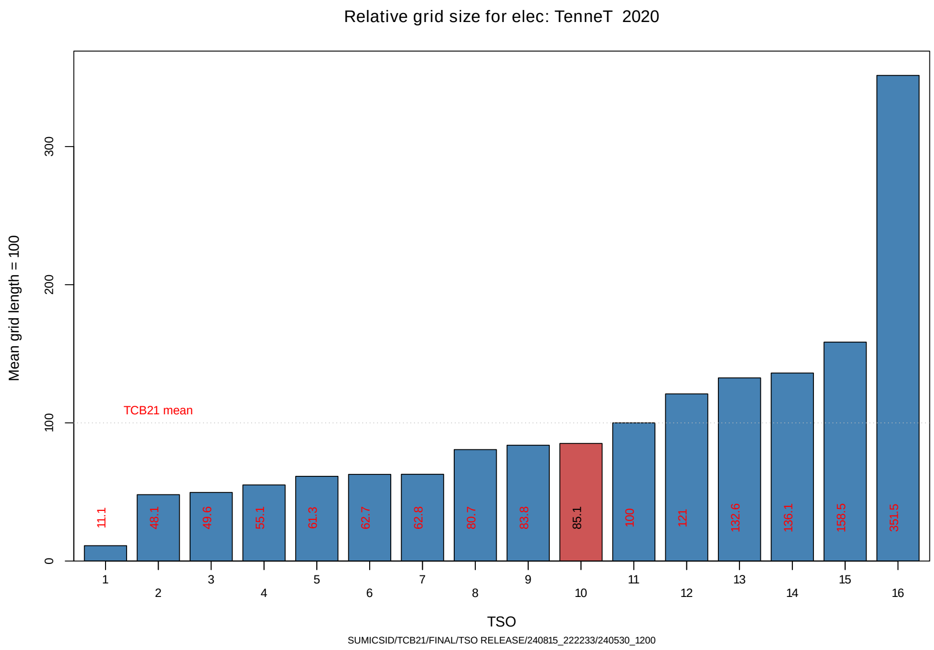

Figure 2.5: Relative gridsize in TCB21, (100=mean level in 2020).

(slope, subsoil quality, other obstacles).On the horizontal axis we plot the share of angular towers to the total number of towers. This indicates the routing complexity in terms of landuse and infrastructure obstacles. The output variable yLines.share-totex-angle-vsum is plotted in 2.7 below with TenneT marked as a red triangle. This figure can be compared to the gridsize figure in 2.5 in terms of ranking in size and routing complexity.To illustrate how the output variable yLines.share-totex-angle-vsum normed per circuitkm, compares to population denisty, we offer 2.8. A higher intensity of routing complexity (x-axis) implies higher capex due to higher incidence of angular towers and/or higher dimensions.

2.5 Age

The age profile of the European operators in comparison to TenneT is illustrated in Figs. 2.9 and 2.11 below.

In Figure 2.9 the ages for all assets in the electricity dataset have been processed as a confidence interval, the yellow box marks the mean in bold black, the box edges are 25% and 75% quartiles and the outer whiskers are limits for one standard deviation up or down, respectively. The mean ages for the assets per type for TenneT are indicated with a red triangle and a (rounded) number. A circle to the left or right of the confidence interval box indicates an outlier.

In Figure 2.10 we investigate the prevalence of overage assets (older than the techno-economic standard age, see Table 4.1) that are still used in 2020. The bars depict the average share of capital for different asset types on the vertical axis. The respective asset ages for TenneT are depicted using red symbols, the blue symbols depict the mean age and shares, respectively, in the TCB21 project. Figure 2.11 depicts the corresponding pattern for piece-count, comparing the share of overage installations of each assettype.

2.6 Cost analysis

In this section we analyze the staff profile, the functional costs and the overhead allocation share for TenneT compared to the electricity operators in TCB21. The cost analysis is purely informative and does not intervene as such in the benchmarking. Using regression we may estimate the expected staff for TenneT based on a

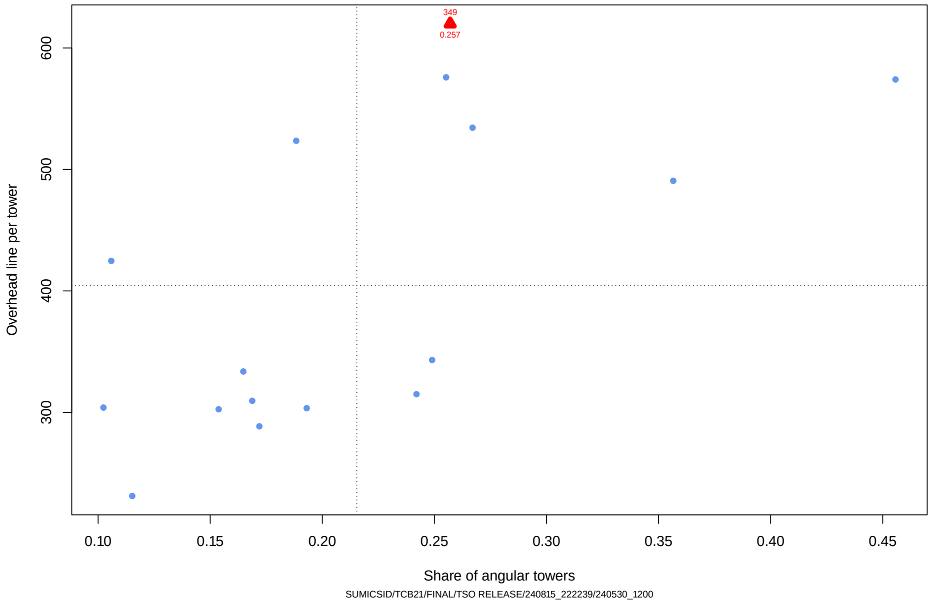

Figure 2.6: Linelength per tower and share of angular towers 2020.

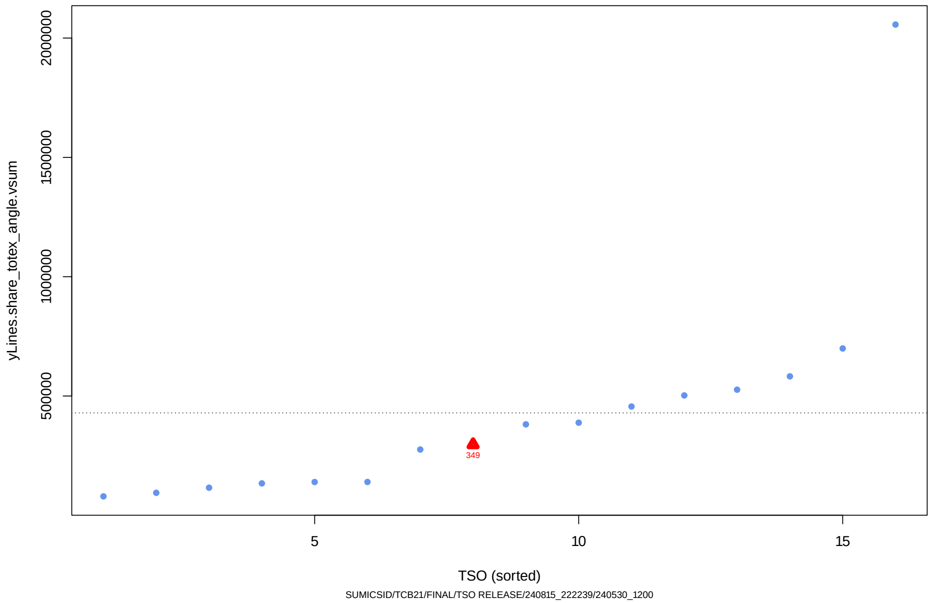

Figure 2.7: Output yLines-share-totex-angle-vsum, sorted in absolute value.

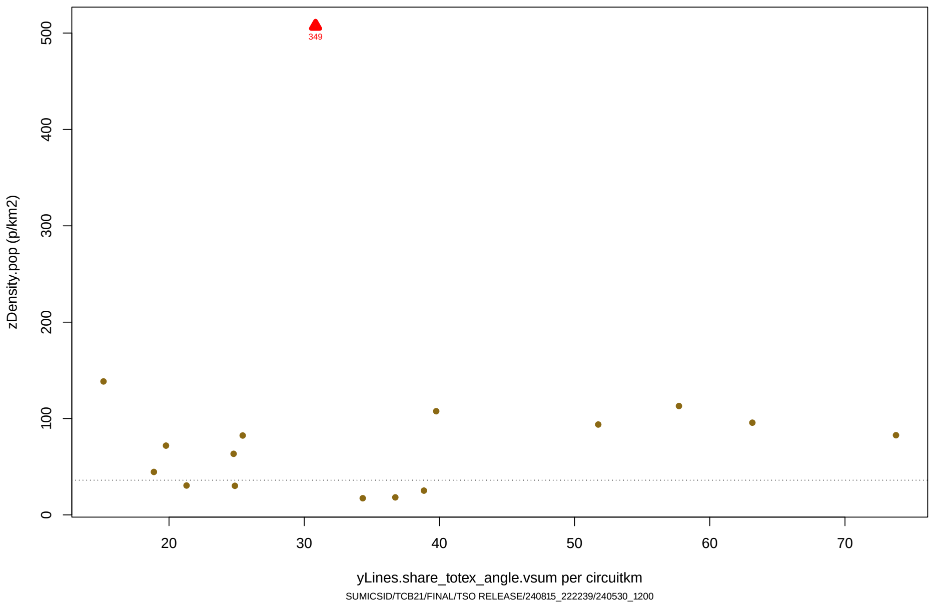

Figure 2.8: yLines-share-totex-angle-vsum vs population density (EUROSTAT,2020).

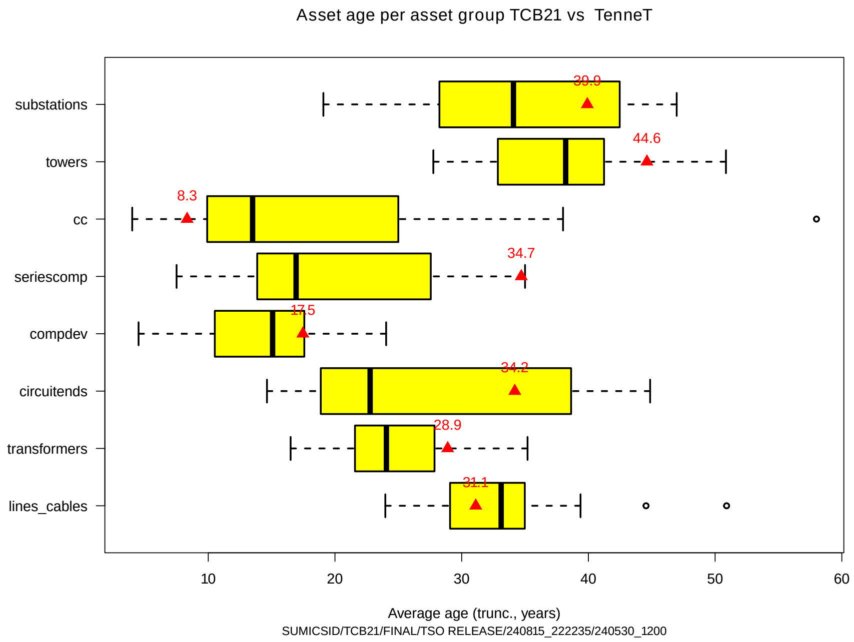

Figure 2.9: Asset ages (confidence interval) for all TCB21 and mean age for TenneT in red.

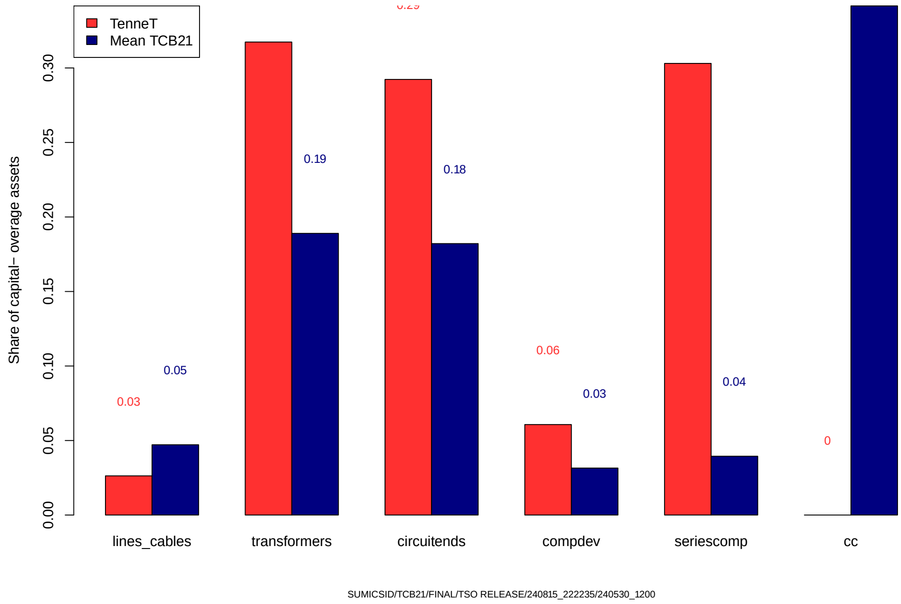

Figure 2.10: Share of overage assets in capital 2020, mean TCB21 in blue, TenneT in red.

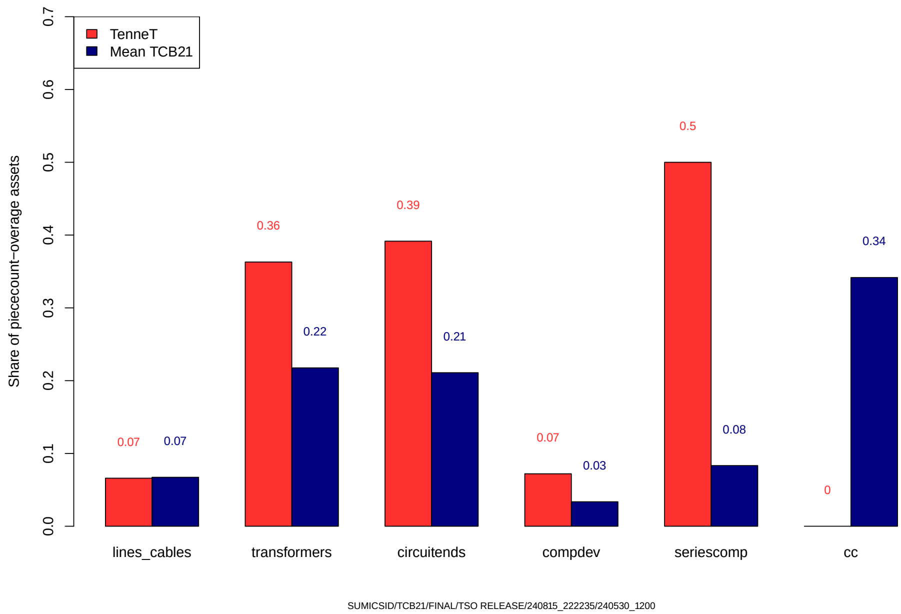

Figure 2.11: Share of overage assets in piece-count 2020, mean TCB21 in blue, TenneT in red.

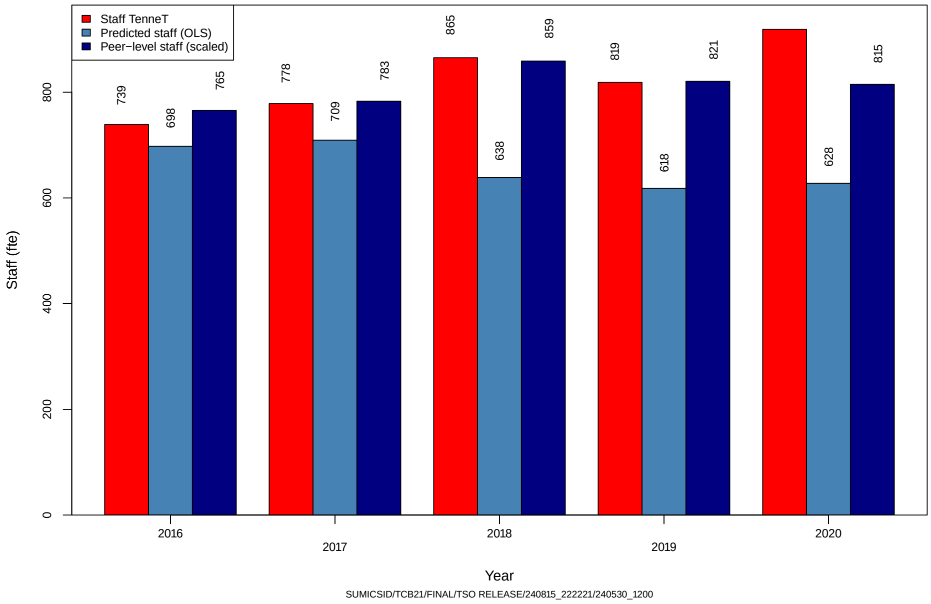

Figure 2.12: Actual staff (fte) compared to size-adjusted level for a median operator in TCB21.

simple model with one factor G; for electricity transformer power (MVA) that explains 93 percent of the variance, enough for an estimation. The median staff for the set of DEA-peers (all core models, excluding outliers in terms of staff intensity) can then be estimated using a scaling of the cost factor G_p/G_k where G_p is the level for a peer p. In Fig.2.12 the predicted staff SP_k for TenneT is represented as bar in light blue, the scaled peer level is graphed in dark blue.

In Fig 2.13 the allocation key for indirect expenditure (I) is based on total expenditure per activity excluding energy and depreciation, i.e. the graph can also be interpreted as the relative shares of expenditure by function. In Fig 2.14 we graph the actual allocation of indirect expenditure to the benchmarked activities T,M,P per operator, along with the mean allocation in the sample.

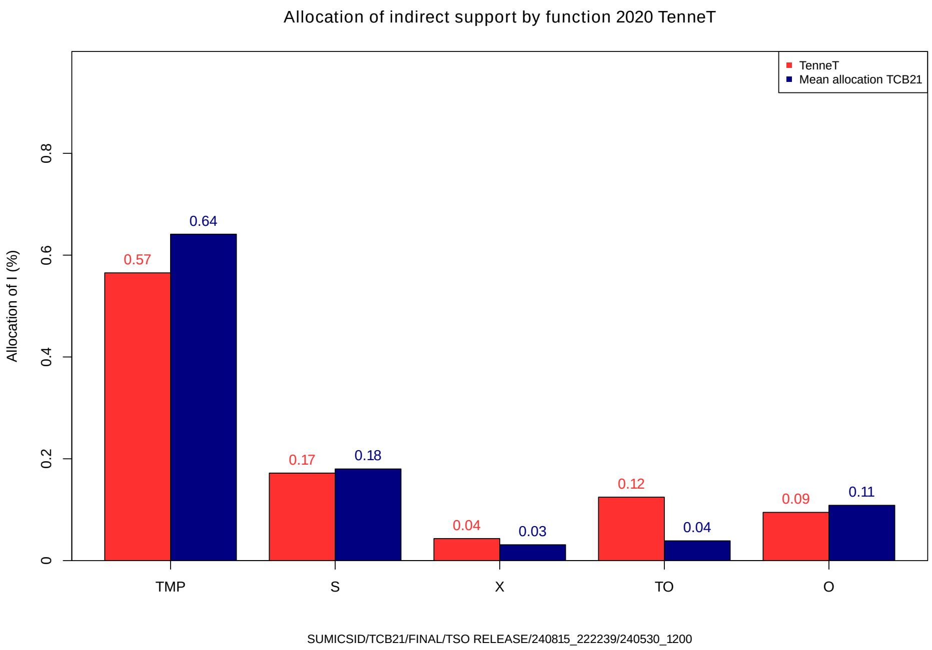

Figure 2.13: Allocation of overhead by function, mean and by operator, 2020.

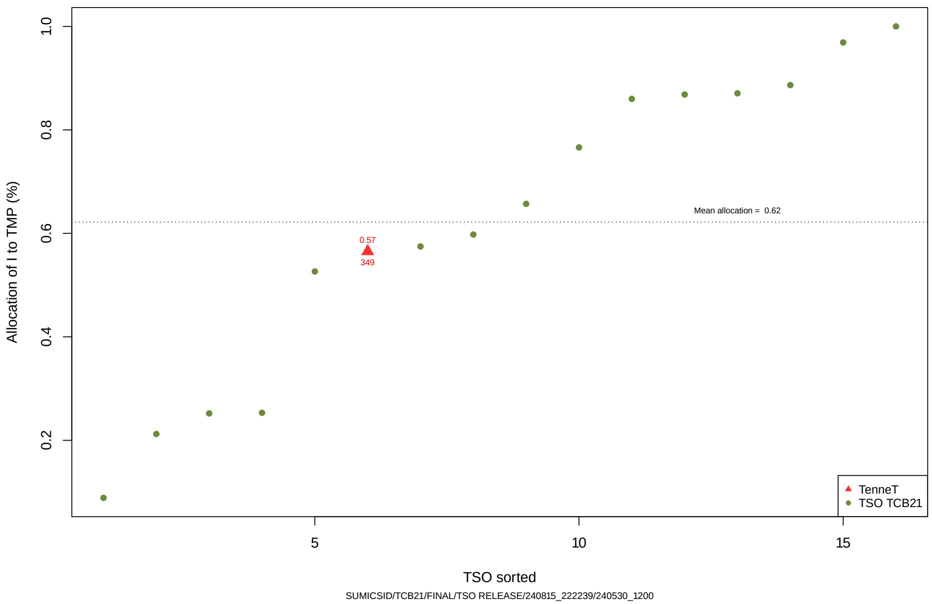

Figure 2.14: Overhead allocation (per cent) to TMP activities in TCB21.

2.7 Indicators

In addition to the non-parametric efficiency results, calculated from a multi-output frontier, we also present a series of KPI for different partial cost observations in Tables 2.6 to 2.13 below. The full sample is denoted as TCB21 in the tables, the *peers* used to calculate mean and median results are the 3 TSOs acting as frontier targets for TenneT in one or several models.

For non-peers, a blank in a table indicates that no data is found for the given indicator and category.The year is 2020 unless mentioned differently. The following sets of indicators are presented:

1. *KPI for staff cost shares*, shares of functional, indirect and personal costs.
2. *Aggregate Totex indicators*, total expenditure, normalized per relevant asset type.
3. *Aggregate Opex indicators*, total operating expenditure, normalized per relevant asset type.
4. *Aggregate Capex indicators*, total capital expenditure, normalized per relevant asset type.
5. *Technical indicators and ratios*, some technical ratios for the asset intensity.
6. *Disaggregated Capex indicators*, capex unit costs for specific asset types.
7. *Disaggregated Opex indicators*, opex unit costs for specific functions per asset type.
8. *Staff cost indicators*, cost per FTE and productivity per asset unit.

KPI for staff cost shares

The indicators for cost shares (notation and formulae in A.3) give an indication of Opex per function, as opposed to Capex, using the cost definitions in the project (thus excluding non-controllable costs for energy, taxes, land, etc). The staff cost shares inform about the percentage of Opex (in EUR) related to direct personnel costs as reported, with and without salary correction using the LCI. Finally, the share of indirect cost per Totex provide an information about the relative importance of indirect costs (full cost before allocations) in relation to Totex (excluding indirect costs). The ratio indirect cost to grid size (normgrid) gives a size-controlled metric.

Table 2.6: KPI for staff cost shares

	TSO 349	Mean TCB21	Median TCB21	Mean Peers	Median Peers
OpexShare.TMP	0.410	0.516	0.520	0.722	0.626
OpexShare.S	0.176	0.282	0.135	0.535	0.719
OpexShare.X	0.053	0.066	0.069	0.065	0.065
OpexShare.TO	0.222	0.132	0.126	0.070	0.070
OpexShare.O	0.099	0.147	0.079	0.048	0.048
OpexShare.I	0.076	0.245	0.195	0.392	0.386
OpexShare.totex.all	0.576	0.664	0.648	0.829	0.885
PersShare.opex.nosalind	0.314	0.494	0.438	0.665	0.739
PersShare.opex.salind	0.254	0.527	0.409	0.711	0.900
PersShare.totex.nosalind	0.130	0.225	0.151	0.391	0.378
PersShare.totex.salind	0.100	0.290	0.142	0.505	0.527
IndirShare.totex	0.050	0.140	0.111	0.168	0.144

Aggregate Totex indicators

The aggregate indicators for Totex (notation and formulae in A.4), are unit-cost ratios with the total expenditure (for function TMP and including all assets) in relation to specific asset metrics, circuit length (total), line length, cable length, circuitpower, divided in EHV and HV if relevant. The unit cost for Totex in relation to NormGrid Totex gives a general comparision.

Table 2.7: Aggregate Totex indicators

	TSO 349	Mean TCB21	Median TCB21	Mean Peers	Median Peers
UCT.circuitkm	36360	18568	16610	12162	9975
UCT.circuitkm.ehv	113816	39787	34417	35764	37398
UCT.circuitkm.hv	53428	889236	28865	19123	17584
UCT.linekm	44761	20342	16752	12398	10652
UCT.linekm.ehv	116896	41647	34423	35856	37641
UCT.linekm.hv	72537	892654	36675	19560	17584
UCT.circuitpower	52	39	28	25	19
UCT.circuitpower.ehv	66	38	27	32	26
UCT.circuitpower.hv	249	8012	198	118	85
UCT.transfo.power	8219	7265	7793	7705	7976
UCT.transfo.power.ehv	8557	9088	8641	10346	10550
UCT.transfo.power.hv	208552	425412	70847	901610	901610
UCT.cablekm	193722	68922293	661029	5212898	5212898
UCT.cablekm.ehv	4319296	107149461	4138662	38251555	38251555
UCT.cablekm.hv	202819	4606914	509218	6087385	6087385
UCT.towers	27747	8826	6498	4610	5423
UCT.subst	1083439	1233085	963226	831693	893465
UCT.subst.ehv	7607624	3900428	3799675	5602858	6382684
UCT.subst.hv	1263360	25485383	1100830	1305054	1001763
UCT.ng	829	610	627	494	396

Aggregate Opex indicators

The aggregate indicators for Opex (notation and formulae in A.5) are unit-cost ratios with operating expenditure in-scope (TMP) expenditure (including standard overhead-allocation) in relation to specific asset metrics, circuit length (total), line length, cable length, circuitpower, divided in EHV and HV if relevant. The unit cost for Opex in relation to NormGrid Opex gives a general comparision.

Table 2.8: Aggregate Opex indicators

	TSO 349	Mean TCB21	Median TCB21	Mean Peers	Median Peers
UCO.circuitkm	14899	9215	6577	9348	6245
UCO.circuitkm.ehv	46639	19138	13944	27518	23414
UCO.circuitkm.hv	21894	571759	14792	14574	10421
UCO.linekm	18342	9825	6844	9498	6669
UCO.linekm.ehv	47901	19551	14851	27580	23566
UCO.linekm.hv	29724	572909	15746	14854	10421
UCO.circuitpower	21	19	11	20	12
UCO.circuitpower.ehv	27	18	10	25	16
UCO.circuitpower.hv	102	5498	102	94	50
UCO.transfo.power	3368	4000	3274	5624	6566
UCO.transfo.power.ehv	3506	5258	3424	8118	6605
UCO.transfo.power.hv	85459	193384	31507	567051	567051
UCO.cablekm	79382	56048269	382995	4909844	4909844
UCO.cablekm.ehv	1769929	85225008	2218376	35284087	35284087
UCO.cablekm.hv	83110	2399149	118066	5737011	5737011
UCO.towers	11370	4133	3398	3434	3492
UCO.subst	443963	630429	435042	603470	676202
UCO.subst.ehv	3117395	2163135	1280887	4366960	3996035
UCO.subst.hv	517690	10839328	499397	897180	948358
UCO.ng.opex	3836	2597	2287	1760	1747

Aggregate Capex indicators

The aggregate indicators for Capex (notation and formulae in A.6) are unit-cost ratios with total capital expenditure (including all in-scope assets, real-annuity format, EUR, 2020) in relation to specific asset metrics, circuit length (total), line length, cable length, circuitpower, divided in EHV and HV if relevant. The unit cost for Capex in relation to NormGrid Capex gives a general comparision.

Table 2.9: Aggregate Capex indicators

	TSO 349	Mean TCB21	Median TCB21	Mean Peers	Median Peers
UCC.circuitkm	21461	9353	7221	2815	3730
UCC.circuitkm.ehv	67177	20649	13107	8246	8085
UCC.circuitkm.hv	31535	317477	24166	4549	5087
UCC.linekm	26419	10516	7294	2900	3798
UCC.linekm.ehv	68995	22096	13109	8276	8085
UCC.linekm.hv	42813	319745	28967	4706	5555
UCC.circuitpower	31	20	12	5	5
UCC.circuitpower.ehv	39	19	13	6	6
UCC.circuitpower.hv	147	2513	92	24	27
UCC.transfo.power	4851	3265	3233	2081	1895
UCC.transfo.power.ehv	5050	3830	3583	2228	1895
UCC.transfo.power.hv	123093	232029	23591	334559	334559
UCC.cablekm	114340	12874023	273808	303054	303054
UCC.cablekm.ehv	2549368	21924454	2271968	2967468	2967468
UCC.cablekm.hv	119709	2207765	119709	350374	350374
UCC.towers	16377	4693	3247	1176	1153
UCC.subst	639475	602656	529163	228224	172232
UCC.subst.ehv	4490229	1737293	1562043	1235898	880456
UCC.subst.hv	745670	14646055	721934	407874	185628
UCC.ng.capex	624	372	367	152	189

Technical indicators and ratios

The technical indicators and ratios (notation and formulae in A.7) give different shares and intensities that could could inform the TSO about specific profiles and conditions without direct relation to costs or benchmarked data.

Table 2.10: Technical indicators and ratios

	TSO 349	Mean TCB21	Median TCB21	Mean Peers	Median Peers
share.towers.steel	1.000	0.751	0.976	0.852	0.984
share.towers.angular	0.257	0.215	0.191	0.208	0.193
transfo.power.circuitkm.ehv	13.302	4.763	3.609	3.657	3.545
transfo.power.circuitkm	4.424	2.947	2.283	1.704	2.004

Disaggregated Capex indicators

The disaggregated Capex metrics (notation and formulae in A.8) are formed as the ratio of partial Capex, i.e. the capital expenditure for a specific asset class (lines, transfo[rmers], etc) in relation to the physical data for the assets (e.g. linekm, number of substations, etc). Note that these partial unit-costs are not corrected for dimensions or location, as in the case of the NormGrid.

Disaggregated Opex indicators

The disaggregated Opex metrics (notation and formulae in A.9) put a subset of the operating cost, e.g maintenance cost (M) and planning (P) in relation to the physical assets in previous tables. Note that the disaggregation is not valid down to asset level, i.e. opex-maintenance cost is not differentiated for maintenance of different asset groups (lines, substations, ...).

Table 2.11: Disaggregated Capex indicators

	TSO 349	Mean TCB21	Median TCB21	Mean Peers	Median Peers
UCC.line.line.km	7195.6	3640.1	3189.0	1220.0	1466.7
UCC.line.line.ng	16.9	8.6	8.6	3.2	3.7
UCC.cable.cable.km	17778.1	450499.2	17778.1	8641.3	8641.3
UCC.cable.cable.ng	9.9	91.8	15.2	5.7	5.7
UCC.transfo.transfo.power	315.7	423.4	171.3	210.4	286.0
UCC.transfo.transfo.pc	99579.2	81186.4	34389.9	64912.8	74983.0
UCC.transfo.transfo.ng	31.8	28.5	13.8	16.0	20.8
UCC.subst.subst.pc	222405.1	199623.0	101454.7	113780.8	56560.8
UCC.subst.subst.ng	18.9	13.7	9.0	7.4	4.9

Table 2.12: Disaggregated Opex indicators

	TSO 349	Mean TCB21	Median TCB21	Mean Peers	Median Peers
UCO.p.inv.tot	0.03	0.02	0.02	0.02	0.01
UCO.m.linekm.tot	10936.66	3782.85	2607.99	2560.66	1558.09
UCO.m.circuitkm.tot	8883.94	3451.74	2353.52	2536.25	1558.09
UCO.m.transfo.power	2008.25	1377.73	1078.60	1381.54	1001.96
UCO.m.ng.opex	937.18	456.89	354.00	346.78	291.89
UCO.m.subst.pc	264719.35	202435.33	182052.66	166552.28	190680.54

Staff cost indicators

The personnel cost is studied in relative terms (e.g. staff cost per FTE, before any LCI correction) and in absolute terms (e.g. total personnel cost for in-scope functions (TMP). We also provide two productivity ratios: FTE-personnel per grid-unit (NormGrid and circuitkm). Notation and formulae provided in A.10)

Table 2.13: Staff cost indicators

	TSO 349	Mean TCB21	Median TCB21	Mean Peers	Median Peers
pers.cost.fte	49644.752	40316.947	43054.093	30223.157	34169.534
pers.cost.tmp	45618971.711	30354212.604	21433101.720	42461811.008	40832593.000
pers.fte.ng	0.010	0.031	0.009	0.104	0.010
pers.fte.circuitkm	0.095	0.246	0.057	0.863	0.067

Chapter 3

Results

In the project, we have developed a series of final models E2388.V2.4, E3395.V2.4 for which variants with environmental correction factors have been applied, i.e., E2388.V2.4.env2, E3395.V2.4.env2.

3.1 DEA results

The interpretation is that using best practice, the benchmarking model estimates that TenneT is able to provide the same services, i.e. keep the present levels of the cost drivers, at 84.53, 72.65, 71.65, 71.65% of the present total expenditure level, respectively. In other words, the model suggests a saving potential of between 15.47 % and 28.35 % of the controllable total expenditure for transport, maintenance and planning.

The models consider both investment efficiency and operating efficiency under a given set of environmental conditions. The material in this report may provide elements to explore other differences than those explicitly included in the model, to understand the scores and the operating practice of the electricity transmission operators in Europe in 2020.

To evaluate the estimated efficiency of TenneT, it is always relevant to compare to the efficiencies of the other TSOs in the TCB21 project, see the scores in Table 3.1 below. Structural comparability is assured by stringent activity decomposition, standardization of cost and asset reporting, harmonized capital costs and depreciation, elimination of country-specific costs related to taxes, land, buildings, and out-of-scope activities, correction for salary cost differences and national inflation as well as currency differences.

Table 3.1: Efficiency scores, DEA(ndrs.exo.ex.asep) year 2020

	Eff 349	Mean eff	Median eff	#peers	#asep.eff	#outliers
E2388.V2.4	0.845	0.882	1.000	5	2	2
E2388.V2.4.env2	0.726	0.900	1.000	5	2	3
E3395.V2.4	0.717	0.883	1.000	3	2	3
E3395.V2.4.env2	0.717	0.885	1.000	4	2	3

3.2 Scale efficiency

The productive efficiency depends on a multitude of factors, including the scale of operations. In DEA, the model can easily calculate these effects through the concept of different assumptions of returns to scale, see Methods and Calculations, Section 6.4.

$$DEA_{SE}(k) = \frac{DEA_{CRS}(k)}{DEA_{VRS}(k)} \tag{3.1}$$

The actual scale efficiency results for the electricity transmission system operators in TCB21 are given in Table 3.2 and in Figs. 3.5 through 3.8 below for all final models. The detailed scores for TenneT under different returns to scale assumptions (non-decreasing returns to scale, NDRS, constant returns to scale, CRS, and variable returns to scale, VRS) and without prior outlier detection are listed in 3.3 below.

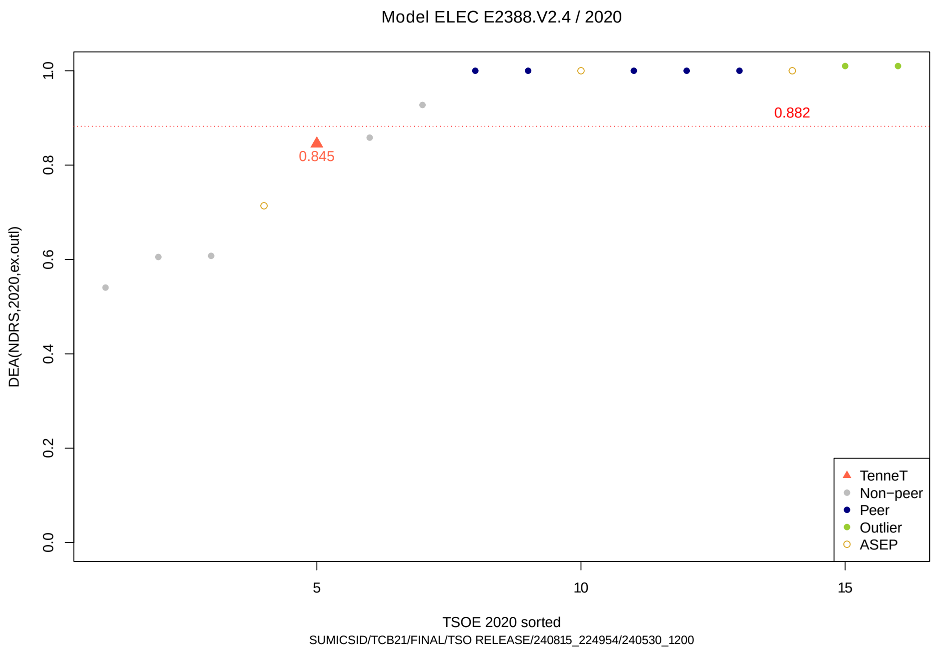

Figure 3.1: Final results for TenneT in model E2388.V2.4 , 2020 , ndrs,.

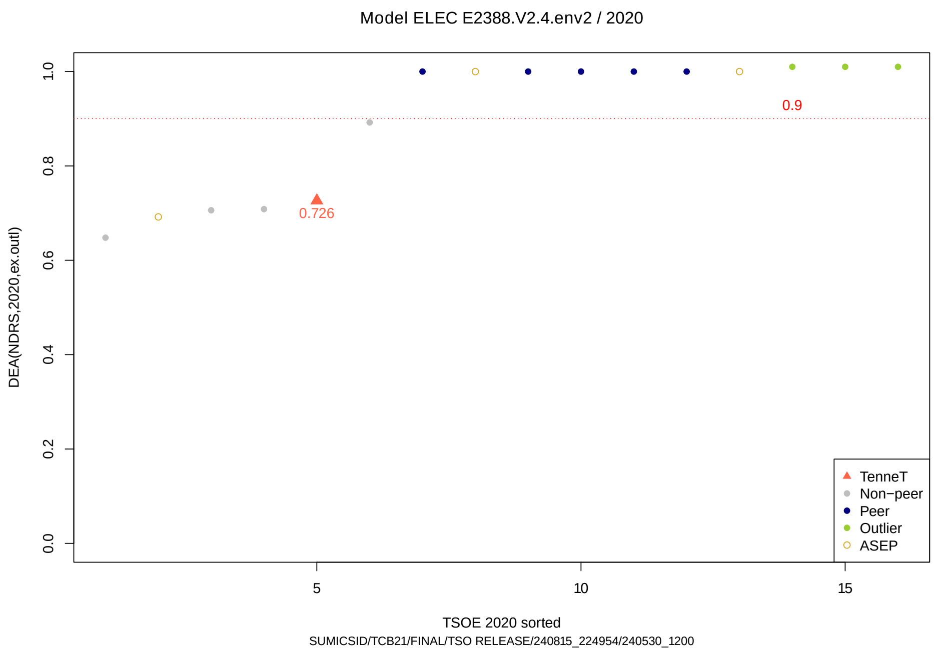

Figure 3.2: Final results for TenneT in model E2388.V2.4.env2 , 2020 , ndrs,.

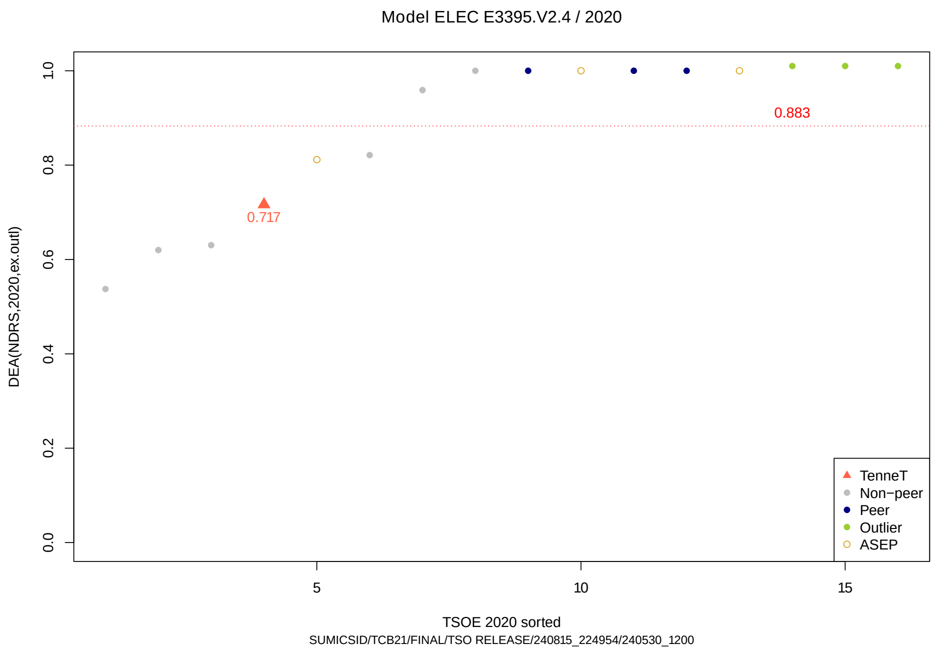

Figure 3.3: Final results for TenneT in model E3395.V2.4 , 2020 , ndrs,.

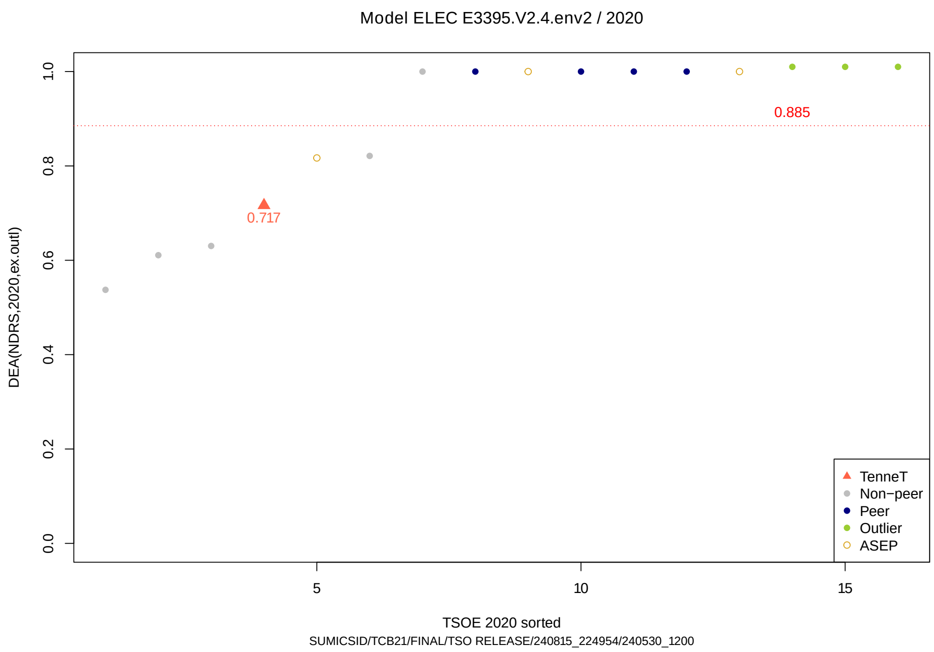

Figure 3.4: Final results for TenneT in model E3395.V2.4.env2 , 2020 , ndrs,.

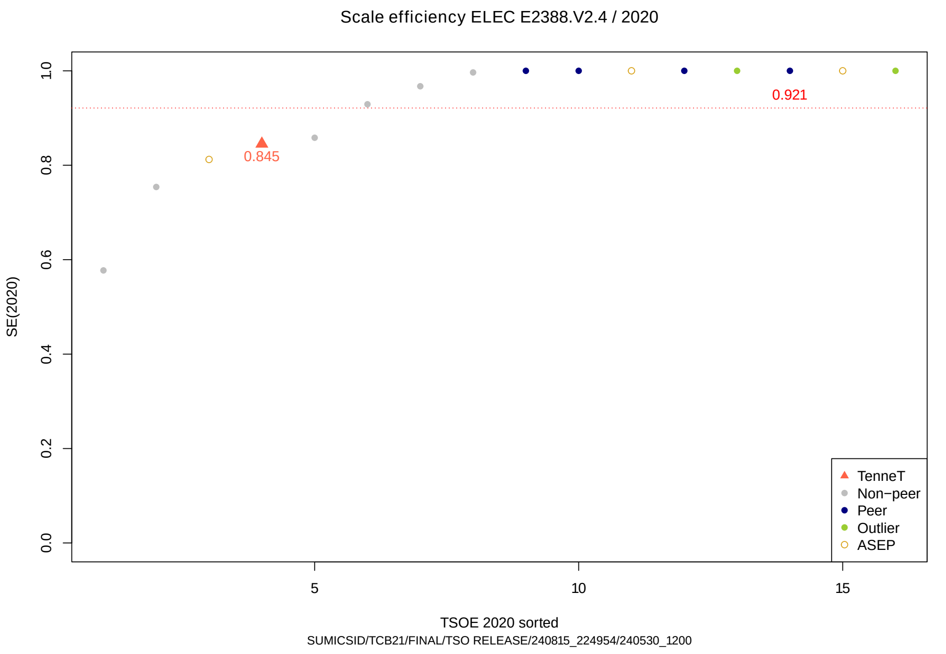

Figure 3.5: Scale efficiency E2388.V2.4 for TenneT

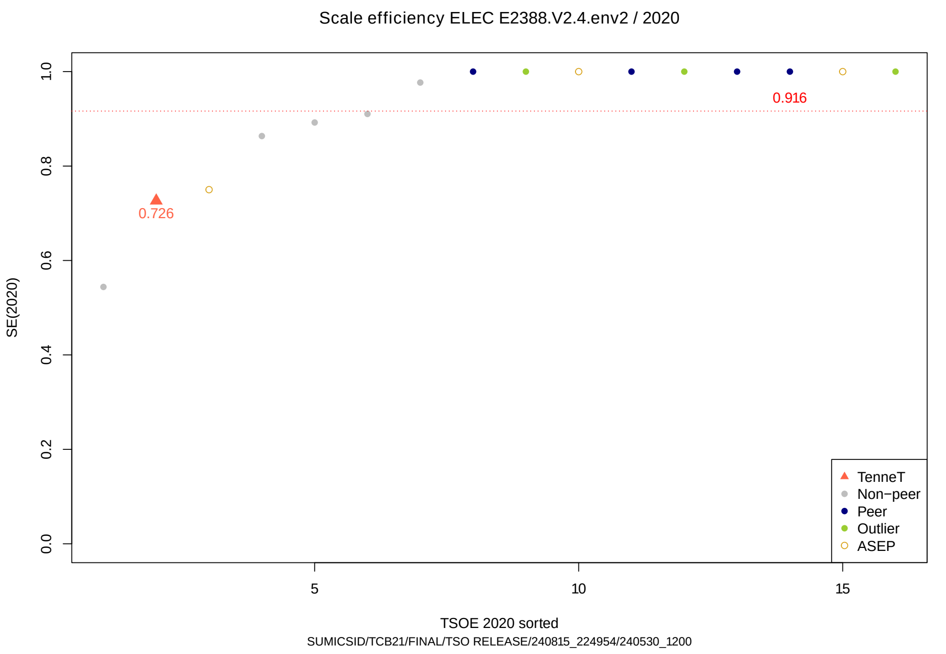

Figure 3.6: Scale efficiency E2388.V2.4.env2 for TenneT

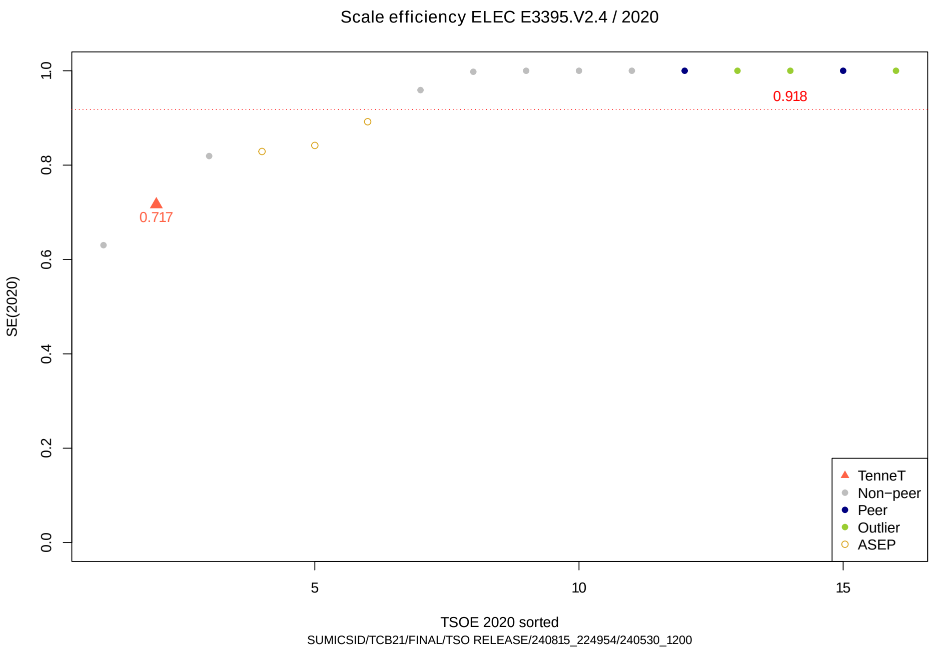

Figure 3.7: Scale efficiency E3395.V2.4 for TenneT

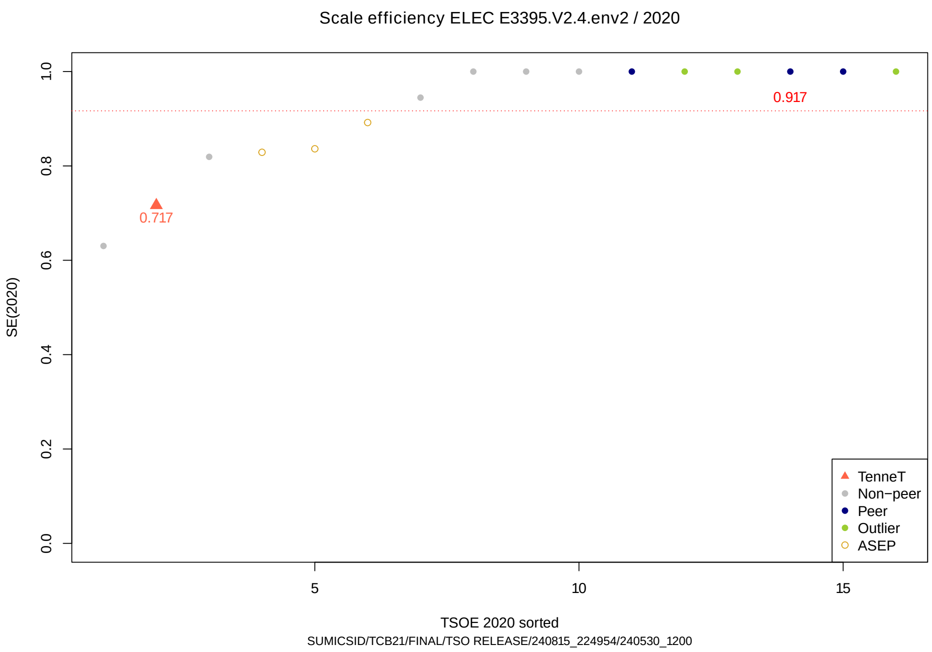

Figure 3.8: Scale efficiency E3395.V2.4.env2 for TenneT

Table 3.2: Scale efficiency DEA(SE) TenneT 2020 OS-pos: -1 <OS, 1 >OS, 0 OS

	SE-2020 349	OS-pos	Mean SE-2020	#SE-efficient	#>OS	#<OS
E2388.V2.4	0.845	1	0.921	8	4	4
E2388.V2.4.env2	0.726	1	0.916	9	4	3
E3395.V2.4	0.717	1	0.918	5	4	4
E3395.V2.4.env2	0.717	1	0.917	6	2	5

Table 3.3: DEA score: alternative RTS and exo, year 2020 TenneT

	NDRS.exo 349	CRS.exo 349	VRS.exo 349	NDRS 349	CRS 349	VRS 349
E2388.V2.4	0.845	0.845	1.000	0.439	0.439	0.495
E2388.V2.4.env2	0.726	0.726	1.000	0.478	0.478	1.000
E3395.V2.4	0.717	0.717	1.000	0.551	0.551	1.000
E3395.V2.4.env2	0.717	0.717	1.000	0.551	0.551	1.000

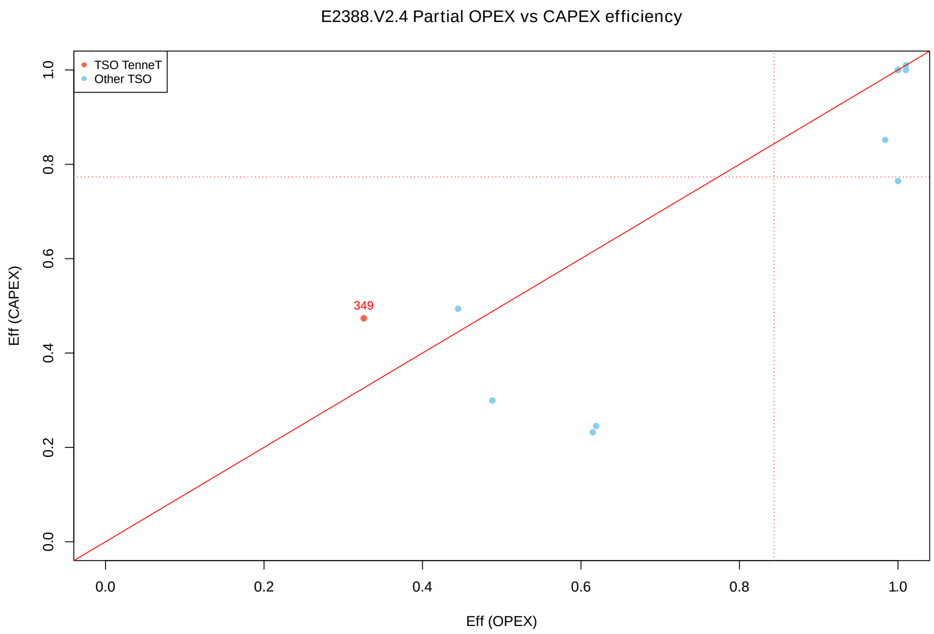

Figure 3.9: Partial OPEX and CAPEX efficiency in TCB21 (red dashed line=mean). E2388.V2.4

3.3 Partial Opex-capex efficiency

As an alternative to Totex benchmarking, we present the partial DEA results for Opex and Capex, as discussed methodologically in the Note on Methods and Calculations, section 5.9. In short, the analysis uses a model where only one dimension, Opex or Capex, is considered controllable and subject to radial reduction to the frontier. Concretely, a partial Opex-DEA efficiency is interpreted as the proportion of Opex that could be saved at the same or lower level of Capex.

In Table 3.4 the partial Opex and Capex efficiencies for TenneT are listed along mean scores for the TCB21 operators. The interesting comparisons are (i) whether TenneT performs better or worse in partial benchmarking than in Totex benchmarking, and (ii) in which direction (opex or capex) does TenneT perform significantly differently. The interpretations relate to the partial performance in opex and capex, respectively.

The partial scores for models E2388.V2.4 and E3395.V2.4 is shown in Figs. 3.9 - 3.14 for Eff(Opex) vs Eff(Capex), Eff(Opex) vs DEA(base) and Eff(Capex) vs DEA(base), respectively. Note that a single point in the graph may represent multiple operators with the same value, the graphs contain all participating operators.

Table 3.4: Partial DEA scores (NDRS, excl. outliers) year 2020

	DEA(Opex) 349	DEA(Capex) 349	Mean DEA(Opex)	Mean DEA(Capex)
E2388.V2.4	0.326	0.474	0.844	0.773
E2388.V2.4.env2	0.319	1.010	0.848	0.821
E3395.V2.4	0.545	0.593	0.910	0.903
E3395.V2.4.env2	0.545	0.593	0.923	0.901

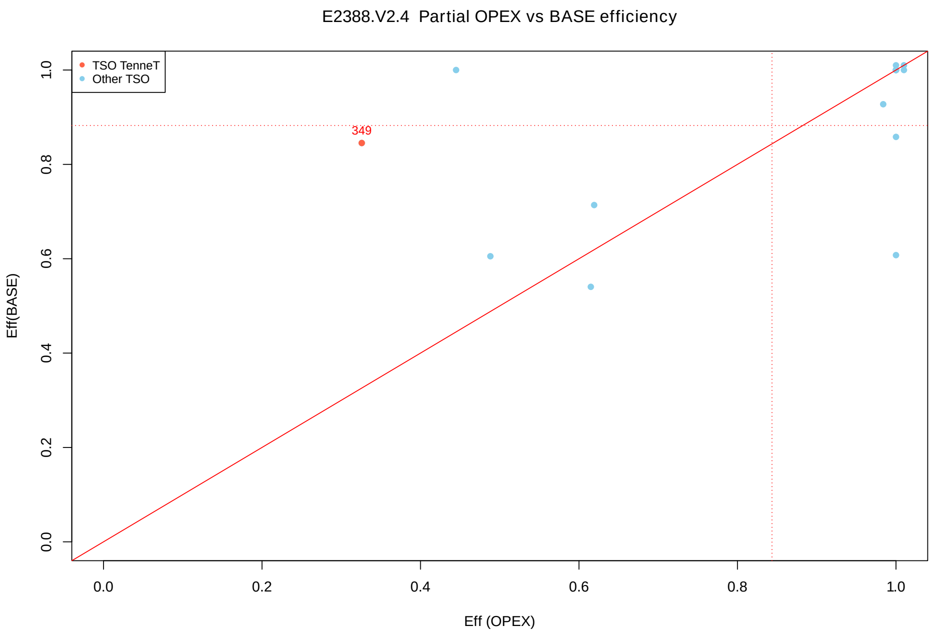

Figure 3.10: Partial OPEX vs TOTEX efficiency in TCB21 (red dashed line=mean). E2388.V2.4

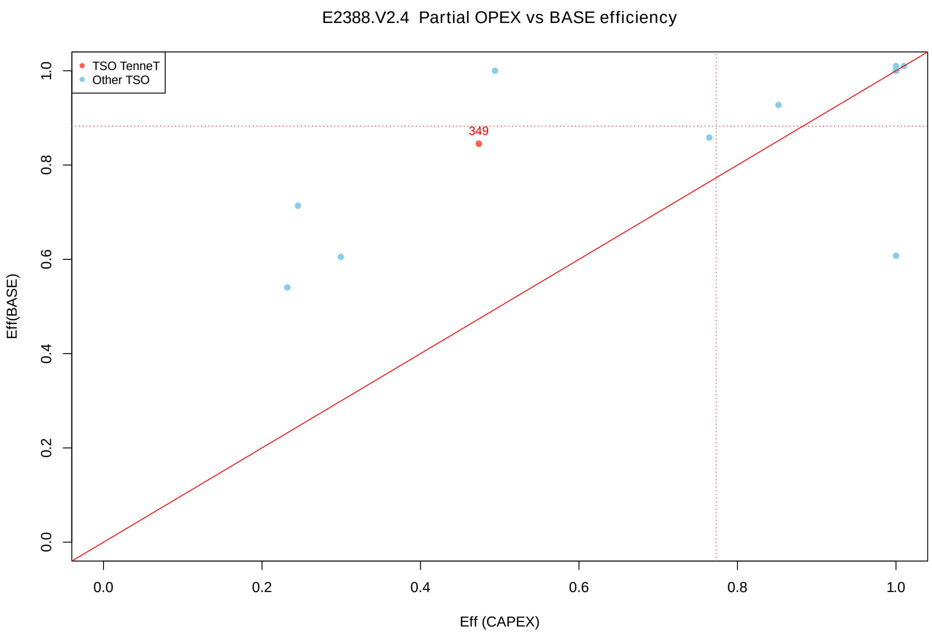

Figure 3.11: Partial CAPEX vs TOTEX efficiency in TCB21 (red dashed line=mean). E2388.V2.4

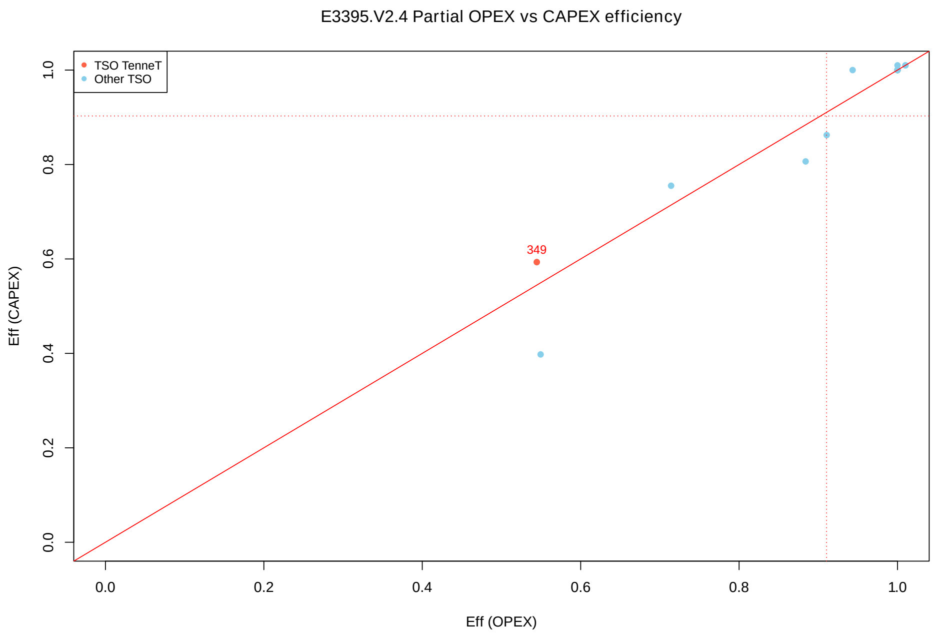

Figure 3.12: Partial OPEX and CAPEX efficiency in TCB21 (red dashed line=mean). E3395.V2.4

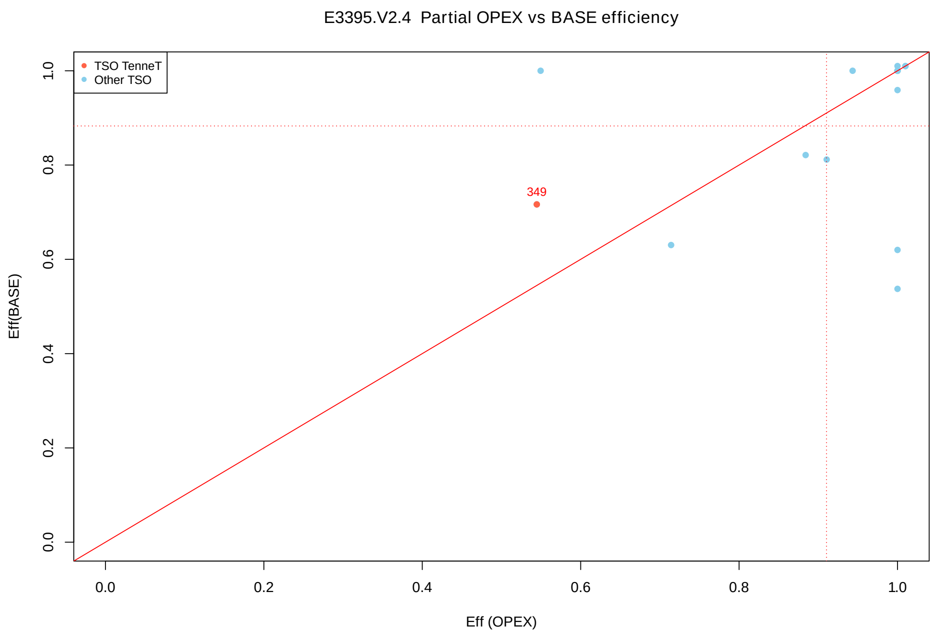

Figure 3.13: Partial OPEX vs TOTEX efficiency in TCB21 (red dashed line=mean). E3395.V2.4

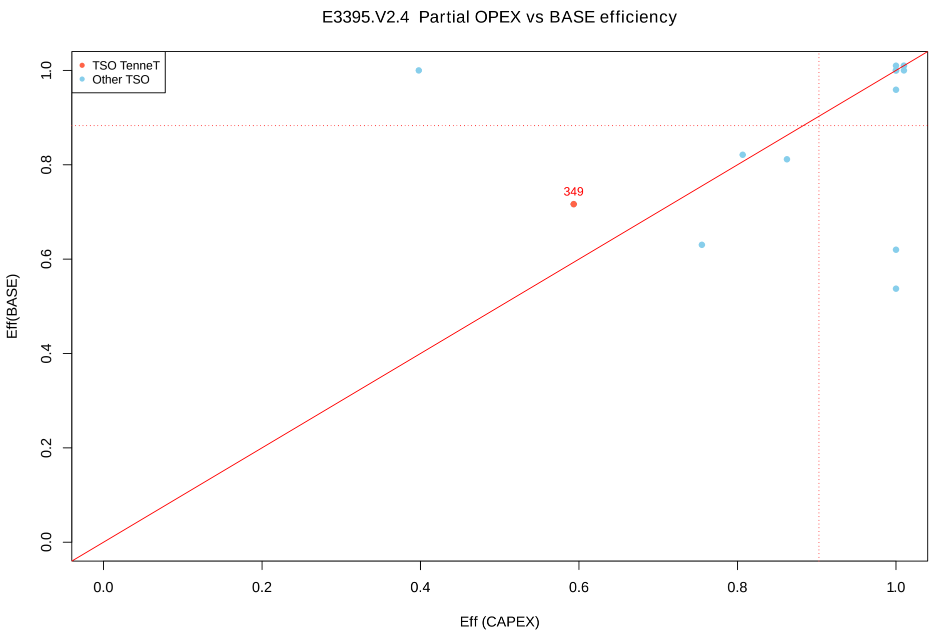

Figure 3.14: Partial CAPEX vs TOTEX efficiency in TCB21 (red dashed line=mean). E3395.V2.4

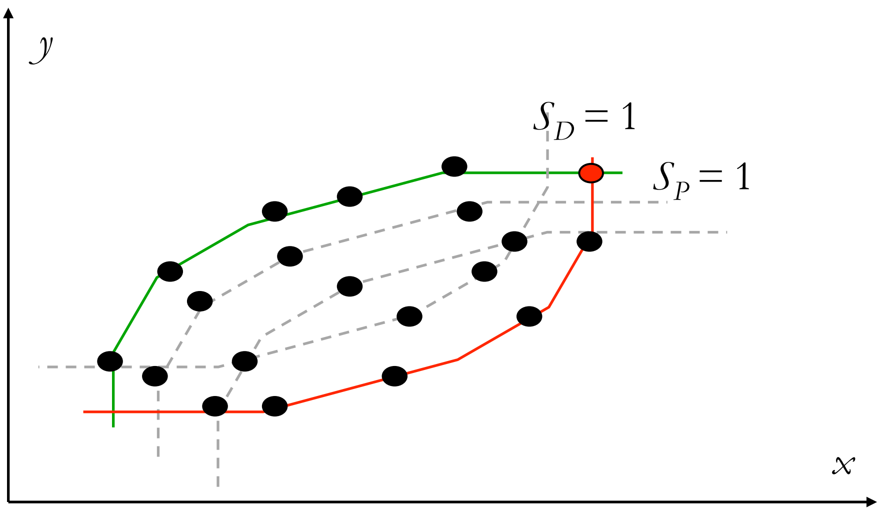

Figure 3.15: Peeling DEA

3.4 Peeling DEA

One approach to estimate the robustness of DEA-results is to use the Peeling DEA method (see Note on Method and Calculations, Section 5.10). In this method, the given model is solved successively in rounds where all fully efficient observations *peers* are removed. The model is then resolved with the remaining units until no observation remains in the set. Call the round in which a unit exits the *positive peel, SP*. Repeat the same exercise from the negative side, i.e., find the most inefficient units by looking at maximization of cost at the minimum of output. Call each successive layer removed the *negative peel,* S_N. A low postive S_P and a high S_N constitute evidence in terms of independent observations of efficiency. Likewise, a high S_P and a low S_N indicates evidence of inefficiency. We denote by $S_C = S_P + (\max S_N - S_N)$ the positive *shell count* S_C for a unit. The lower the S_C, the more certain the efficiency can be ascertained, and vice versa.

Some units with odd production profiles may show up as full efficient, i.e., $S_P = 1$ and in the same time fully anti-efficient, i.e., $S_N = 1$. These units have an extreme profile called *grey* as they are in the edges of the production space, see the red unit in Figure 3.15. For this reason, the detection of grey units is the third level of outlier detection in the project.

Below in Figs. 3.16 to 3.19 and in Tables 3.5 to 3.8 we provide the results for TenneT in terms of S_P, S_N, S_C and the number of Grey units compared to the mean ranking in the sample.

Table 3.5: Peeling DEA scores (NDRS, excl. outliers) year 2020 E2388.V2.4

	SP	SN	SC	#Grey
TenneT	3.00	1.00	4.00	0
mean TCB21	2.69	1.19	3.50	0

Table 3.6: Peeling DEA scores (NDRS, excl. outliers) year 2020 E2388.V2.4.env2

	SP	SN	SC	#Grey
TenneT	2.00	1.00	3.00	0
mean TCB21	2.06	1.31	2.75	0

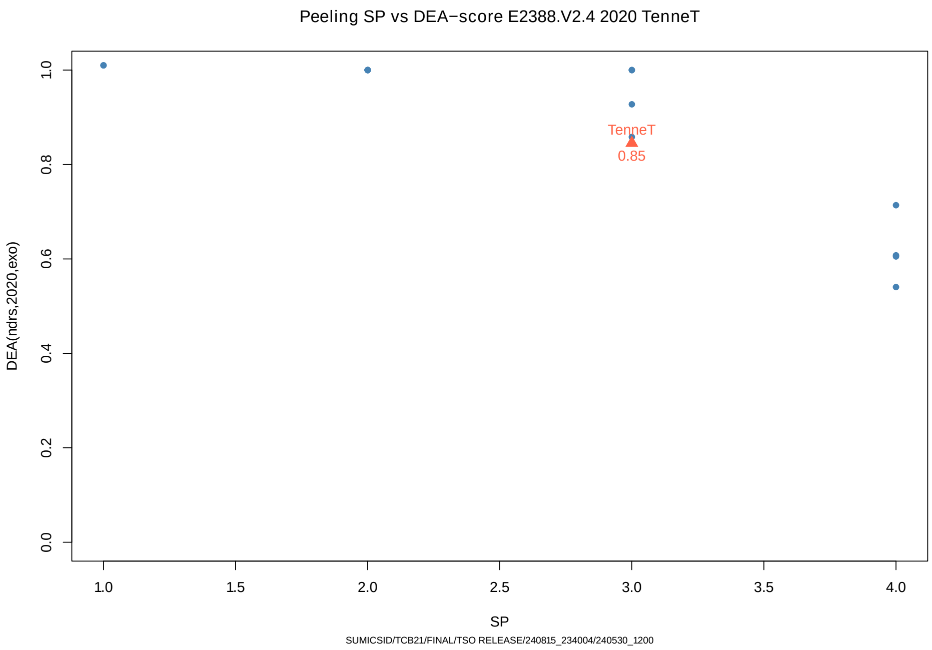

Figure 3.16: Peeling SP vs DEA(ndrs,exo,2020) E2388.V2.4 TenneT

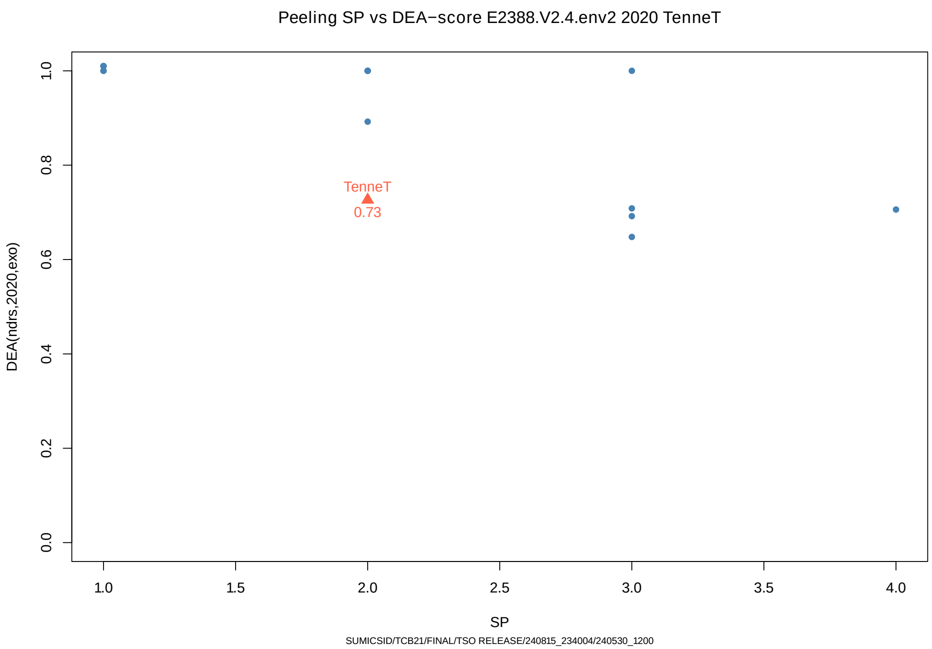

Figure 3.17: Peeling SP vs DEA(ndrs,exo,2020) E2388.V2.4.env2 TenneT

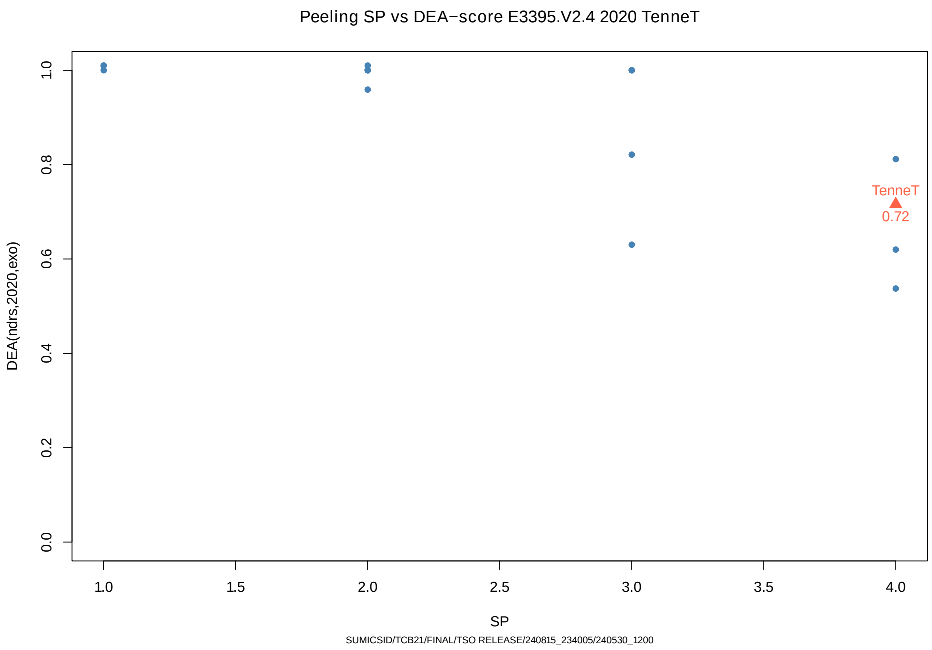

Figure 3.18: Peeling SP vs DEA(ndrs,exo,2020) E3395.V2.4 TenneT

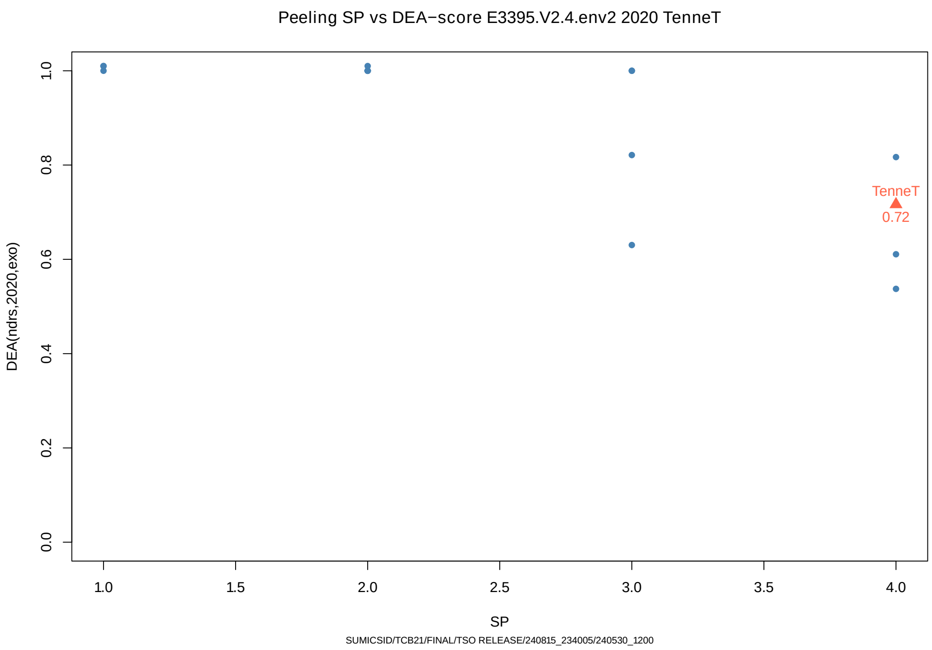

Figure 3.19: Peeling SP vs DEA(ndrs,exo,2020) E3395.V2.4.env2 TenneT

Table 3.7: Peeling DEA scores (NDRS, excl. outliers) year 2020 E3395.V2.4

	SP	SN	SC	#Grey
TenneT	4.00	1.00	6.00	0
mean TCB21	2.56	1.88	3.69	0

Table 3.8: Peeling DEA scores (NDRS, excl. outliers) year 2020 E3395.V2.4.env2

	SP	SN	SC	#Grey
TenneT	4.00	1.00	6.00	0
mean TCB21	2.56	2.12	3.44	0

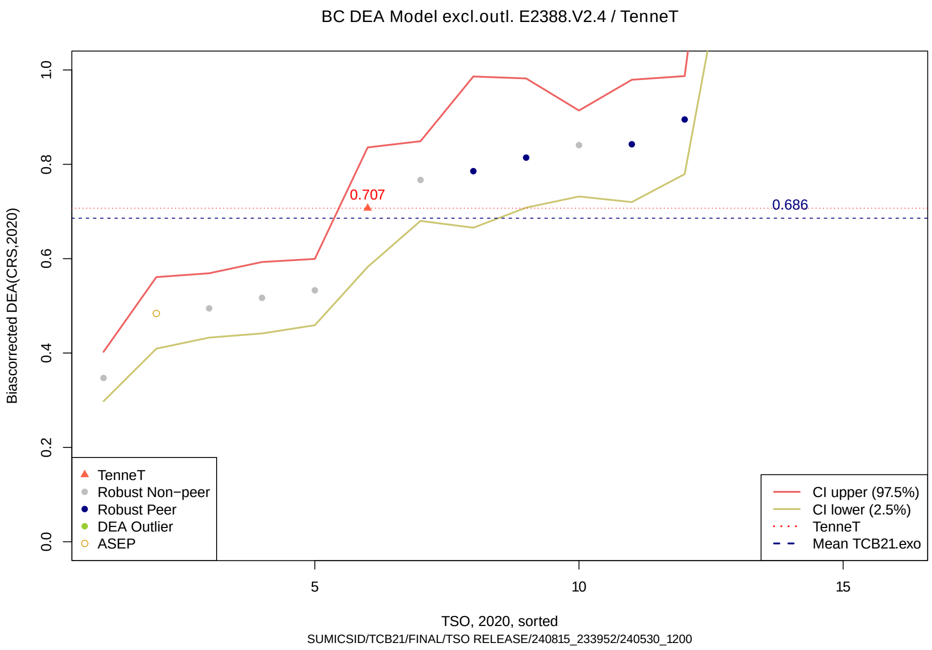

Figure 3.20: Bias-corrected DEA (RDEA.bc) E2388.V2.4

3.5 Robust DEA

DEA conventionally gives a deterministic point estimate without statistical properties. However, seminal work on bias-correction and bootstrapping in DEA from Simar and Wilson (1998) and Dario and Simar (2007) has developed a link to statistical estimations to enable the calculation of confidence intervals for DEA scores under CRS, bias-corrected scores, and point-estimates for bias by observation. For a further introduction, see Bogetoft and Otto (2011), Chap. 6.

DEA is a cautious evidence-based model that avoids extrapolation and a priori assumptions. The frontier is made uniquely by those observations that are in the set in a specific run. Intuitively, this resembles a local competition where some athletes are participating as qualifications for the Olympic Games. What if some competitors would fall sick the same day, or some outsider athletes unexpectedly would arrive? How can we be sure that a silver medalist is good enough to qualify? How stable are the rankings if the reference set changes?

Robust DEA (RDEA) provides answers for these questions by providing a statistical estimate for the range of scores that would be obtained if the observations in the dataset are seen as sampled from a larger population. Specifically, we address the question of *sampling bias* due to missing or added observations. We obtain upper and lower confidence intervals for the scores in the (asymptotically) full dataset. This implies that units that have special profiles tend to get overestimated efficiency since the chance is high that they may not have many valid comparators in the sample.

The confidence intervals below are for the bias corrected efficiency $\tilde{\theta}_k$ (RDEA.bc); to get confidence intervals for the uncorrected efficiency $\hat{\theta}_k$, add the biases (RDEA.bias) to both upper and lower values for the intervals: RDEA.bc.CIL, RDEA.bc.CIU. The dependent variable is as before dTotex. In the RDEA.exo runs, the outliers from the models $\hat{\theta}_k(T)$ are removed, the results are therefore directly comparable with the results in section 3.1, although under CRS rather than NDRS. Robustness results for alternative models and variants were presented at project workshops WS3 and WS4 and in the Note on Model Specification. The respective results are listed in Table 3.9 for TenneT and for the mean TSO in Table 3.10 below. The scores are also graphed in Figs. 3.20 to 3.27 below for each model.

Note that the RDEA.exo scores below do not include outliers (superefficient units) in Figs and Tables: the marker is missing from the graph and the score (set to 1.01) is excluded from the mean. Also, the "BC Peers" in the graphs are the peers in RDEA, not the peers in the respective DEA-runs presented as main results.

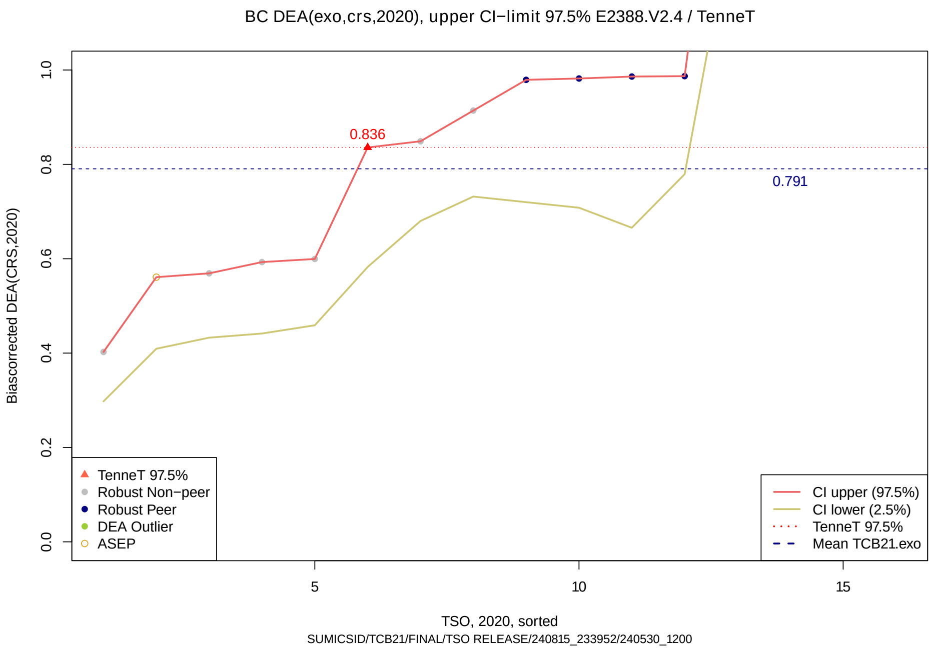

Figure 3.21: CI:Upper limit Bias-corrected DEA (RDEA.bc.CIU) E2388.V2.4

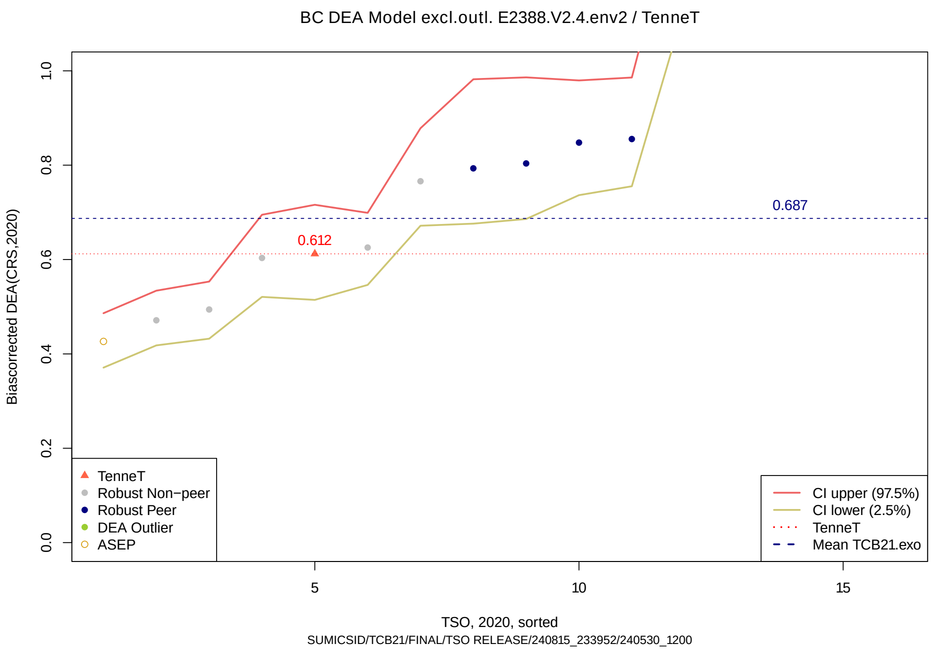

Figure 3.22: Bias-corrected DEA (RDEA.bc) E2388.V2.4.env2

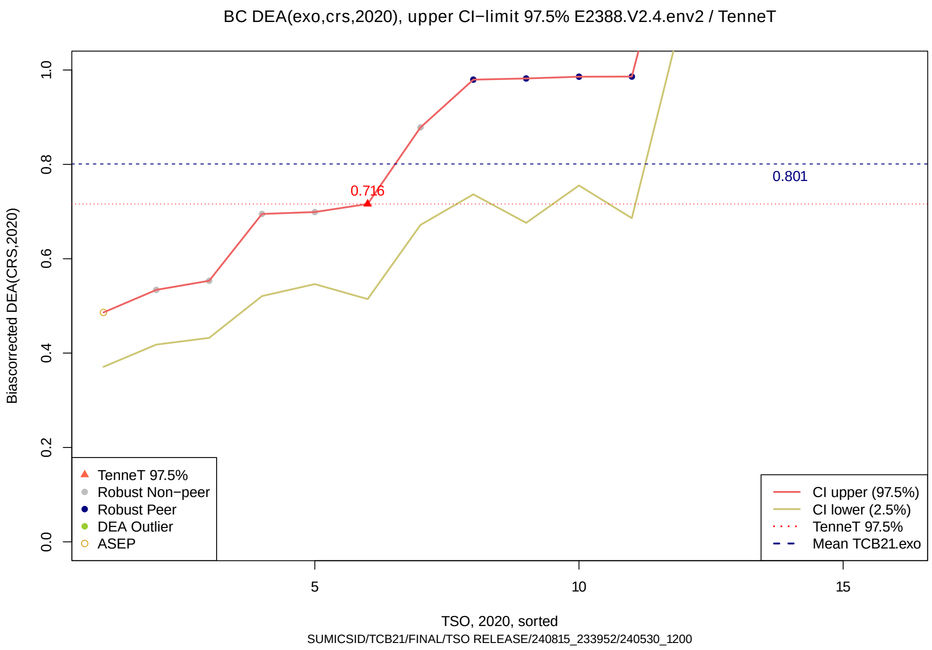

Figure 3.23: CI:Upper limit Bias-corrected DEA (RDEA.bc.CIU) E2388.V2.4.env2

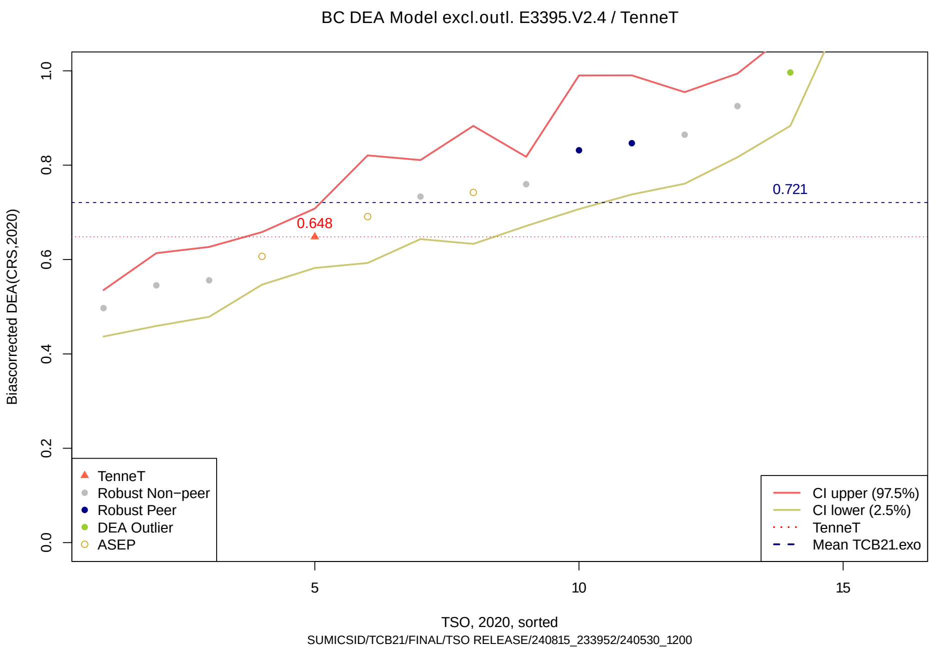

Figure 3.24: Bias-corrected DEA (RDEA.bc) E3395.V2.4

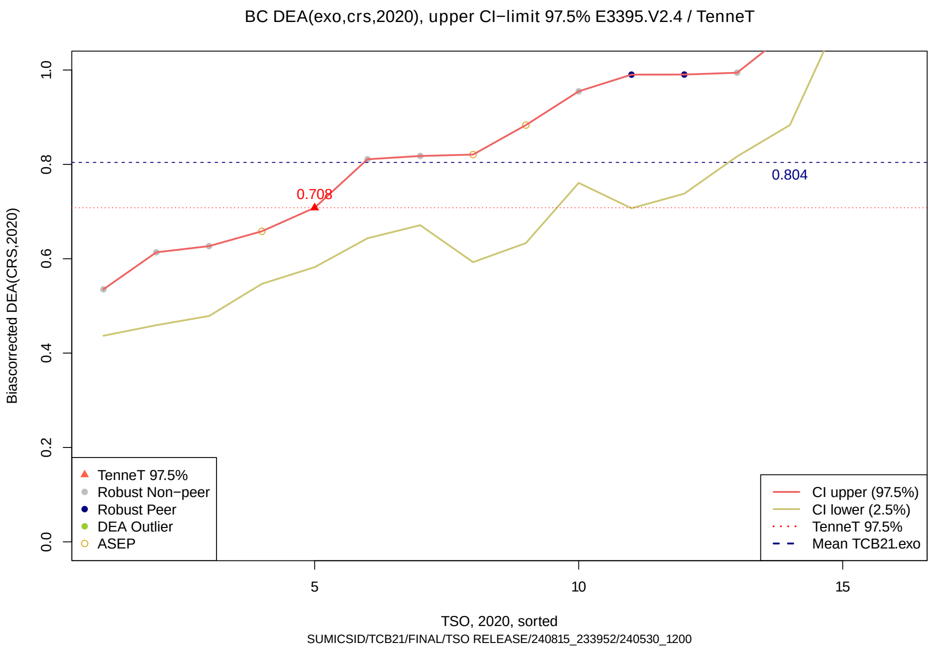

Figure 3.25: CI:Upper limit Bias-corrected DEA (RDEA.bc.CIU) E3395.V2.4

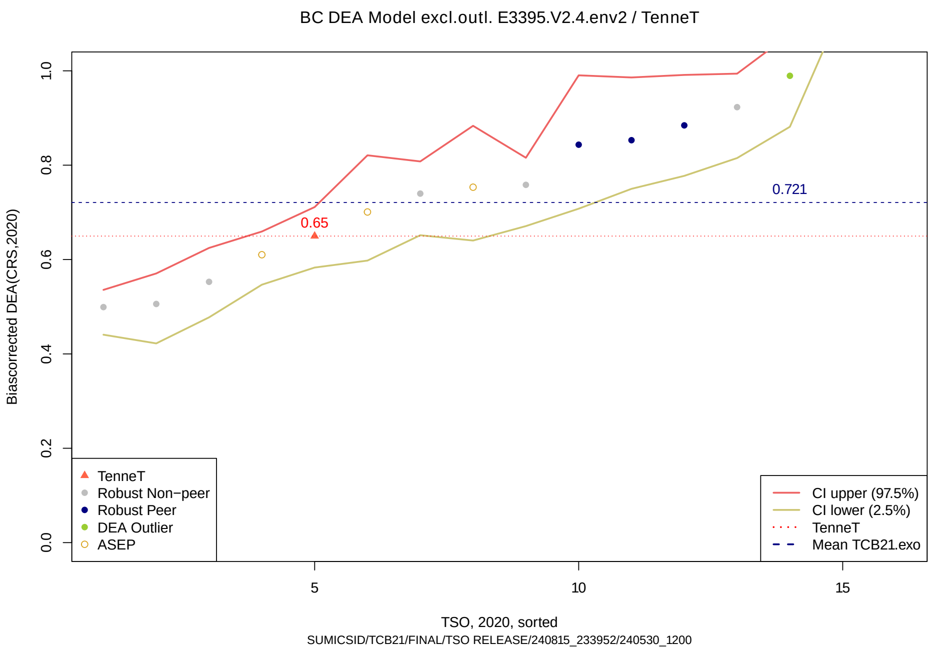

Figure 3.26: Bias-corrected DEA (RDEA.bc) E3395.V2.4.env2

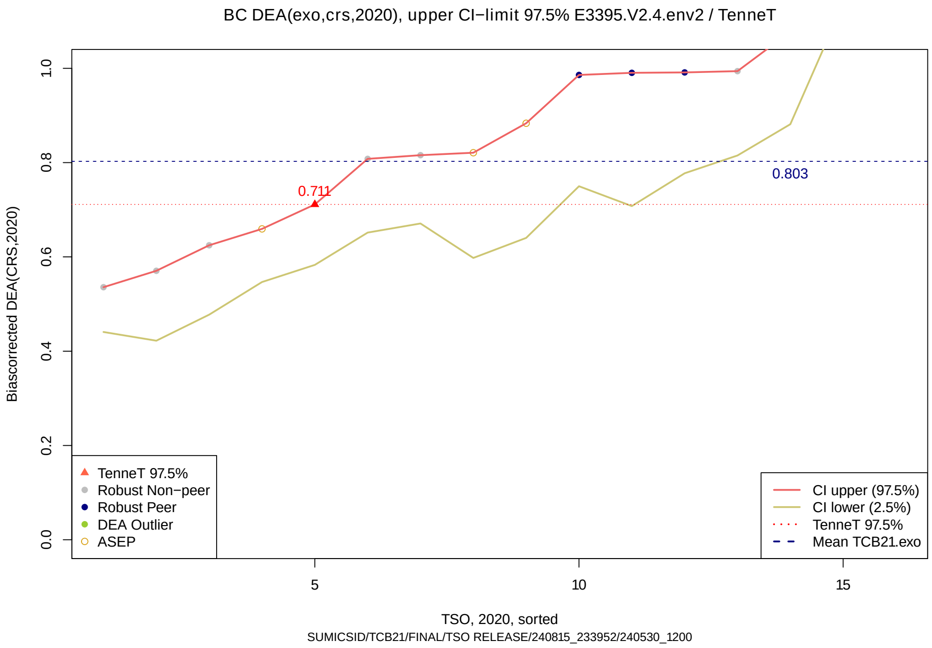

Figure 3.27: CI:Upper limit Bias-corrected DEA (RDEA.bc.CIU) E3395.V2.4.env2

Table 3.9: RDEA.exo scores,year 2020, TenneT

	RDEA.bc.CIL.349	RDEA.bc.349	RDEA.bc.CIU.349	RDEA.bias.349
E2388.V2.4	0.582	0.707	0.836	0.138
E2388.V2.4.env2	0.514	0.612	0.716	0.114
E3395.V2.4	0.582	0.648	0.708	0.068
E3395.V2.4.env2	0.583	0.650	0.711	0.067

Table 3.10: Mean RDEA.exo scores,year 2020, elec

	RDEA.bc.CIL	RDEA.bc	RDEA.bc.CIU	RDEA.bias
E2388.V2.4	0.591	0.686	0.791	0.117
E2388.V2.4.env2	0.596	0.687	0.801	0.126
E3395.V2.4	0.629	0.721	0.804	0.090
E3395.V2.4.env2	0.630	0.721	0.803	0.089

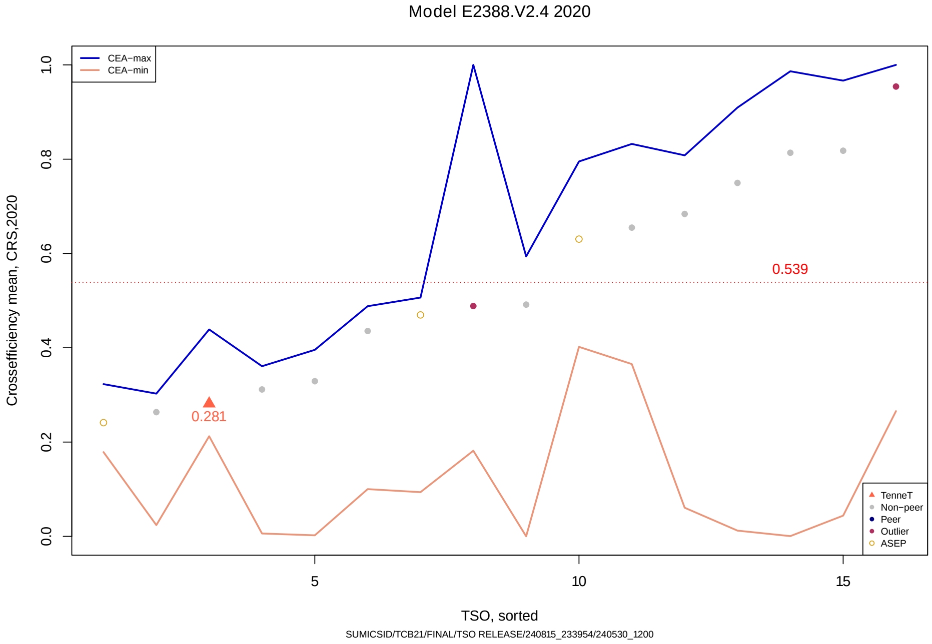

Figure 3.28: CEA results (ave, max, min), E2388.V2.4 crs ,2020.

3.6 Crossefficiency CEA

The results in DEA are determined by default through an open weighting of the inputs and output, i.e., we assume no a priori prices, values or relations in the respective classes of inputs and outputs. This assumption is very cautious as the model would assign the highest possible value to output(s) that are comparatively better represented for any given operator. The individual evaluations, also called *dual output-weights*, valid only for a single operator and not intervening in the conventional DEA.

In Crossefficiency analysis (CEA) we challenge this assumption by assigning successively the weights of all other $n-1$ operators to the given operator assessed. The CEA-score is then obtained as the mean score for the weights of all operators and not only its own. This approach guarantees robustness to extreme output-weights and also gives insights into possible clusters of operators.

The results for CEA (under CRS and 2020) for all final models are presented in Table 3.11 below. The results are given for the average output weights (CEA-ave) and for the maximum output weights that are exogenous (i.e. not from the unit at hand), along with mean and median results for the 2020 TCB21 operators.

Table 3.11: CEA scores (CRS)2020

	CEA-ave 349	CEA-max 349	Mean CEA-ave	Median CEA-ave	Mean CEA-max
E2388.V2.4	0.28	0.44	0.54	0.49	0.67
E2388.V2.4.env2	0.31	0.48	0.52	0.51	0.69
E3395.V2.4	0.44	0.55	0.52	0.48	0.65
E3395.V2.4.env2	0.42	0.55	0.52	0.48	0.66

The detailed results for each model are given in Figs. 3.28 through 3.31 below, where in addition to CEA-ave and CEA-max, we also provide CEA-min, which is the most disfavorable output weights for TenneT given by any operator in the reference set.

The differences between the individual DEA dual weights for TenneT and the mean of the weights for the operators (including TenneT) is illustrated in Figs. 3.32 through 3.35. Note that no weight restrictions are applied, thus a TSO may assign a zero-valued output weight.

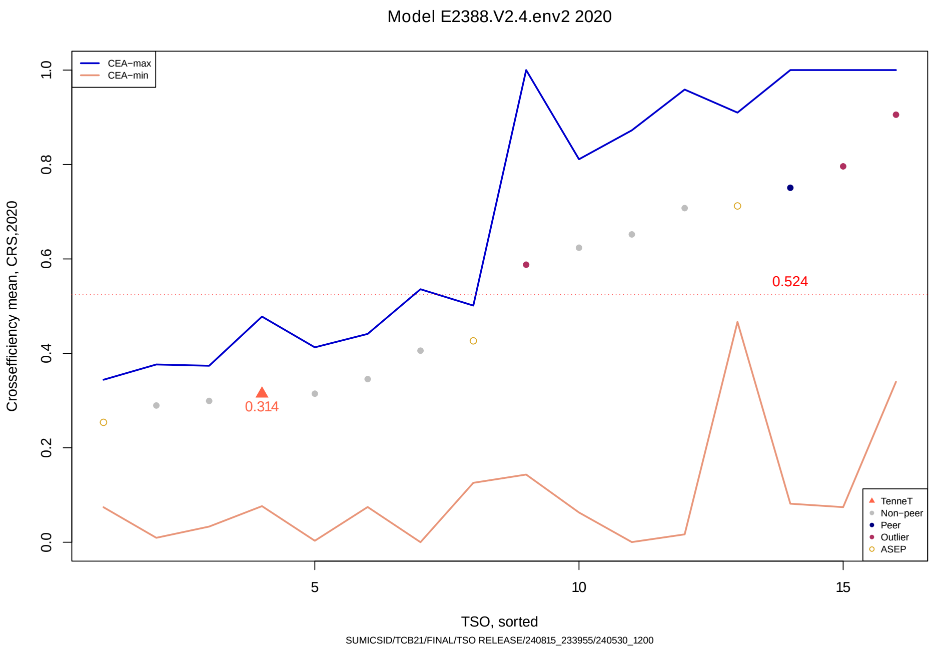

Figure 3.29: CEA results (ave, max, min), E2388.V2.4.env2 crs ,2020.

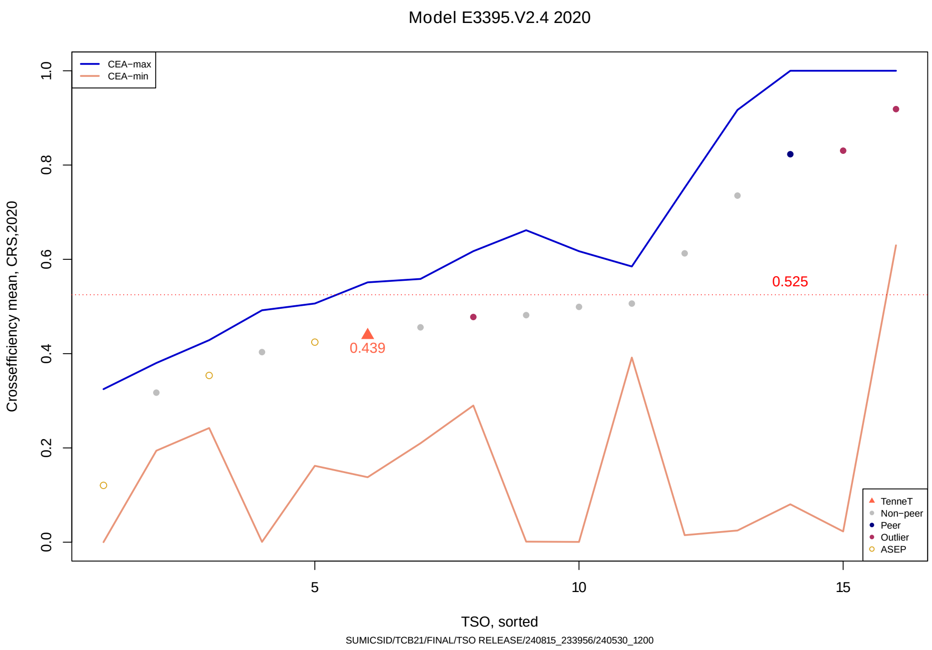

Figure 3.30: CEA results (ave, max, min), E3395.V2.4 crs ,2020.

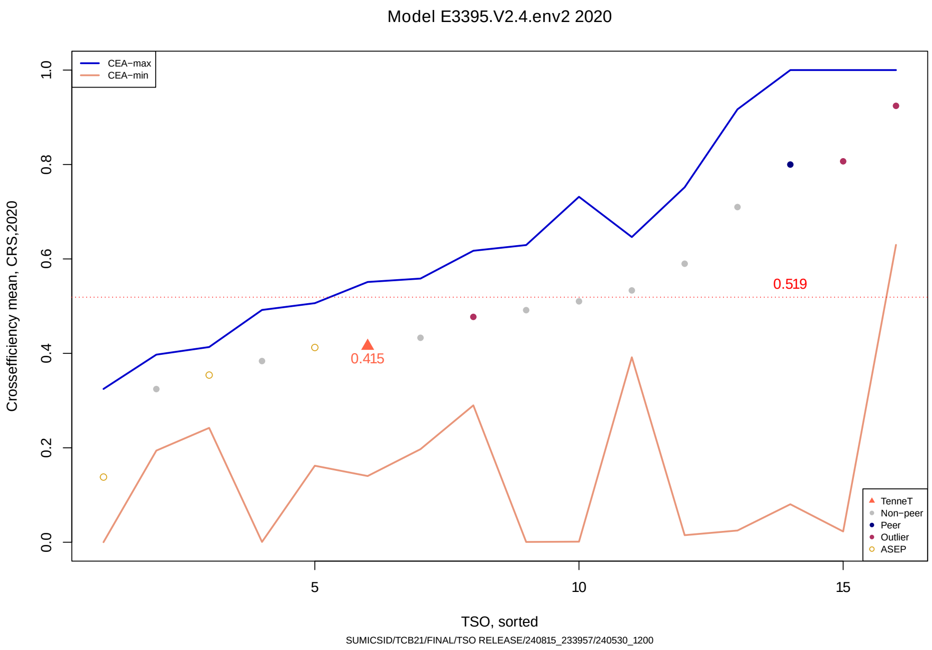

Figure 3.31: CEA results (ave, max, min), E3395.V2.4.env2 crs ,2020.

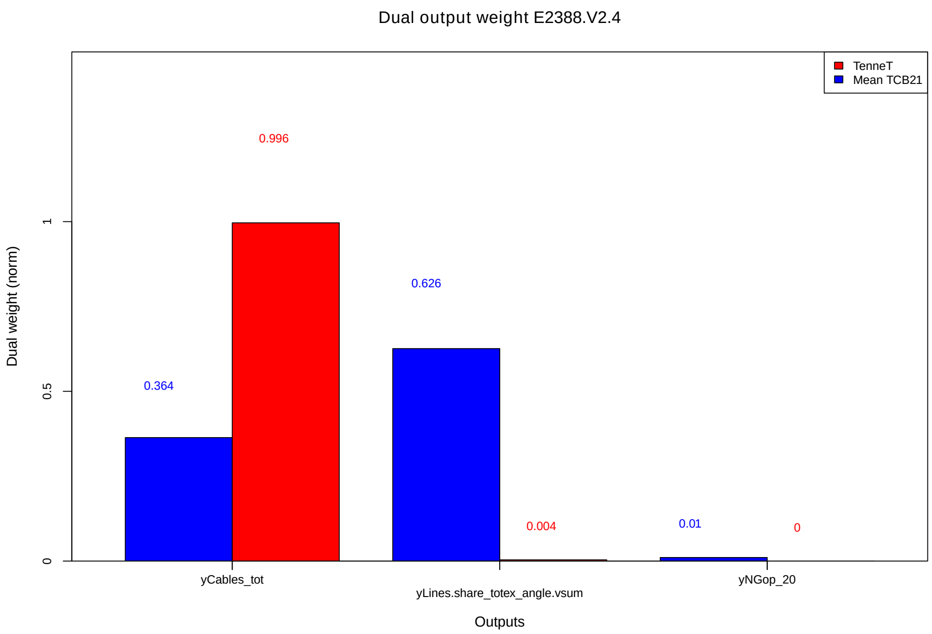

Figure 3.32: Dual weights CEA (mean and TSO), E2388.V2.4 crs, 2020.

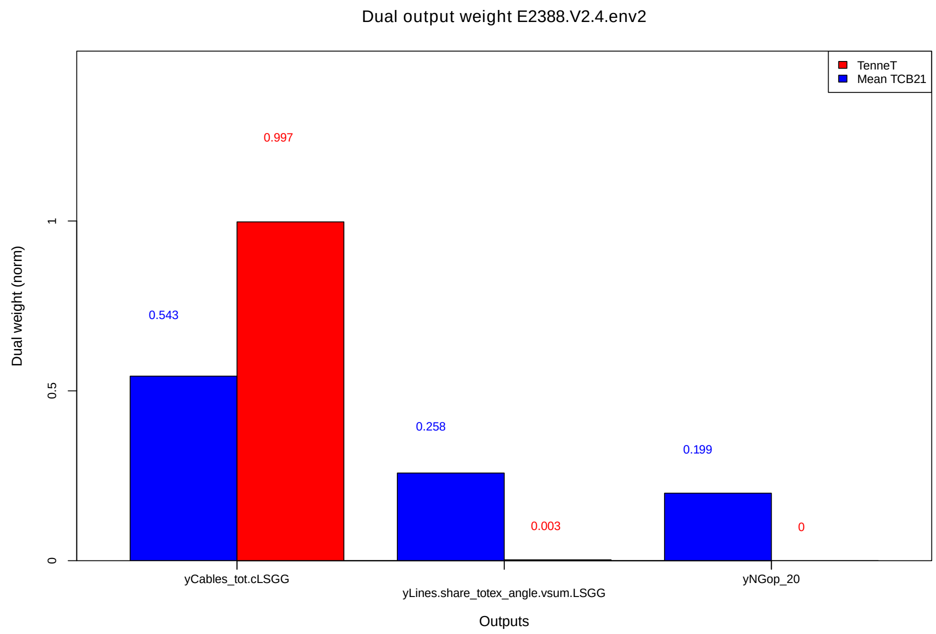

Figure 3.33: Dual weights CEA (mean and TSO), E2388.V2.4.env2 crs, 2020.

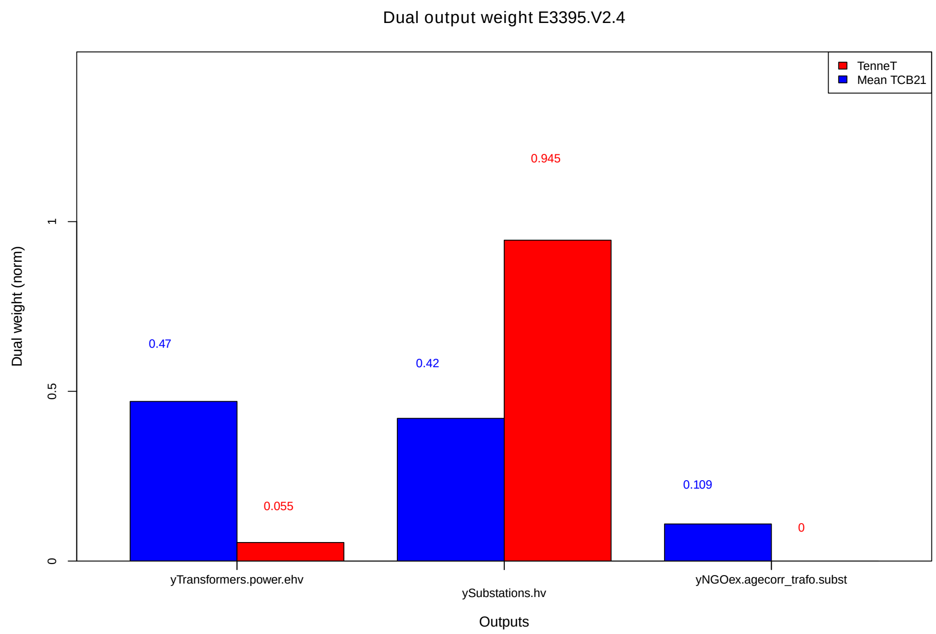

Figure 3.34: Dual weights CEA (mean and TSO), E3395.V2.4 crs, 2020.

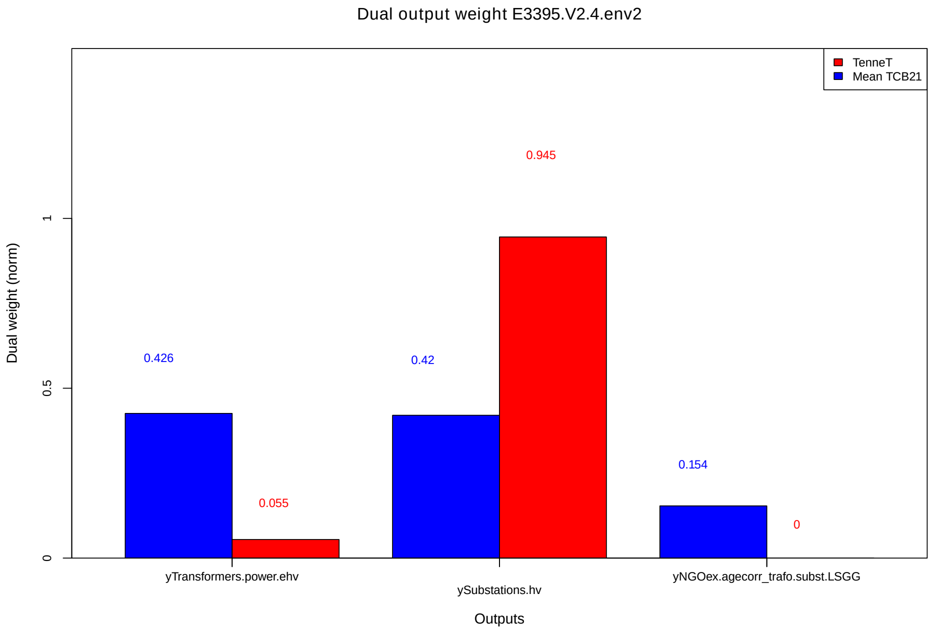

Figure 3.35: Dual weights CEA (mean and TSO), E3395.V2.4.env2 crs, 2020.

Chapter 4

Sensitivity analysis

The calculated cost functions are proportional to a number of parameters, e.g. the NormGrid weights. However, since a frontier benchmarking is an investigation into relative, not absolute, changes, the scales of the inputs and outputs are not important. The relevant evaluation in this context is whether a change in a technical parameter would lead to changes in the relative ranking or level of the benchmarked units. To investigate this aspect, following the Method Note and WS5, the following model parameters have been varied and the resulting changes in the efficiency score for TenneT are illustrated in the following graphs.

Tested parameters

1. Interest rate,
2. Age assumptions for standardized life time,
3. Salary corrections for capitalized labor in investments,
4. Impact of different labour cost indexes (LCI),
5. Impact of different inflation indexes (PI),
6. Overhead allocation rules
7. Environmental correction factors
8. Alternative residual variables

4.1 Interest rate

In the following analysis we change the real interest rate over a range from 0.05% to 5%, listing the individual score as well as mean score (DEA(ndrs,exo, 2020)), using the same outliers as for the default setting. The impact is qualitatively illustrated in Figs. 4.1 to 4.4 below. The detail of the results are also given in Appendix Tables A.11 to A.14 per model.

4.2 Standardized age assumptions

The following analysis looks at the impact on the score of the assumptions regarding the standardized life time per asset. For simplicity, we have reduced the simulation to two alternative cases, Age_{low} and Age_{high}, respectively with correspondingly about 10 years shorter and longer lifetimes. The exact parameters are reproduced in Table 4.1 below. See Figs. 4.5 to 4.8 for graphs. The impact on the individual scores for TenneT and the mean score (DEA(ndrs,exo,2020)) is listed per model in in Appendix Tables A.15 to A.18.

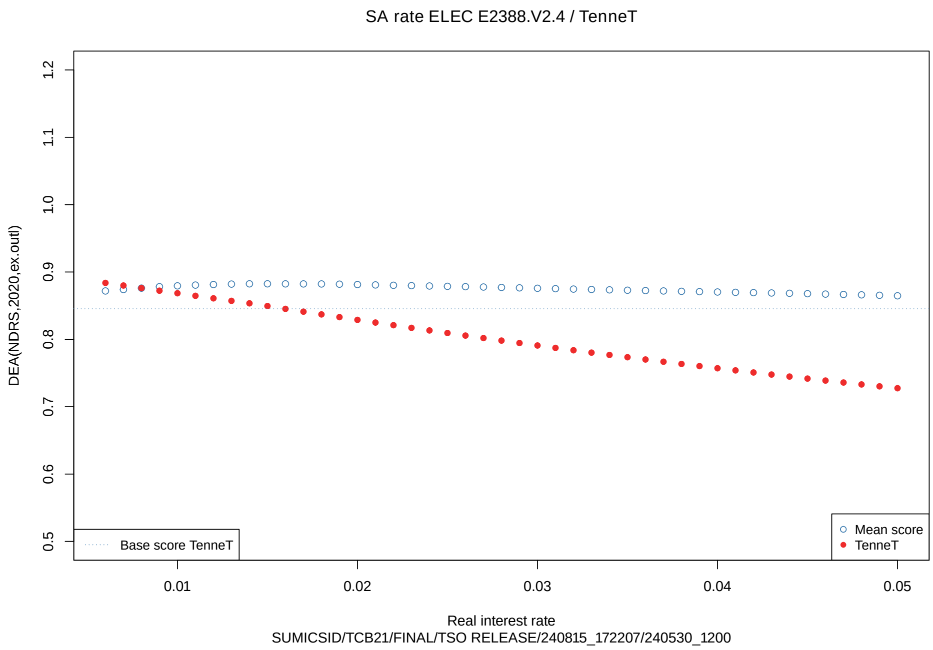

Figure 4.1: DEA(ndrs,exo,2020) scores for TenneT varying the interest rate from 0.5% to 5%, E2388.V2.4

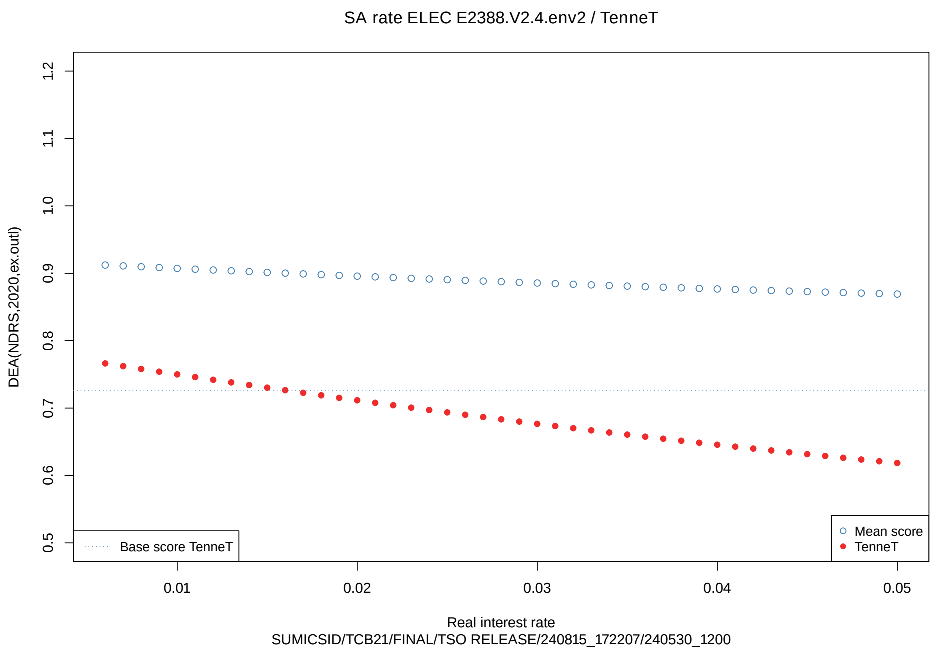

Figure 4.2: DEA(ndrs,exo,2020) scores for TenneT varying the interest rate from 0.5% to 5%, E2388.V2.4.env2

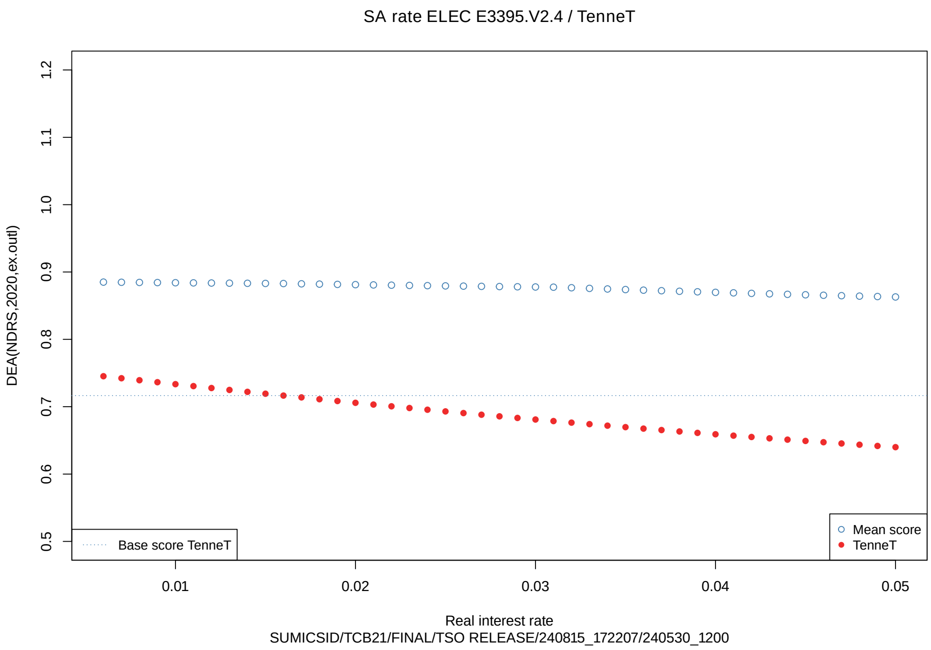

Figure 4.3: DEA(ndrs,exo,2020) scores for TenneT varying the interest rate from 0.5% to 5%, E3395.V2.4

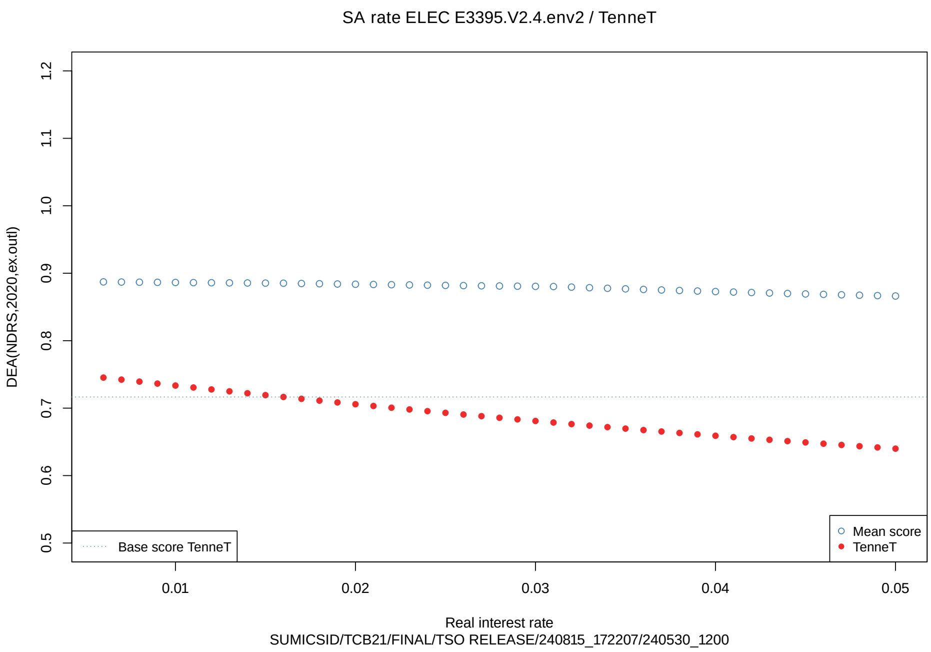

Figure 4.4: DEA(ndrs,exo,2020) scores for TenneT varying the interest rate from 0.5% to 5%, E3395.V2.4.env2

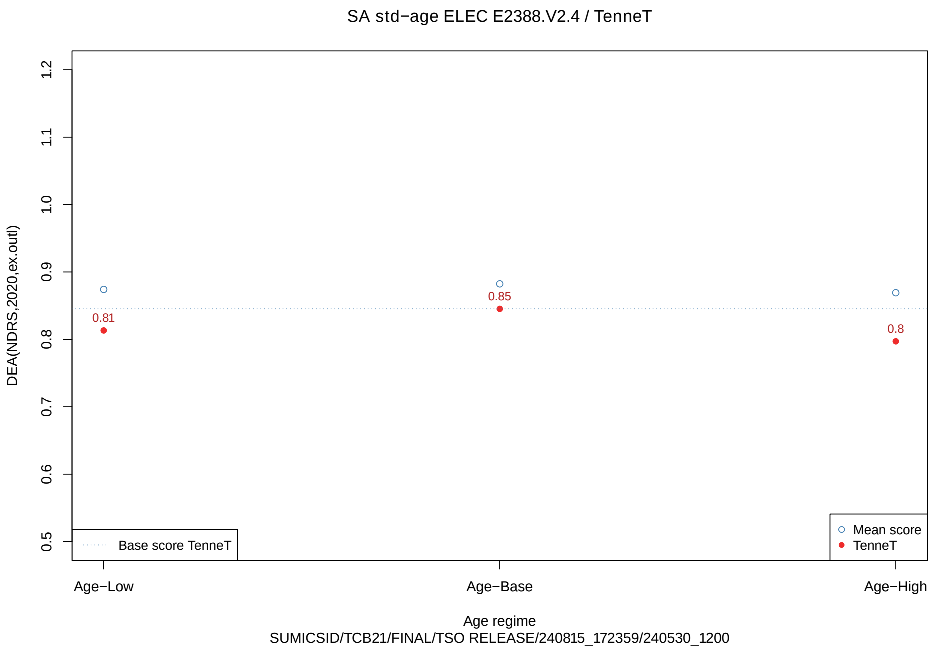

Figure 4.5: DEA(ndrs,exo,2020) score for TenneT under alternative standard age regimes, E2388.V2.4

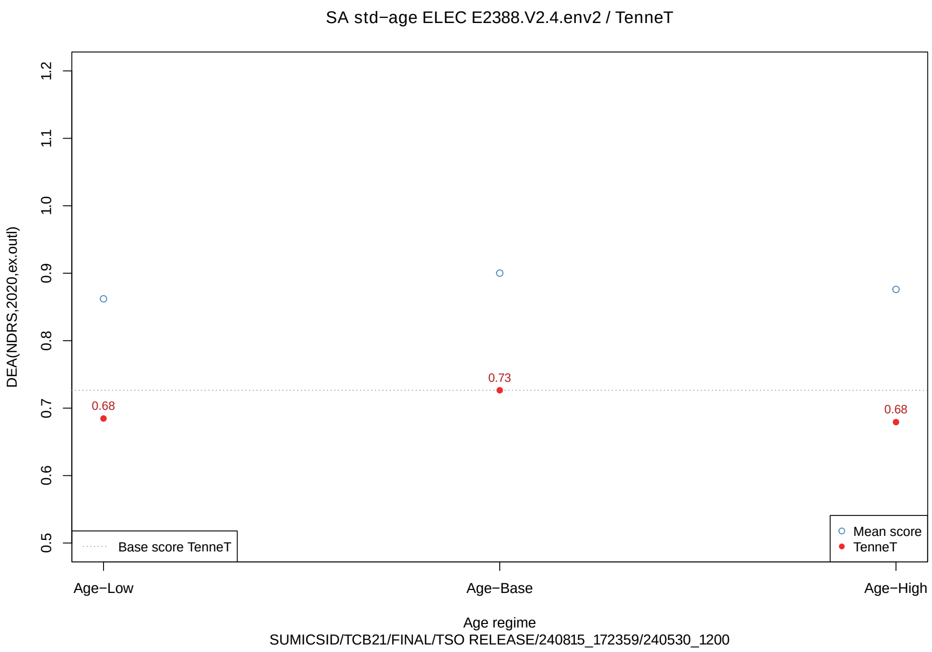

Figure 4.6: DEA(ndrs,exo,2020) score for TenneT under alternative standard age regimes, E2388.V2.4.env2

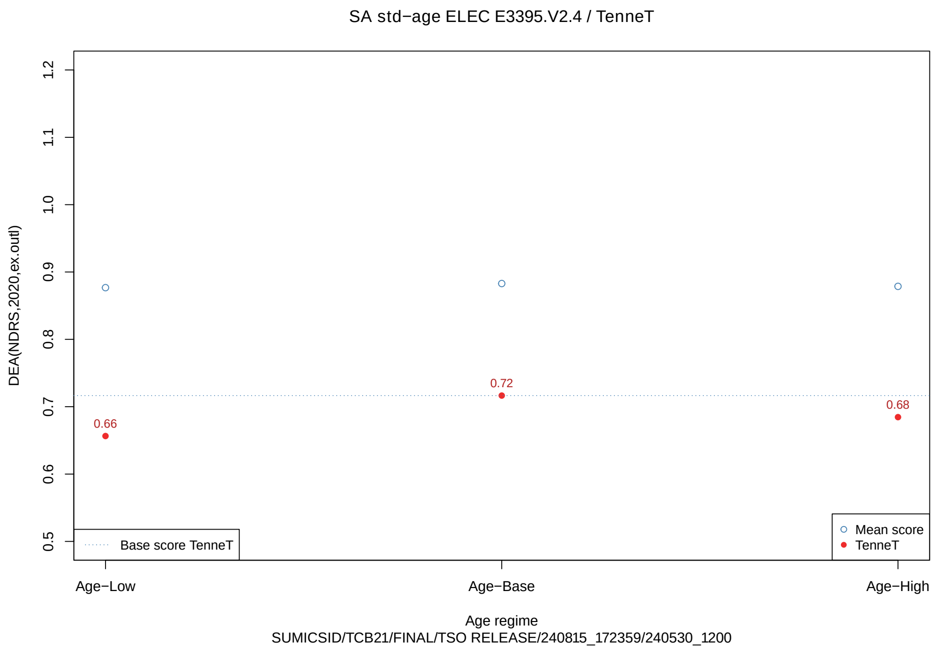

Figure 4.7: DEA(ndrs,exo,2020) score for TenneT under alternative standard age regimes, E3395.V2.4

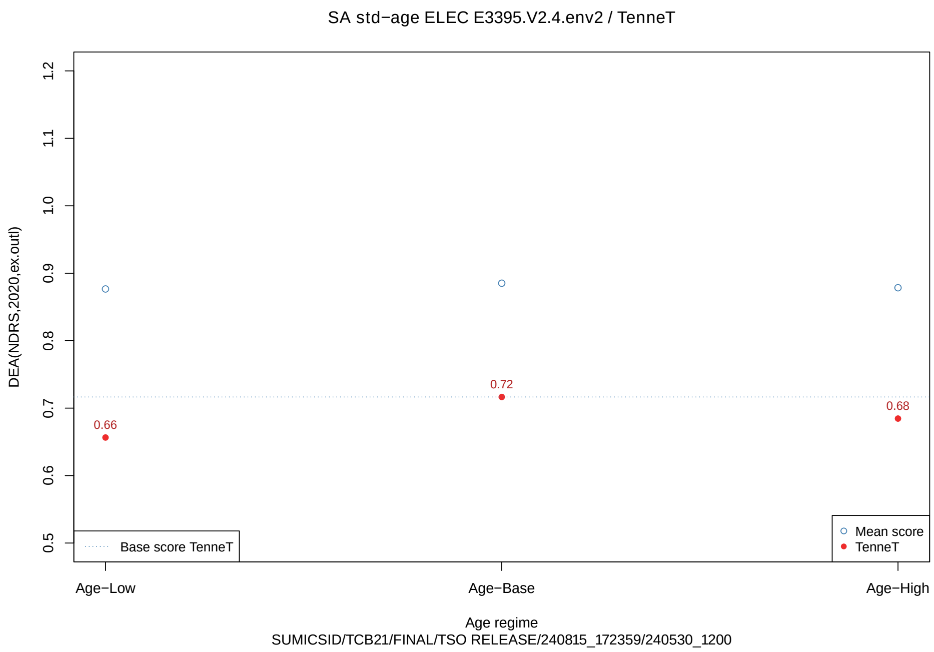

Figure 4.8: DEA(ndrs,exo,2020) score for TenneT under alternative standard age regimes, E3395.V2.4.env2

Table 4.1: Techno-economic life SA (years)

Asset	Base case	Age-Low	Age-High
Lines-cables	60	40	70
Transformers	40	30	50
Circuit ends	45	35	55
Compensating devices	40	30	50
Series compensations	40	30	50
Control centers	20	20	30
Towers	60	40	70
Substations	40	30	50
Lines-towers	60	40	70
Cables	50	40	60
Other equip	20	10	30
Equipment	10	10	20

4.3 Impact of labour cost indexes (LCI)

Analysis presented in the Note on Method and Calculations indicates that the preferred labour cost index (LCI) for the electricity sector is LCI-UTIL. The impact is qualitatively illustrated in Figs. 4.9 to 4.12 below. The detail of the results are given in Appendix A.7 in Tables A.19 to A.22 per model.

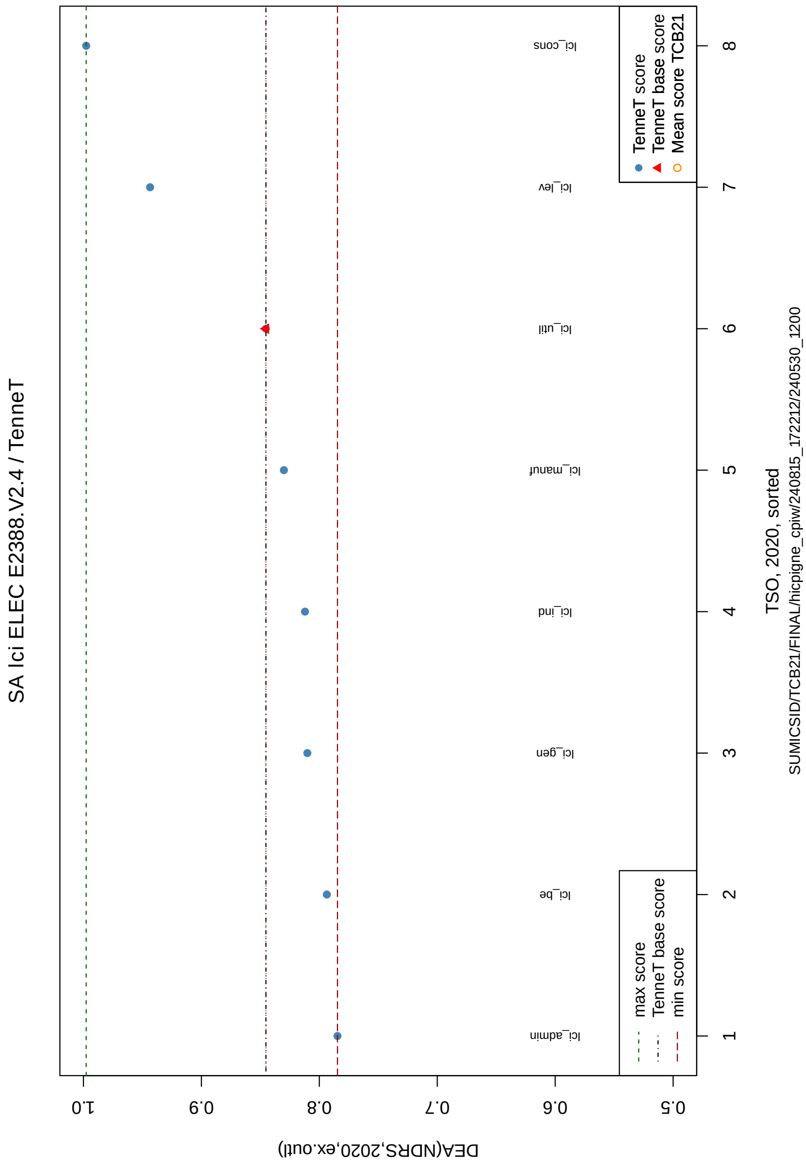

Figure 4.9: DEA(ndrs,exo,2020) score for alternative LCI in E2388.V2.4 for TenneT

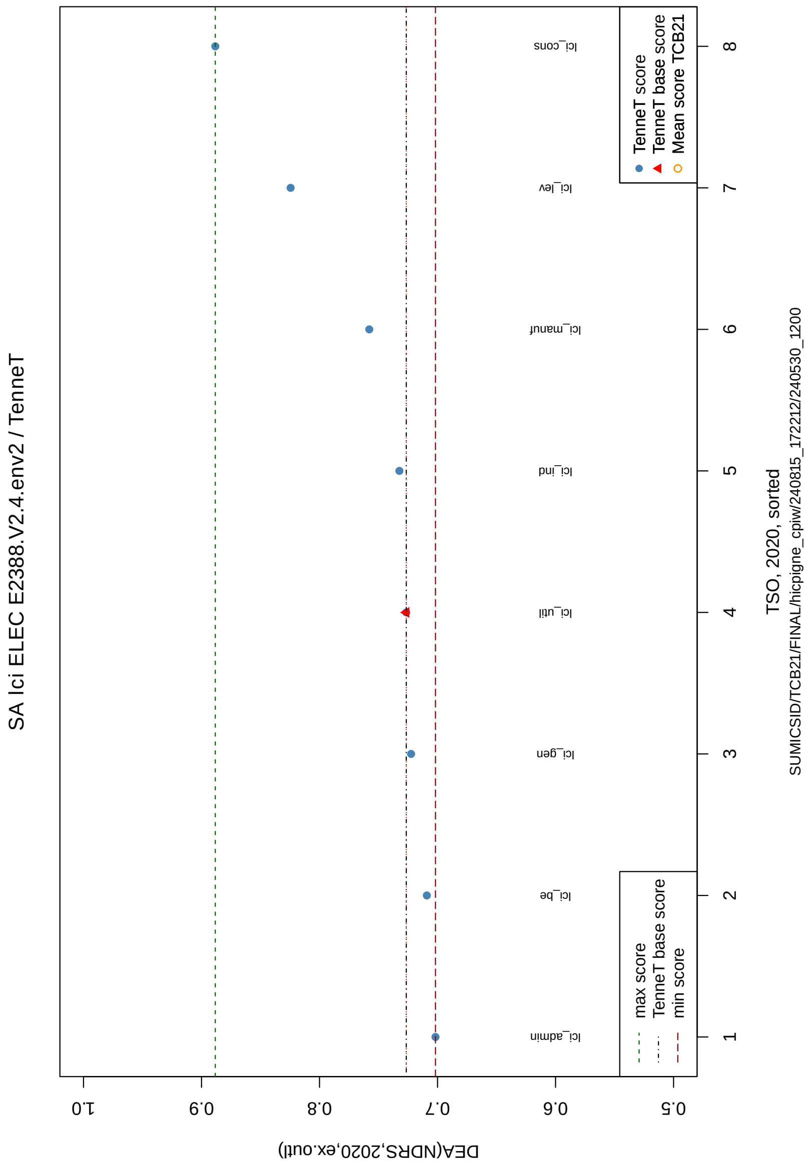

Figure 4.10: DEA(ndrs,exo,2020) score for alternative LCI in E2388.V2.4.env2 for TenneT

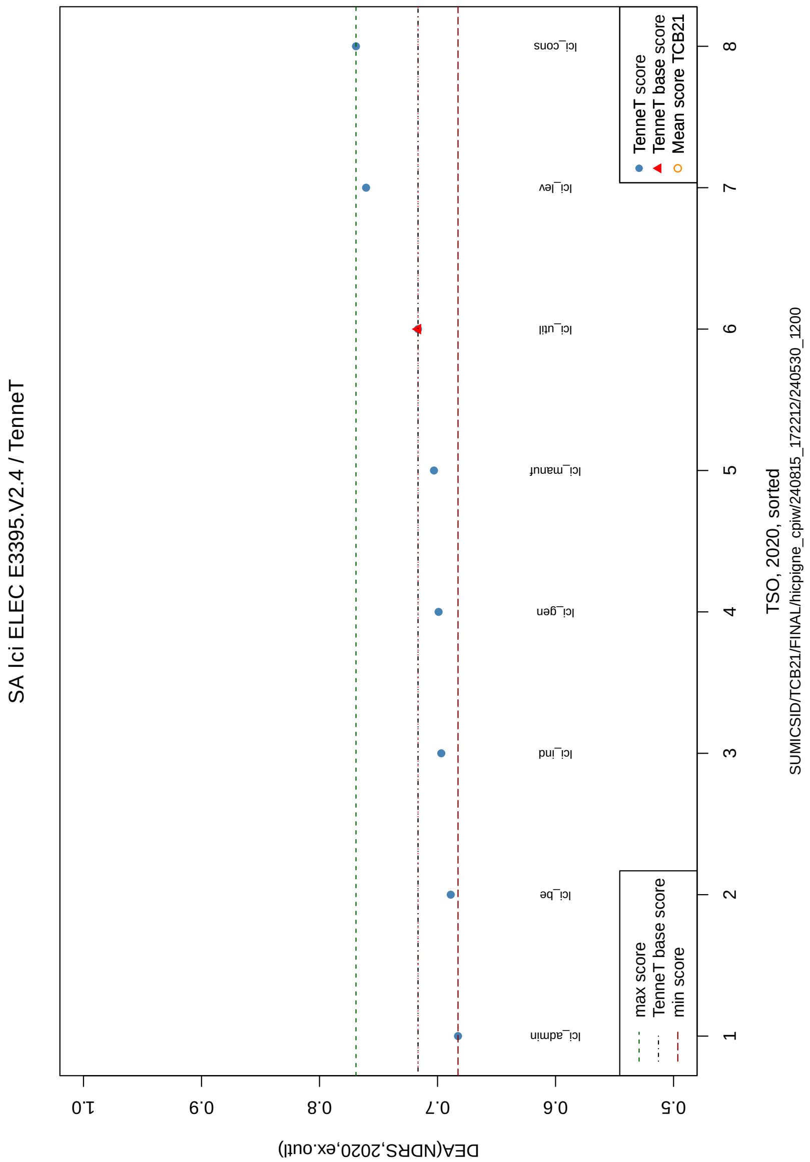

Figure 4.11: DEA(ndrs,exo,2020) score for alternative LCI in E3395.V2.4 for TenneT

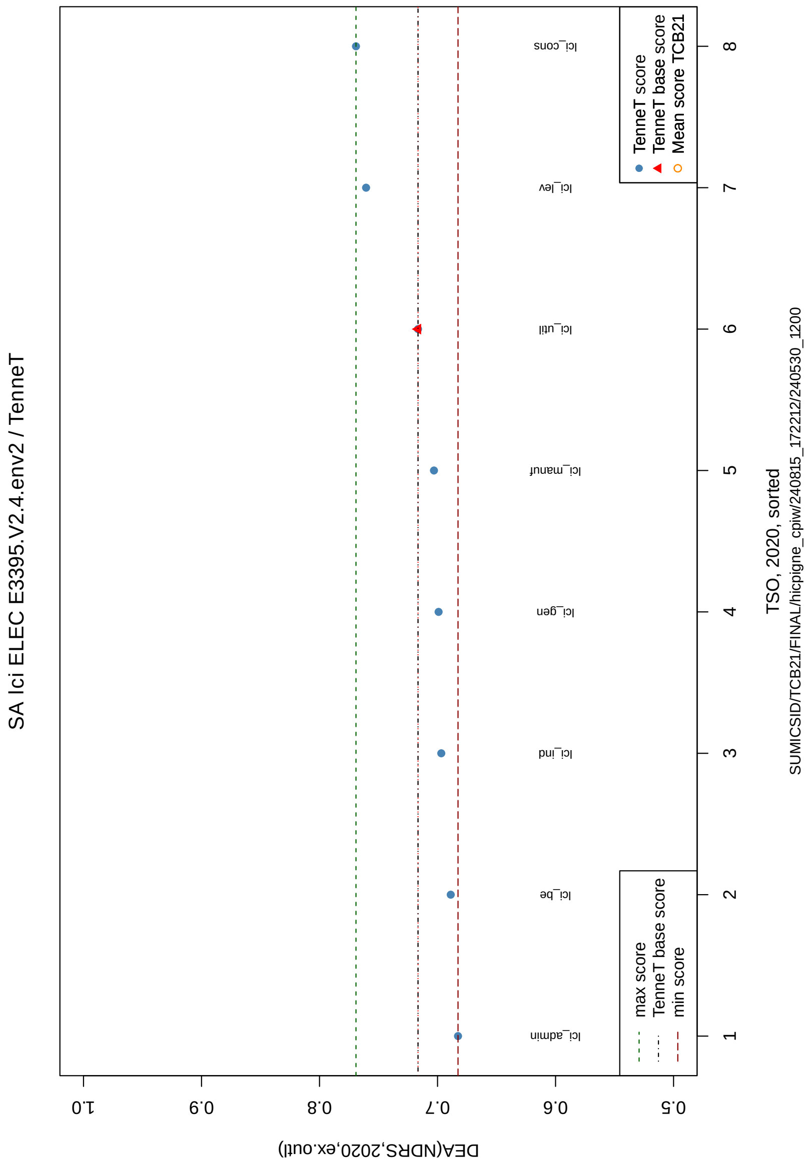

Figure 4.12: DEA(ndrs,exo,2020) score for alternative LCI in E3395.V2.4.env2 for TenneT

4.4 Salary corrections for capitalized labor in investments

In the base model, there is no adjustment for labour cost differences in investments. The impact of this assumption is investigated in this section per model, varying the basis for local LCI adjustements of historic investments from 0 to 50 percent of the nominal investment value. The impact is qualitatively illustrated in Figs. 4.13 to 4.16 below. The detail of the results are given Appendix A.8 in Tables A.23 to A.26 per model.

The formula for adjustment is the following.

$$Capex_{it}^{adj} = Capex_{it}(1 - \psi(1 - mean_t(\frac{LCI_{EU}}{LCI_{k(i)t}}))) \tag{4.1}$$

where $Capex_{it}$ is the real annuity capex for operator i in year t, LCI_{kt} is the labor cost index for country k in year t, $k(i)$ is the country for operator i, and ψ is the capex-laborcost share. The notation denotes the proportion for adjustment ψ, i.e., $\psi = 0.25 = 25$ percent of nominal investment is adjusted.

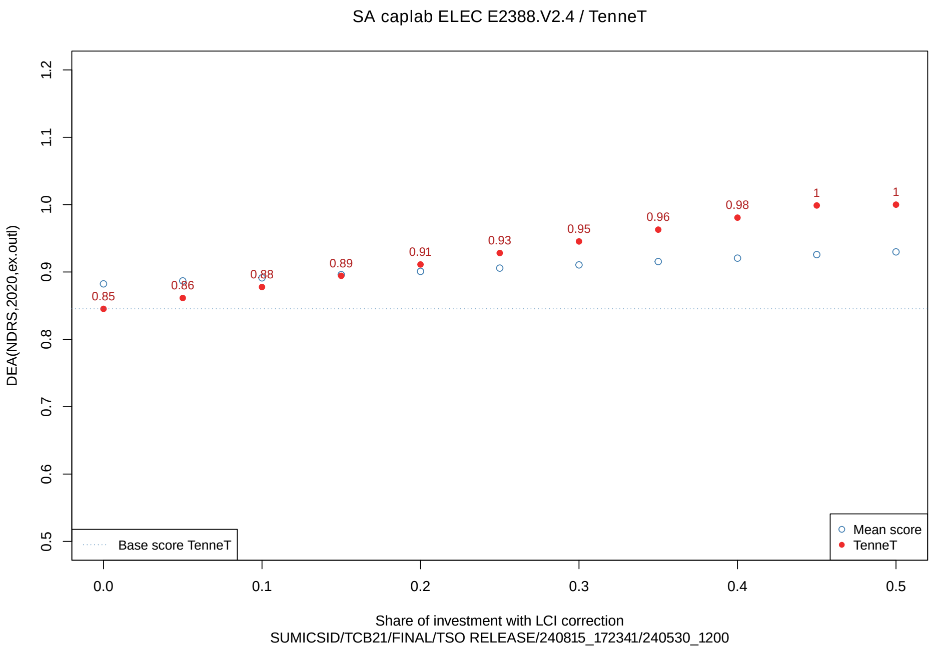

Figure 4.13: DEA(ndrs,exo,2020) score as function of share of LCI-adjusted capex in E2388.V2.4 , TenneT and mean for TCB21.

4.5 Impact of inflation indexes (PI)

Analysis presented in the Note on Method and Calculations indicates that the preferred price index (PI) for the electricity sector is HICPIGNE(WB-CPI). However, there are a series of eligible PI tested in Figs. 4.17 to 4.20 below. The detail of the results are given in Appendix A.9 in Tables A.27 to A.30 per model.

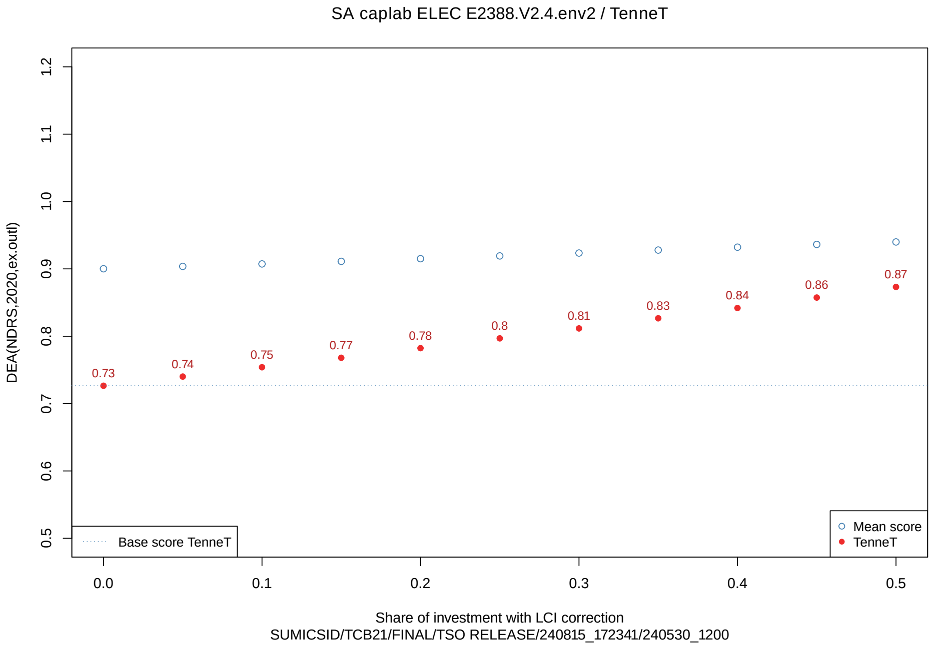

Figure 4.14: DEA(ndrs,exo,2020) score as function of share of LCI-adjusted capex in E2388.V2.4.env2 , TenneT and mean for TCB21.

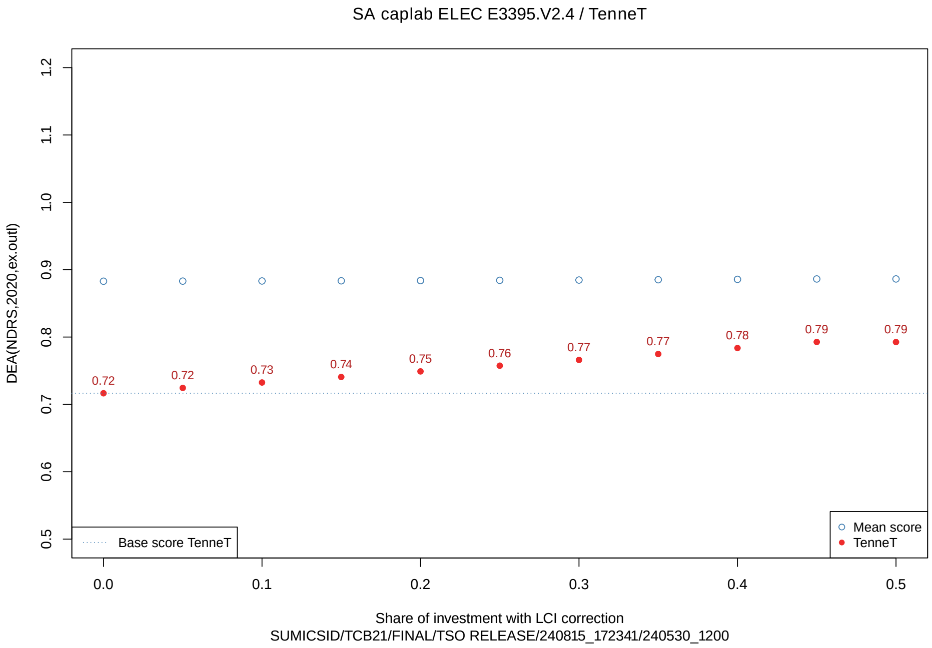

Figure 4.15: DEA(ndrs,exo,2020) score as function of share of LCI-adjusted capex in E3395.V2.4 , TenneT and mean for TCB21.

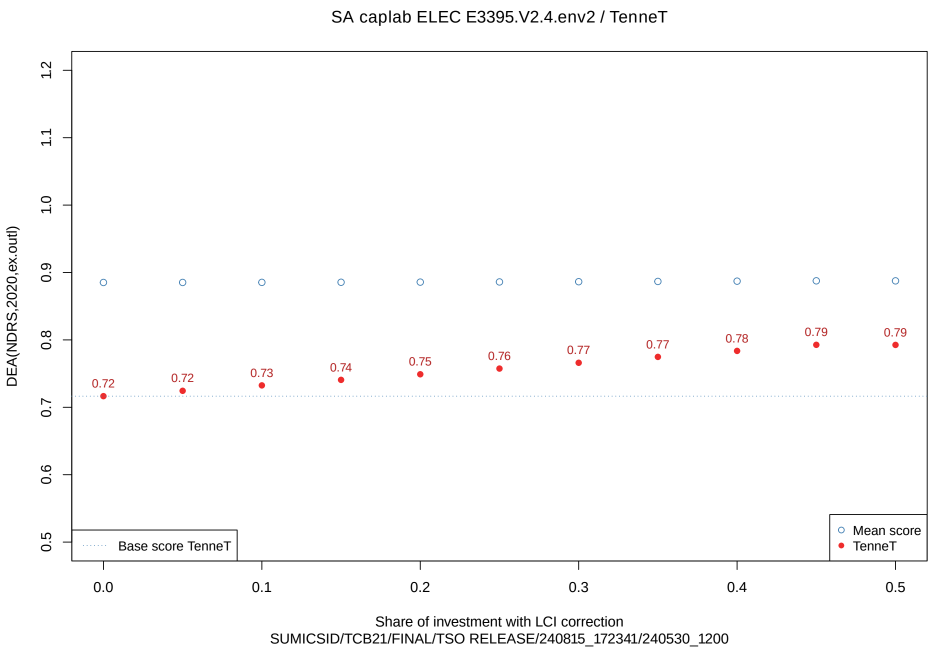

Figure 4.16: DEA(ndrs,exo,2020) score as function of share of LCI-adjusted capex in E3395.V2.4.env2 , TenneT and mean for TCB21.

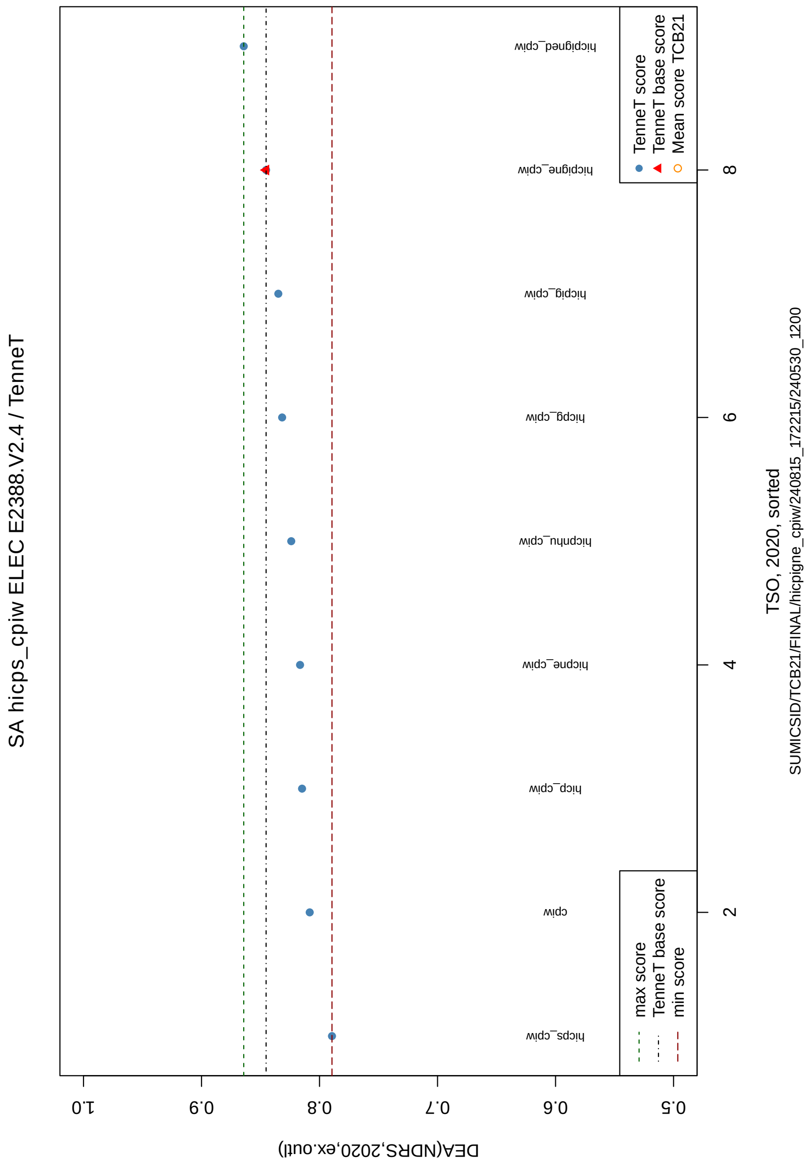

Figure 4.17: DEA(ndrs,exo,2020) score for alternative inflation indexes in E2388.V2.4 for TenneT .

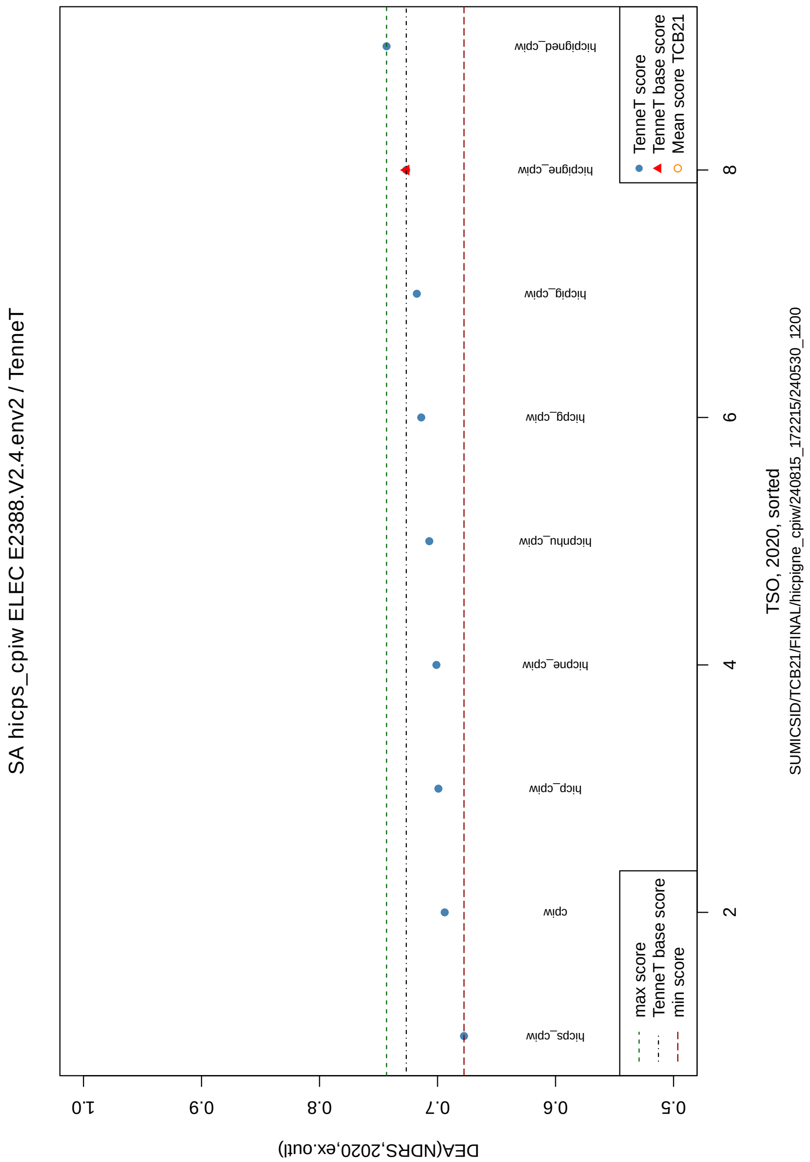

Figure 4.18: DEA(ndrs,exo,2020) score for alternative inflation indexes in E2388.V2.4.env2 for TenneT .

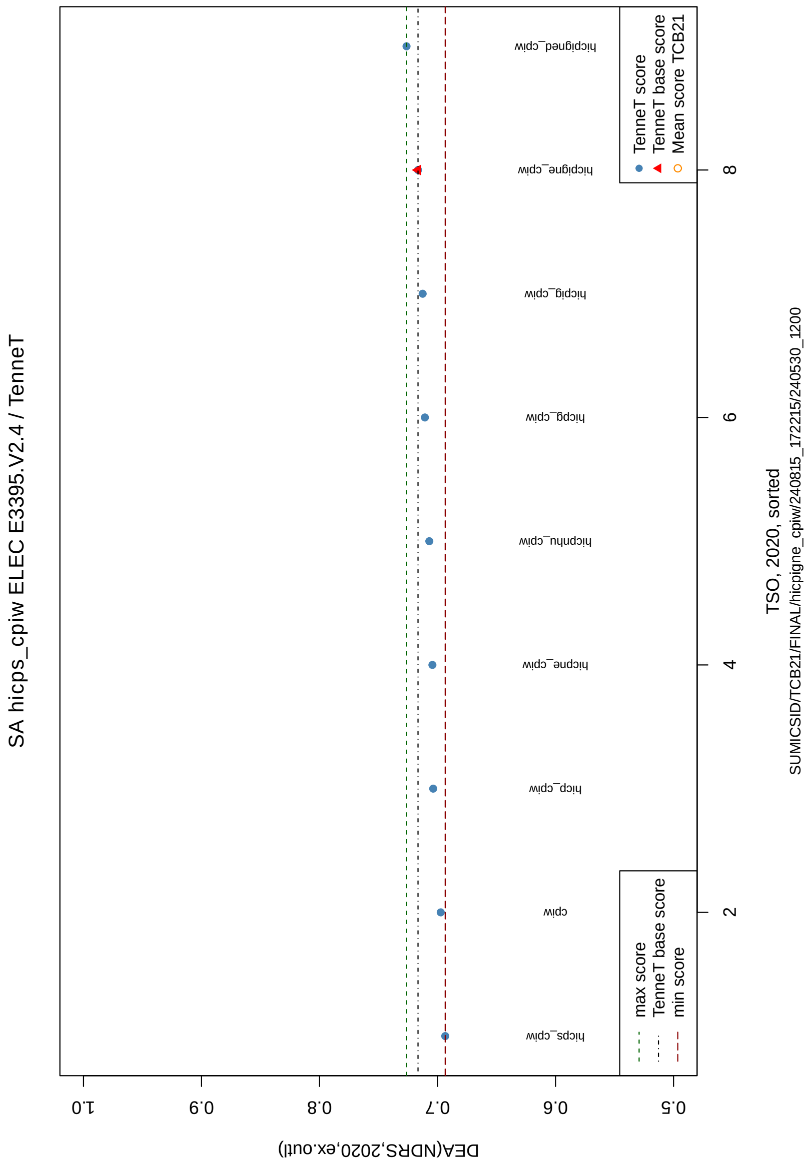

Figure 4.19: DEA(ndrs,exo,2020) score for alternative inflation indexes in E3395.V2.4 for TenneT .

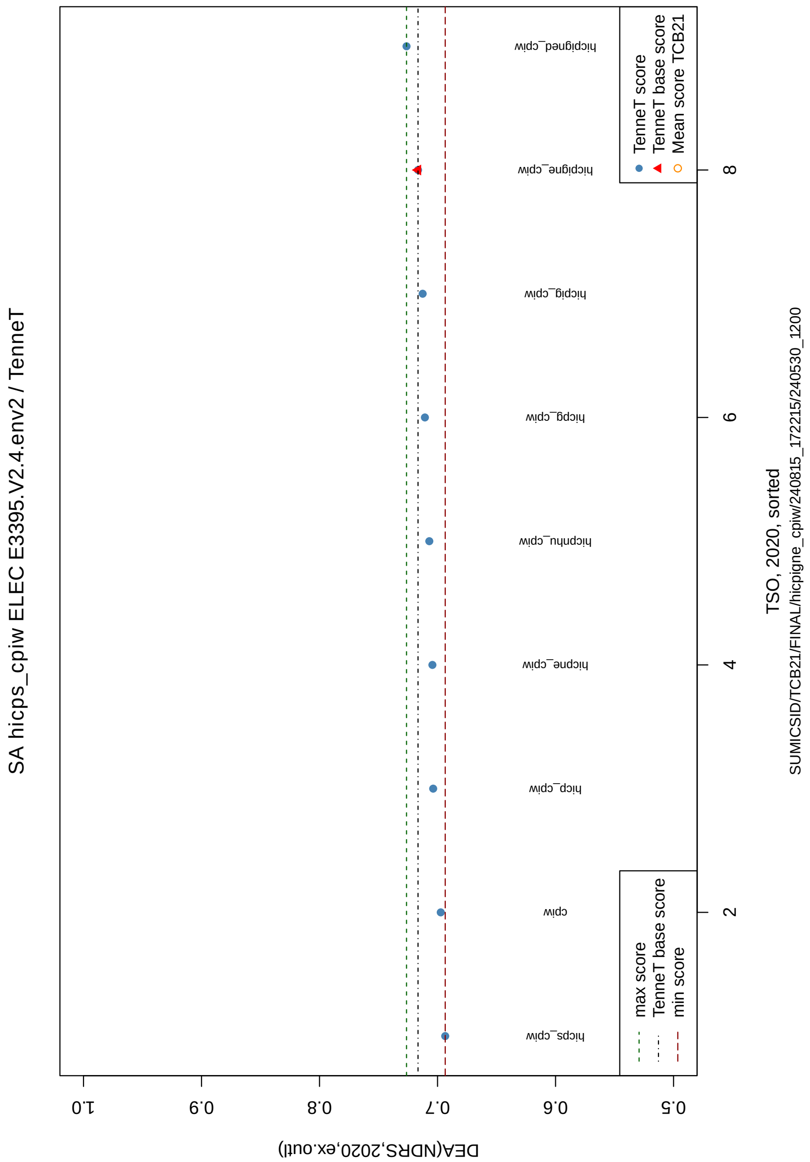

Figure 4.20: DEA(ndrs,exo,2020) score for alternative inflation indexes in E3395.V2.4.env2 for TenneT .

4.6 Overhead allocation rules

Indirect cost for support is allocated to the benchmarked cost using a cost-based allocation with some deductions. The sensitivity of this assumption is tested in Appendix A.10 below using the DEA(ndrs.exo.2020) scores. The impact is qualitatively illustrated in Figs. 4.21 to 4.24 below. The detail of the results are given Appendix A.10 in Tables A.31 to A.34 per model.

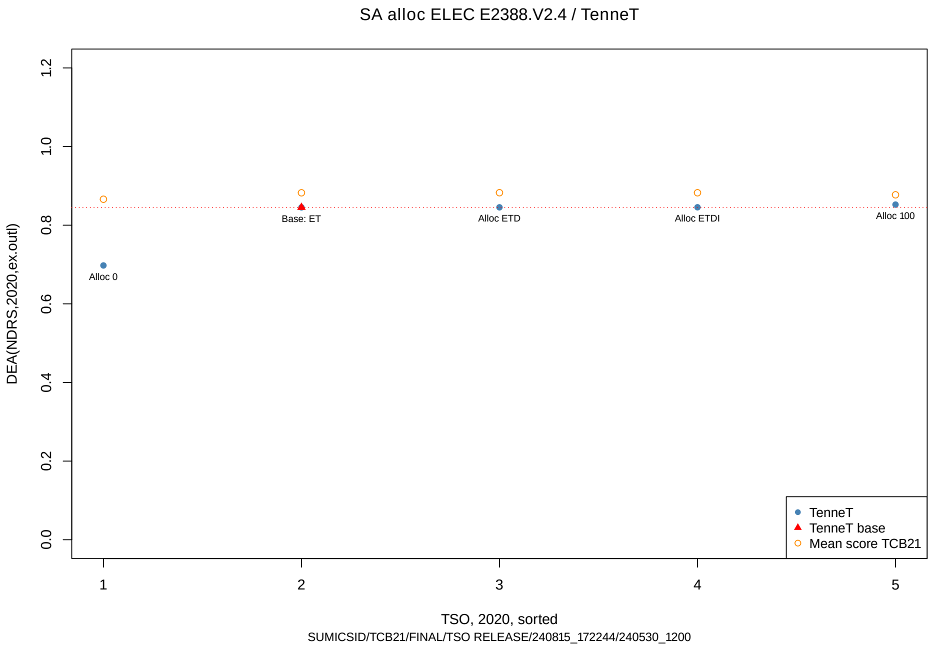

Figure 4.21: DEA(ndrs,exo,2020) scores for TenneT under alternative overhead allocation regimes, E2388.V2.4

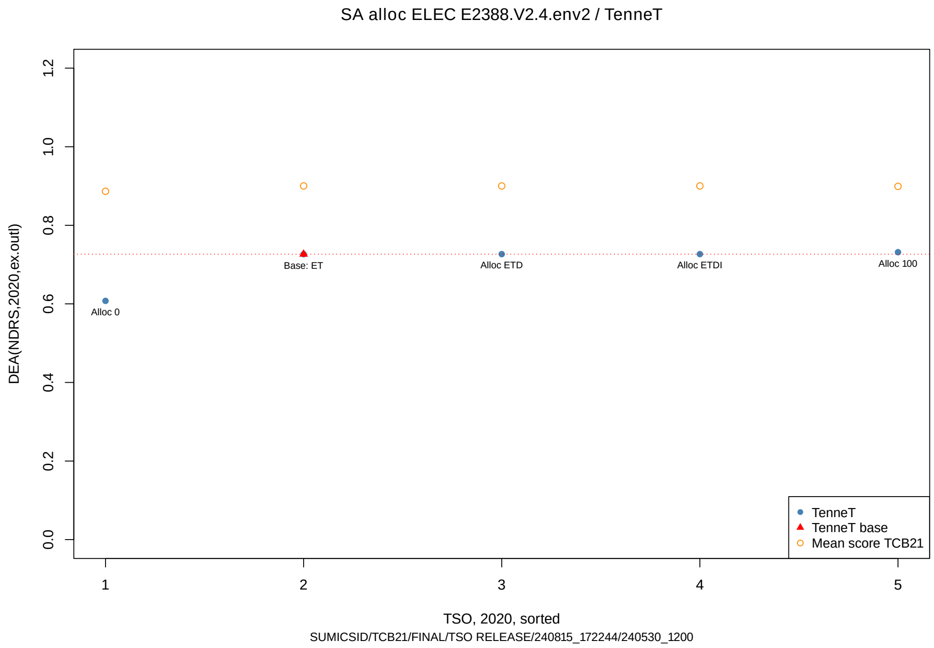

Figure 4.22: DEA(ndrs,exo,2020) scores for TenneT under alternative overhead allocation regimes, E2388.V2.4.env2

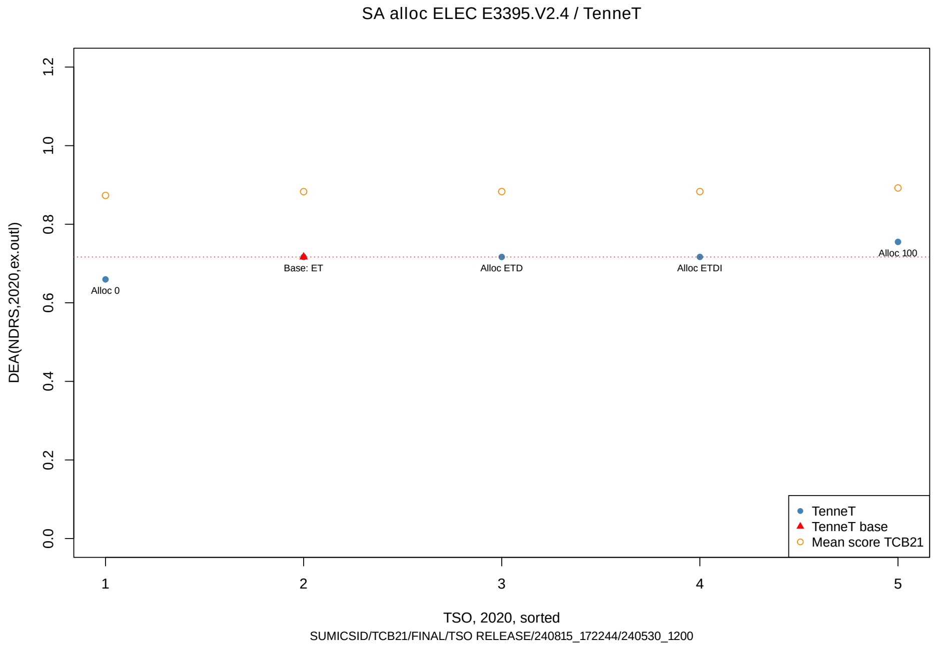

Figure 4.23: DEA(ndrs,exo,2020) scores for TenneT under alternative overhead allocation regimes, E3395.V2.4

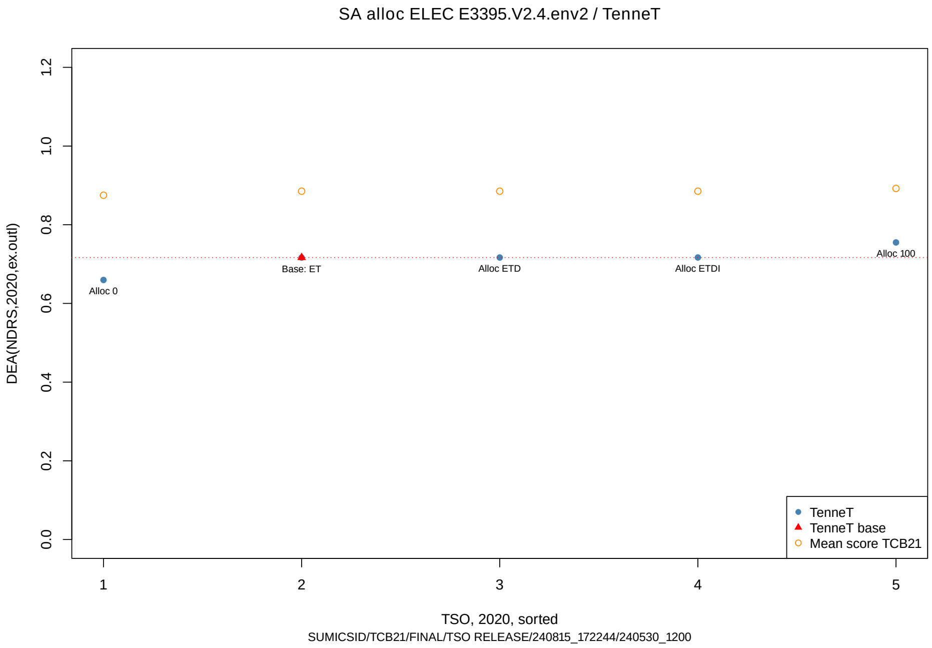

Figure 4.24: DEA(ndrs,exo,2020) scores for TenneT under alternative overhead allocation regimes, E3395.V2.4.env2

4.7 Environmental correction factors

For each model, a variant using environmental correction factors expressing the complexity of network installations and operations in different environments related to landuse, slope, top- and subsoil structure, wind, humidity and wetness conditions(see list of notation in Table 4.2 below). The factors are applied to the relevant output elements, e.g., the wind-complexity only applies to overhead-line outputs in electricity, not to cables or transformers.

The factors are chosen based on their explanatory power in the Model Specification Note. The impact is qualitatively illustrated in Figs. 4.25 to 4.26 below. The detailed impact is listed in Appendix A.11 in Tables A.35 to A.36 below.

The change is the ratio of the score for the alternative environmental correction Z to the base score for the environmental variant of the corresponding environmental model, i.e.:

$$change.Z = \frac{DEA(ndrs, 2020, Z)}{Base.DEA.env(ndrs, 2020)} \tag{4.2}$$

The operators 'max' and 'min' denote the maximum and minimum corresponding ratios, respectively.

The notation in the name (X.Y) indicates the correction applied to term1 (X) and term 2 (Y), respectively. A zero (0) denotes no correction term. For the model specifications, see Tables 2.2 to 2.5.

Table 4.2: Notation for environmental factors.

Acronym	Definition
L	Landuse impact
S	Slope
H	Humidity
GG	Top- and Subsoil Gravel
V	Volume of stone
W	Wind
cX	Landuse impact
csX	Landuse impact

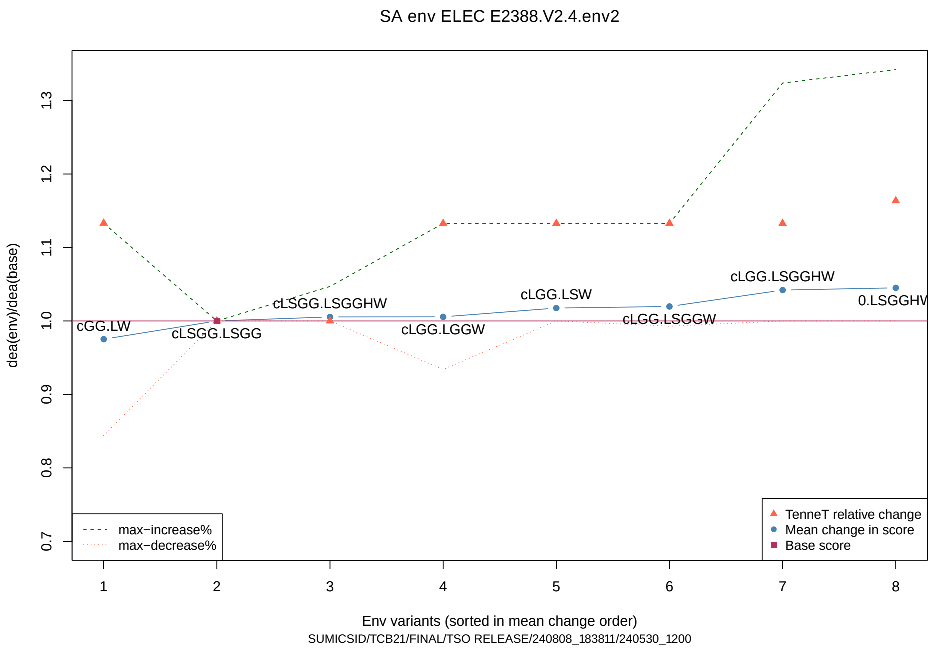

Figure 4.25: Relative change in DEA(ndrs,exo,2020) score for alternative environmental correction factors in E2388.V2.4.env2 for TenneT and TCB21 operators.

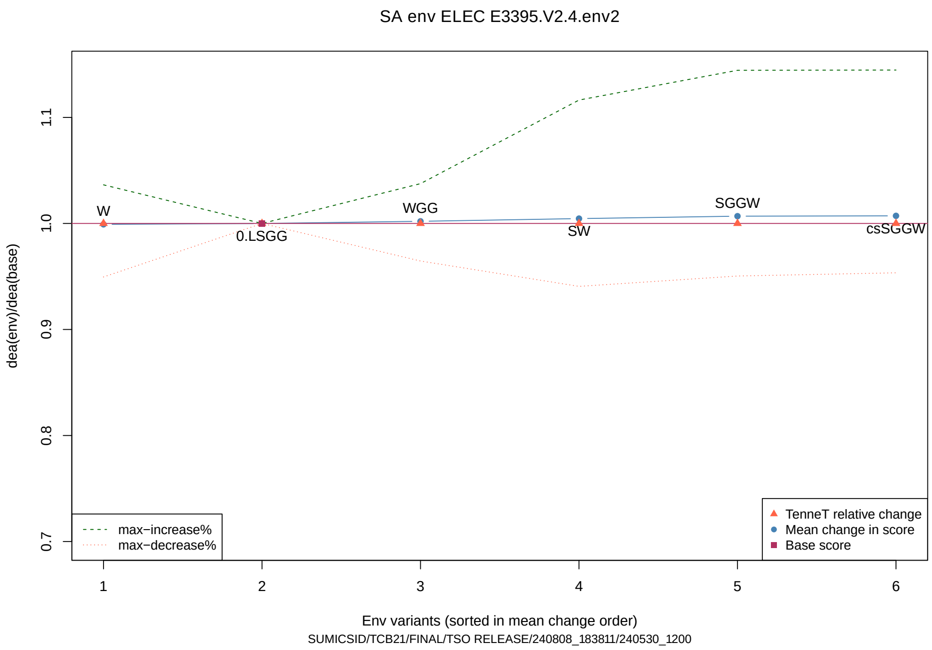

Figure 4.26: Relative change in DEA(ndrs,exo,2020) score for alternative environmental correction factors in E3395.V2.4.env2 for TenneT and TCB21 operators.

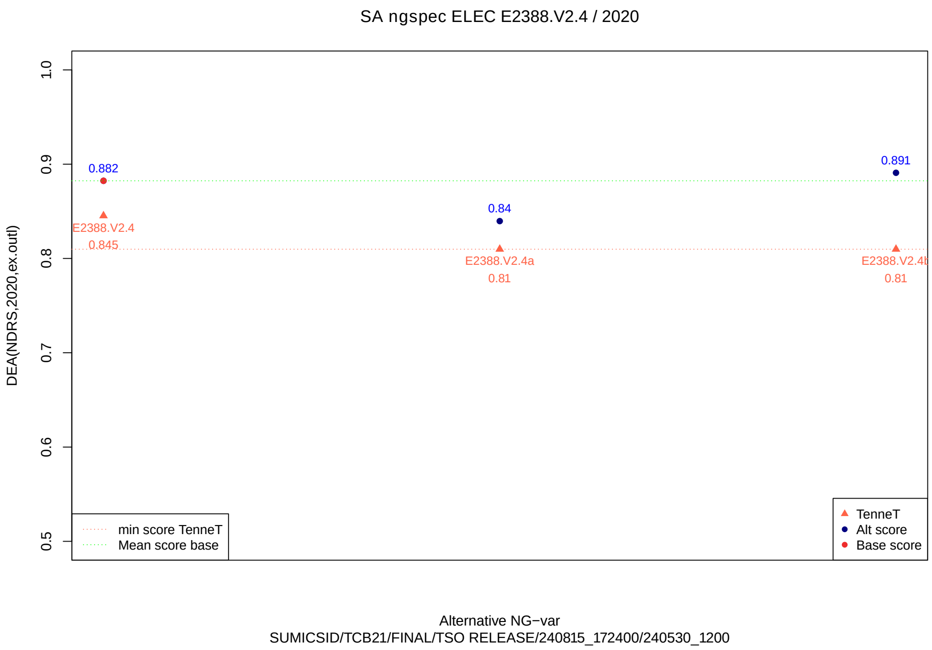

Figure 4.27: Scores DEA(ndrs,exo,2020) for alternative NG-variables in E2388.V2.4 for TenneT in TCB21.

4.8 Alternative residual variables

For the ELEC models, the completeness process provided residual variables for the outputs not captured by the original output parameters (see the Note on Model Specification). The residual parameters are constructed by sums of NormGrid assets while excluding as far as possible the assets that are covered by the incumbent parameters.

In this section, we provide a sensitivity analysis for the choice of these residual parameters by testing a set a plausible residual variables that might have been used.

The alternative residual parameters here have worse statistical quality those selected for the respective core models in the Model Specification Note. The impact is therefore provided for informative purposes without claim on its feasbility or adequacy as a final parameter choice. Descriptive statistics for the alternative residual parameters are listed in Tables 4.3 to 4.6 below. The base models specifications are discussed above in Section 2.3. The scores are graphed in Figs 4.27 to 4.28 below, and listed in Tables 4.3 to 4.6. The maximum increase is the maximum difference in score using the alternative variable NG_Y, ceteris paribus, to the base score for each respective model, i.e.:

$$max.increase = max\{DEA(ndrs, 2020, NG_Y) - DEA(ndrs, 2020, base)\} \tag{4.3}$$

The maximum decrease is the largest negative difference in score between the model using the alternative variable NG_Y, ceteris paribus, and the base score for each respective model, i.e.:

$$max.decrease = -max\{DEA(ndrs, 2020, base) - DEA(ndrs, 2020, NG_Y)\} \tag{4.4}$$

The mean absolut change is the average absolute difference in score between the model using the alternative variable NG_Y, ceteris paribus, and the base score for each respective model, i.e.:

$$mean.abs.change = \sum_j \{\{\|DEA(ndrs, 2020, base) - DEA(ndrs, 2020, NG_Y)\|\} \tag{4.5}$$

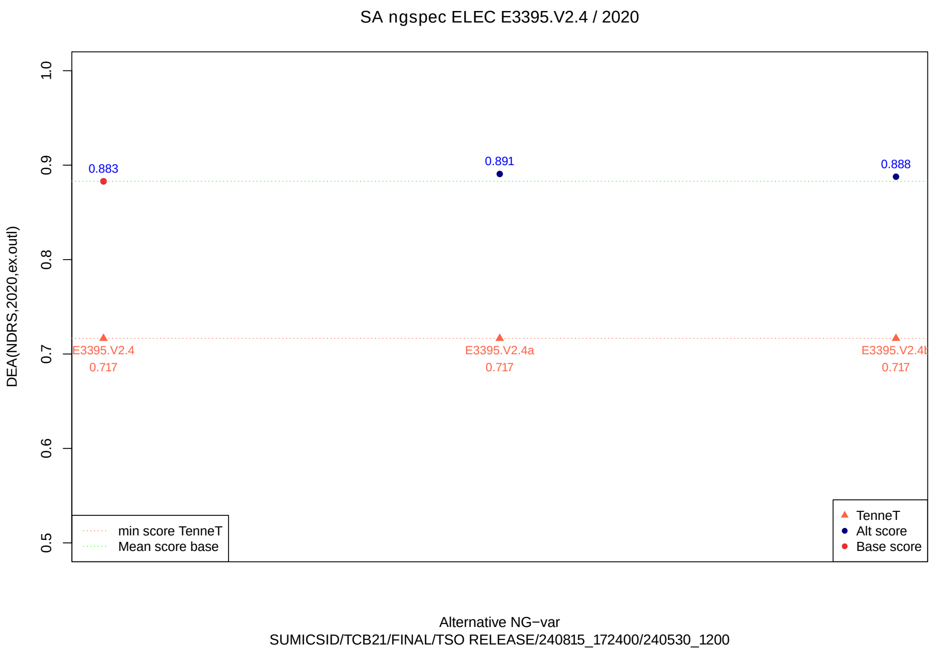

Figure 4.28: Scores DEA(ndrs,exo,2020) for alternative NG-variables in E3395.V2.4 for TenneT in TCB21.

Table 4.3: SA Model data, E2388.V2.4a, 2020

Type	Name	Value	Mean	TSO/mean
Input	dTotex	349,950,687	195,946,005	1.79
Output	yCables_tot	1,806	436	4.14
Output	yLines.share_totex_angle.vsum	296,823	429,252	0.69
Output	yNGCex_10	4,650,719	3,481,680	1.34

Table 4.4: SA Model data, E2388.V2.4b, 2020

Type	Name	Value	Mean	TSO/mean
Input	dTotex	349,950,687	195,946,005	1.79
Output	yCables_tot	1,806	436	4.14
Output	yLines.share_totex_angle.vsum	296,823	429,252	0.69
Output	yNGOex.agecorr_10	59,635	40,063	1.49

Table 4.5: SA Model data, E3395.V2.4a, 2020

Type	Name	Value	Mean	TSO/mean
Input	dTotex	349,950,687	195,946,005	1.79
Output	yTransformers.power.ehv	40,899	26,060	1.57
Output	ySubstations.hv	277	116	2.38
Output	yNGOex.agecorr_20	89,719	79,311	1.13

Table 4.6: SA Model data, E3395.V2.4b, 2020

Type	Name	Value	Mean	TSO/mean
Input	dTotex	349,950,687	195,946,005	1.79
Output	yTransformers.power.ehv	40,899	26,060	1.57
Output	ySubstations.hv	277	116	2.38
Output	yNGCex_trafo.ehv.subst.hv	8,867,762	7,916,542	1.12

Table 4.7: Sensitivity analysis ngspec model E2388.V2.4 TenneT

	E2388.V2.4	E2388.V2.4a	E2388.V2.4b
TenneT	0.845	0.810	0.810
mean.score	0.882	0.840	0.891
mean.abs.change	0.000	0.053	0.054
min.decrease	-0.000	-0.083	-0.215
max.increase	0.000	0.466	0.178

Table 4.8: Sensitivity analysis ngspec model E3395.V2.4 TenneT

	E3395.V2.4	E3395.V2.4a	E3395.V2.4b
TenneT	0.717	0.717	0.717
mean.score	0.883	0.891	0.888
mean.abs.change	0.000	0.008	0.008
min.decrease	-0.000	-0.053	-0.063
max.increase	0.000	0.000	0.025

Chapter 5

Cost development

In this chapter the dynamic cost development for TenneT compared to that for the electricity operators in TCB21 is analyzed by cost type for the benchmarked activities T,M,P. The cost development indexed at 2016 for Totex, Capex and Opex for TenneT, its peers and the mean electricity operator are listed in 5.1 below. All results are inflation-adjusted and adjusted for LCI. The cumulative change in this section refers to the ratio below between a year t and the initial year 2016:

$$dev.Totex_t = \frac{Totex_t}{Totex_{2016}} \tag{5.1}$$

In a serie of graphs we show the relative cost development to grid growth, see Figs 5.1 to 5.5 below. The line for TenneT is drawn as red line, the peers (all models) are navyblue and the mean results are in grey. Grid growth is measured as NormGrid. All cost data are adjusted for inflation using 2020 as base year, the analysis thus concerns real cost development.

This information is useful to consider specific sources of efficiency and in-efficiency compared to the comparators, considering the earlier analyses for profile, age and sensitivity.

Table 5.1: Cost development (index=2016)

	2016	2017	2018	2019	2020
dev.Totex TenneT	1.000	1.061	1.128	1.185	1.288
dev.Capex TenneT	1.000	1.079	1.141	1.287	1.357
dev.Opex TenneT	1.000	1.040	1.113	1.065	1.207
dev.Totex.peers	1.000	1.028	1.021	1.023	1.151
dev.Totex.mean.tcb21	1.000	1.051	1.073	1.115	1.190
grid.growth TenneT	1.000	1.034	1.052	1.069	1.077
grid.growth.mean.tcb21	1.000	1.021	1.042	1.066	1.085

Figure 5.1: Development of totex for TenneT 2016-2020.

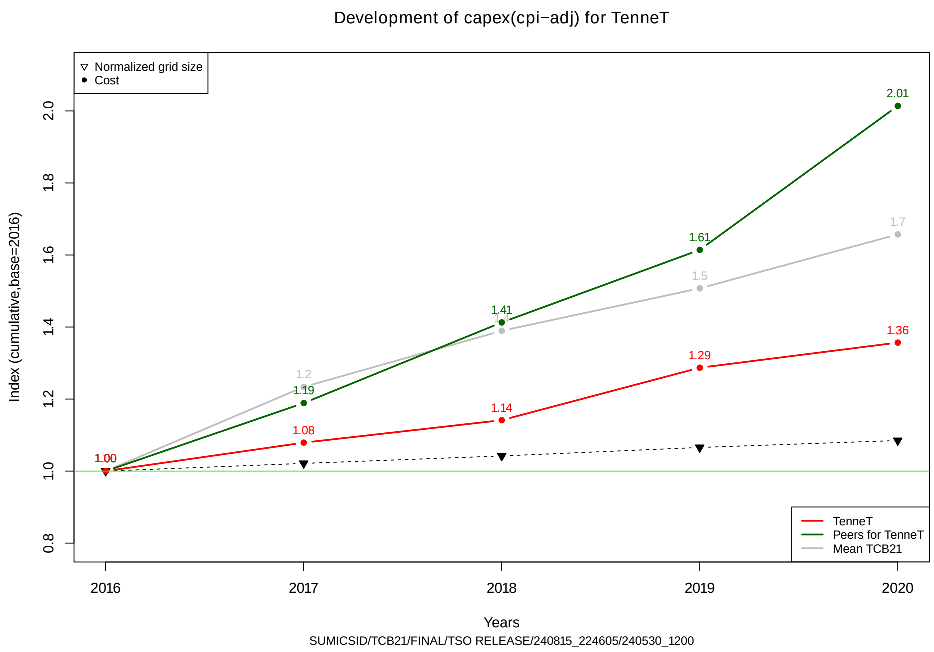

Figure 5.2: Development of capex for TenneT 2016-2020.

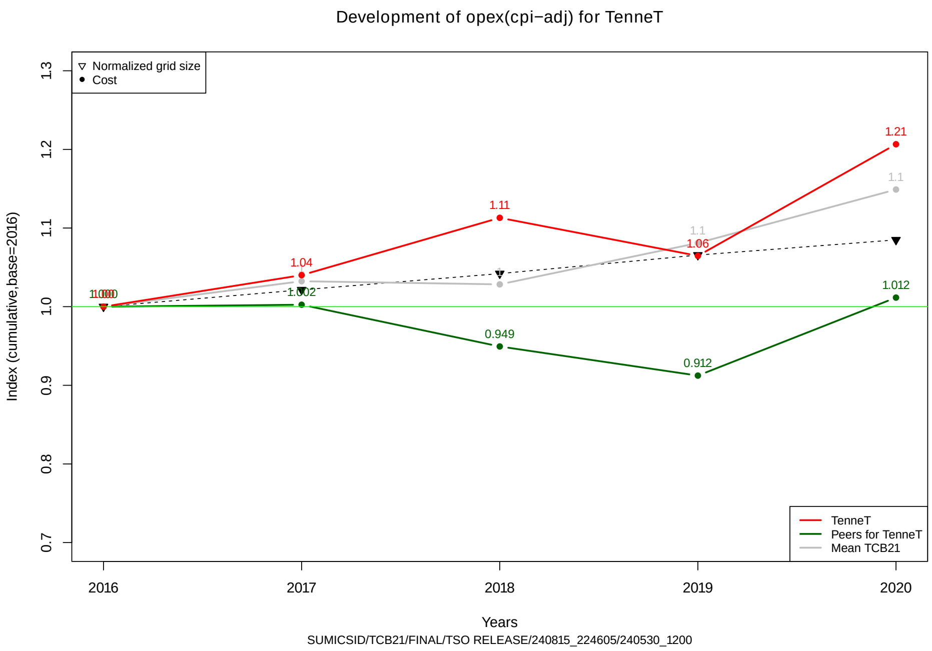

Figure 5.3: Development of opex for TenneT 2016-2020.

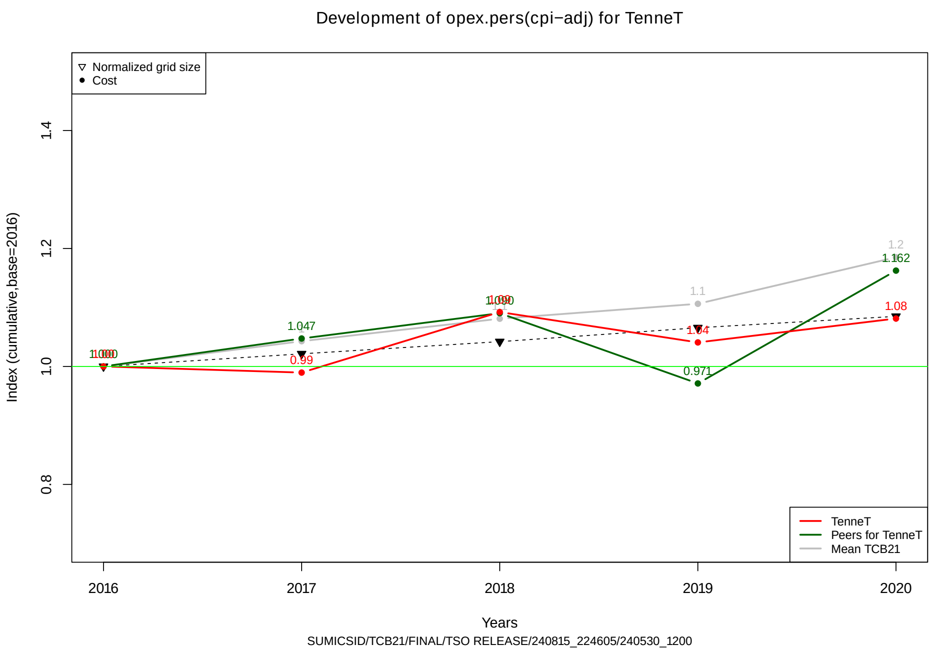

Figure 5.4: Development of opex.pers for TenneT 2016-2020.

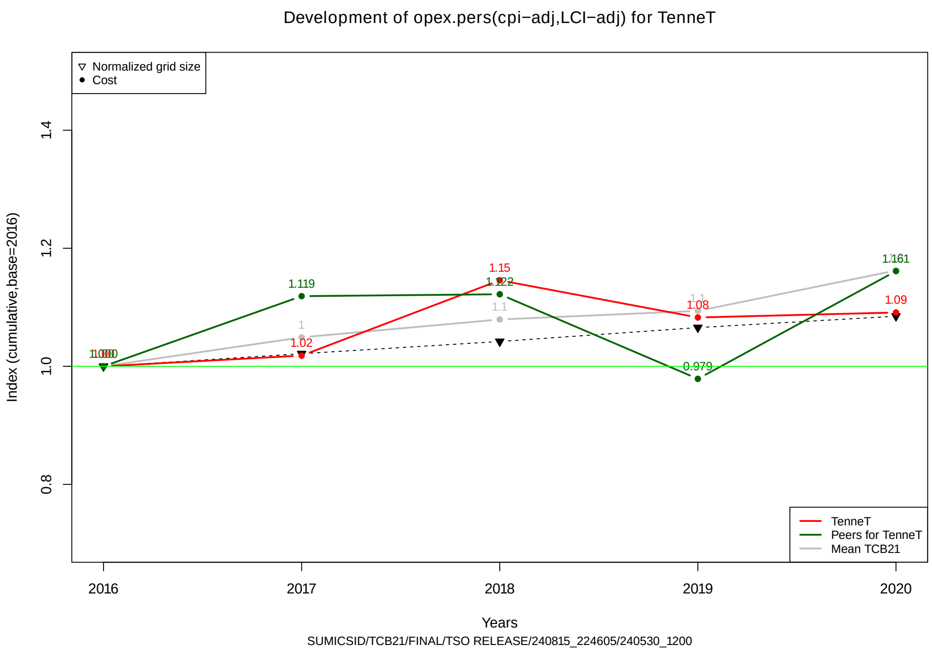

Figure 5.5: Development of opex.pers.lci for TenneT 2016-2020.

Appendix A

Appendix

A.1 Parameters and reference values

The settings in Table A.1 are used in the calculations for the efficiency with the numerical parameters in Table A.2. The choice of these parameters is discussed further in the notes on Method and Model Specification, respectively.

Table A.1: Key settings.

parameter.names	parameter.values
Run date	15/08/2024
Real interest rate	0.016
CAPEX Exchange rate EUR 2020	1
OPEX Exchange rate EUR 2020	1
Inflation index:	hicpigne_cpiw
Labor cost index:	plci_util

Table A.2: Key parameters.

parameter.names	parameter.values
Labor cost index 2016	1.37
Labor cost index 2017	1.32
Labor cost index 2018	1.30
Labor cost index 2019	1.32
Labor cost index 2020	1.34
Overhead allocation TMP	0.57
Overhead allocation S	0.17
Overhead allocation X	0.04
Overhead allocation TO	0.12
Overhead allocation O	0.09
Investment life Lines-cables	60.00
Investment life Transformers	40.00
Investment life Circuit ends	45.00
Investment life Compensating devices	40.00
Investment life Series compensations	40.00
Investment life Control centers	20.00
Investment life Towers	60.00
Investment life Substations	40.00
Investment life Lines-towers	60.00
Investment life Cables	50.00
Investment life Other equip	20.00
Investment life Equipment	10.00

A.2 Notation for indicators

Table A.3: Notation KPI for staff cost shares

variable	formula
OpexShare.TMP	xOpex(TMP)/xTotex(TMP)
OpexShare.S	xOpex(S)/xTotex(TMP)
OpexShare.X	xOpex(X)/xTotex(TMP)
OpexShare.TO	xOpex(TO)/xTotex(TMP)
OpexShare.SF	xOpex(SF)/xTotex(TMP)
OpexShare.O	xOpex(O)/xTotex(TMP)
OpexShare.I	xOpex(I)/xTotex(TMP)
OpexShare.totex.all	xOpex(all.fcn)/xTotex(all.fcn)
PersShare.opex.nosalind	xOpex(pers,no.indircost,no.LCI)/xOpex(TMP,no.indircost,no.LCI)
PersShare.opex.salind	xOpex(pers,no.indircost,LCI)/xOpex(TMP,no.indircost,LCI)
PersShare.totex.nosalind	xOpex(pers,no.indircost,LCI)/xTotex(TMP,no.indircost,no.LCI)
PersShare.totex.salind	xOpex(pers,no.indircost,LCI)/xTotex(TMP,no.indircost,LCI)
IndirShare.totex	xOpex(I)/xTotex(TMP,no.indircost)

Table A.4: Notation Aggregate Totex indicators

variable	formula
UCT.circuitkm	xTotex/yCircuits.tot
UCT.circuitkm.ehv	xTotex/yCircuits.ehv
UCT.circuitkm.hv	xTotex/yCircuits.hv
UCT.linekm	xTotex/yLines.tot
UCT.linekm.ehv	xTotex/yLines.ehv
UCT.linekm.hv	xTotex/yLines.hv
UCT.circuitpower	xTotex/yCircuits.power.tot
UCT.circuitpower.ehv	xTotex/yCircuits.power.tot
UCT.circuitpower.hv	xTotex/yCircuits.power.hv
UCT.transfo.power	xTotex/yTransformers.power
UCT.transfo.power.ehv	xTotex/yTransformers.power.ehv
UCT.transfo.power.hv	xTotex/yTransformers.power.hv
UCT.cablekm	xTotex/yCables.tot
UCT.cablekm.ehv	xTotex/yCables.ehv
UCT.cablekm.hv	xTotex/yCables.hv
UCT.towers	xTotex/yTowers.tot
UCT.subst	xTotex/ySubstations.pc
UCT.subst.ehv	xTotex/ySubstations.ehv
UCT.subst.hv	xTotex/ySubstations.hv
UCT.ng	xTotex/yNGa

Table A.5: Notation Aggregate Opex indicators

variable	formula
UCO.circuitkm	xOpex/yCircuits.tot
UCO.circuitkm.ehv	xOpex/yCircuits.ehv
UCO.circuitkm.hv	xOpex/yCircuits.hv
UCO.linekm	xOpex/yLines.tot
UCO.linekm.ehv	xOpex/yLines.ehv
UCO.linekm.hv	xOpex/yLines.hv
UCO.circuitpower	xOpex/yCircuits.power.tot
UCO.circuitpower.ehv	xOpex/yCircuits.power.ehv
UCO.circuitpower.hv	xOpex/yCircuits.power.hv
UCO.transfo.power	xOpex/yTransformers.power
UCO.transfo.power.ehv	xOpex/yTransformers.power.ehv
UCO.transfo.power.hv	xOpex/yTransformers.power.hv
UCO.cablekm	xOpex/yCables.tot
UCO.cablekm.ehv	xOpex/yCables.ehv
UCO.cablekm.hv	xOpex/yCables.hv
UCO.towers	xOpex/yTowers.tot
UCO.substations	xOpex/ySubstations.pc
UCO.subst.ehv	xOpex/ySubstations.ehv
UCO.subst.hv	xOpex/ySubstations.hv
UCO.ng.opex	xOpex/yNGO

Table A.6: Notation Aggregate Capex indicators

variable	formula
UCC.circuitkm	xCapex/yCircuits.tot
UCC.circuitkm.ehv	xCapex/yCircuits.ehv
UCC.circuitkm.hv	xCapex/yCircuits.hv
UCC.linekm	xCapex/yLines.tot
UCC.linekm.ehv	xCapex/yLines.ehv
UCC.linekm.hv	xCapex/yLines.hv
UCC.circuitpower	xCapex/yCircuits.power.tot
UCC.circuitpower.ehv	xCapex/yCircuits.power.tot
UCC.circuitpower.hv	xCapex/yCircuits.power.hv
UCC.transfo.power	xCapex/yTransformers.power
UCC.transfo.power.ehv	xCapex/yTransformers.power.ehv
UCC.transfo.power.hv	xCapex/yTransformers.power.hv
UCC.cablekm	xCapex/yCables.tot
UCC.cablekm.ehv	xCapex/yCables.ehv
UCC.cablekm.hv	xCapex/yCables.hv
UCC.towers	xCapex/yTowers.tot
UCC.subst	xCapex/ySubstations.pc
UCC.subst.ehv	xCapex/ySubstations.ehv
UCC.subst.hv	xCapex/ySubstations.hv
UCC.ng.capex	xCapex/yNGCa

Table A.7: Notation Technical indicators and ratios

variable	formula
share.towers.steel	yTowers.steel/yTowers.tot
share.towers.angular	yTowers.angular/yTowers.tot
transfo.power.circuitkm.ehv	yTransformers.power.ehv/yCircuits.ehv
transfo.power.circuitkm	yTransformers.power/yCircuits.tot

Table A.8: Notation Disaggregated Capex indicators

variable	formula
UCC.line.line.km	xCapex(lines)/yLines.tot
UCC.line.line.ng	xCapex(lines)/yNGcp.lines
UCC.cable.cable.km	xCapex(cables)/yCables.tot
UCC.cable.cable.ng	xCapex(cables)/yNGcp.cables
UCC.transfo.transfo.power	xCapex(transformers)/yTransformers.power
UCC.transfo.transfo.pc	xCapex(transformers)/yTransformers.pc
UCC.transfo.transfo.ng	xCapex(transformers)/yNGcp.20
UCC.subst.subst.pc	xCapex(circuitends)/ySubstations.pc
UCC.subst.subst.ng	xCapex(circuitends)/yNGcp.30

Table A.9: Notation Disaggregated Opex indicators

variable	formula
UCO.p.inv.tot	xOpex(P)/mean(xCapex(new inv-2016-2020))
UCO.m.linekm.tot	xOpex(M) /yLines.tot
UCO.m.circuitkm.tot	xOpex(M) /yCircuits.tot
UCO.m.transfo.power	xOpex(M)/yTransformers.power
UCO.m.ng.opex	xOpex(M) /yNGO
UCO.m.subst.pc	xOpex(M)/ySubstations.pc

Table A.10: Notation Staff cost indicators

variable	formula
pers.cost.fte	xCost(pers,excl LCI)/Pers(fte)
pers.cost.tmp	xCost(pers, TMP)
pers.fte.ng	Pers(fte)/yNGC
pers.fte.circuitkm	Pers(fte)/yCircuits.tot

A.3 UC graphs

The unit cost (UC) measures in the following graphs are defined for a TSO k and a year y as follows:

$$UC_{totex}(k,y) = xTotex(k,y)/yNGa(k,y)$$
$$UC_{opex}(k,y) = xOpex(k,y)/yNGa(k,y)$$
$$UC_{capex}(k,y) = xCapex(k,y)/yNGa(k,y)$$

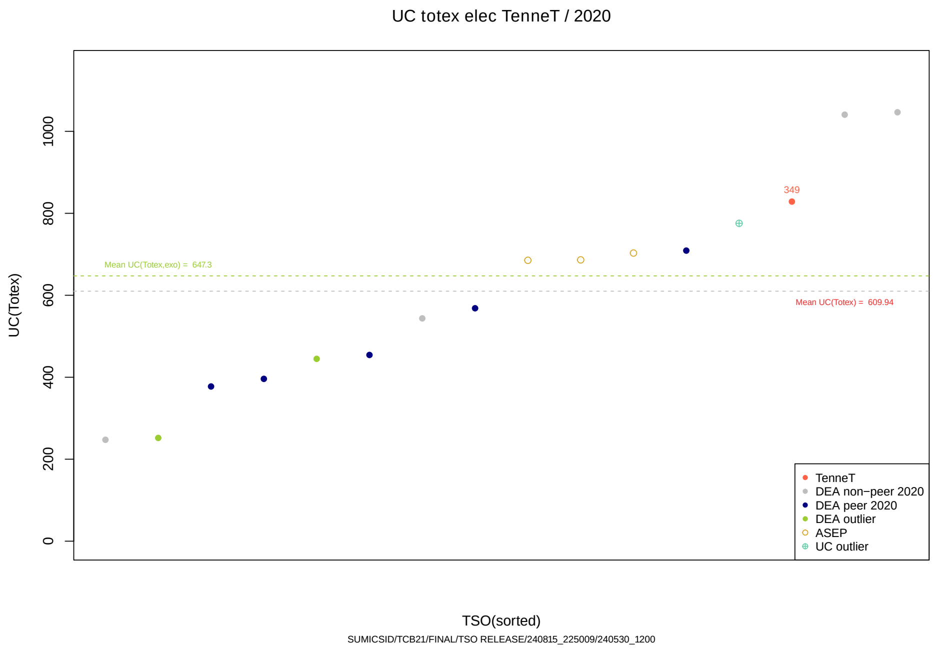

Figure A.1: Unit cost (UC) Totex.

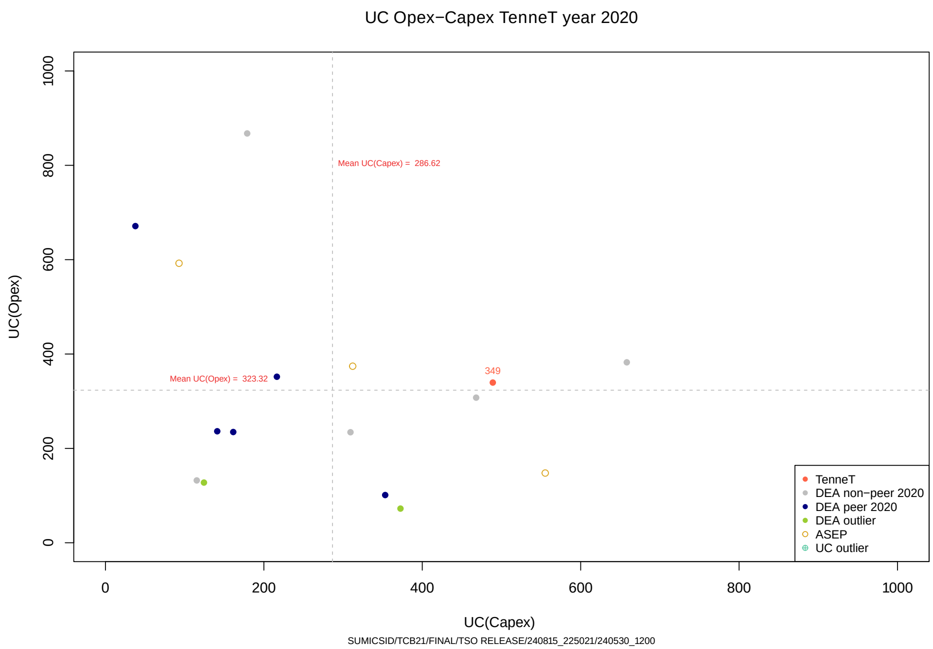

Figure A.2: Unit cost UC(Opex) vs UC(Capex).

A.4 Labour cost indexes

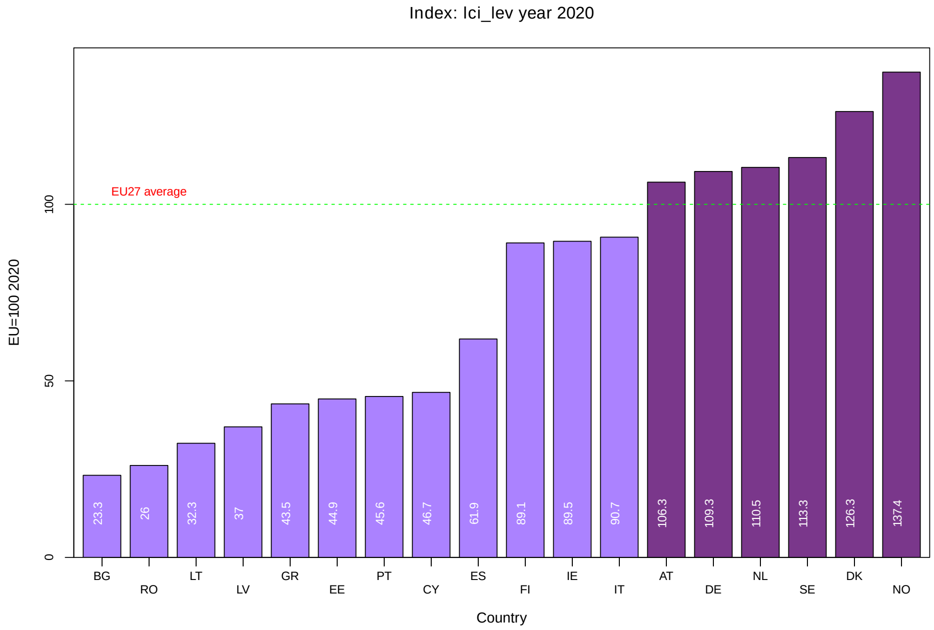

Figure A.3: Labour cost index LCI-LEV 2020 by country.

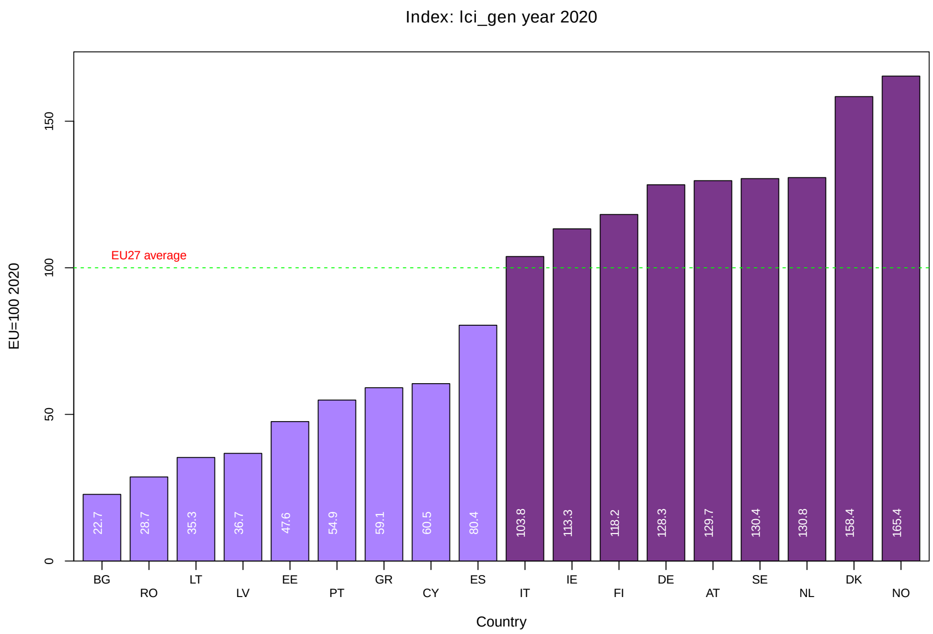

Figure A.4: Labour cost index LCI-GEN 2020 by country.

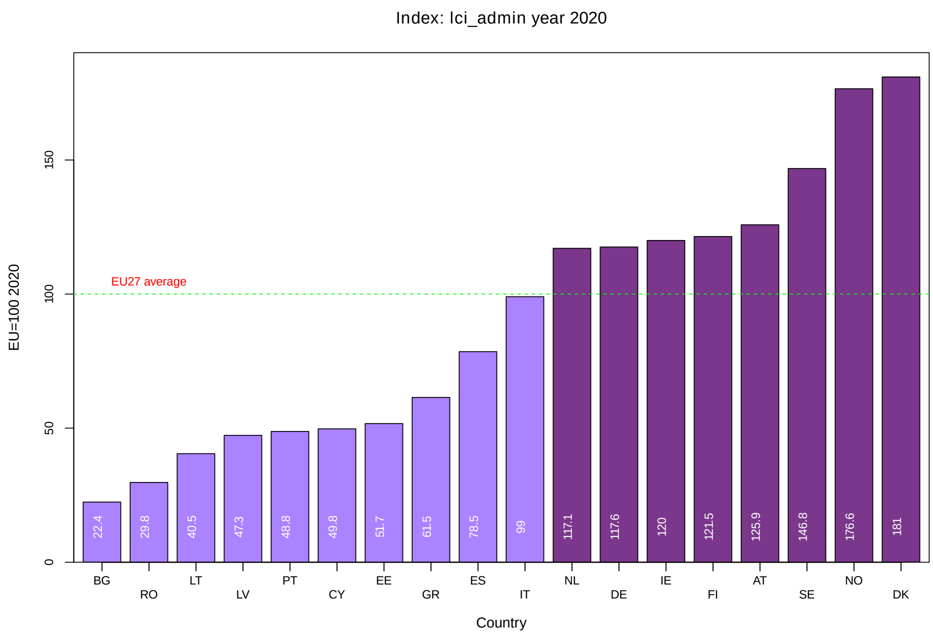

Figure A.5: Labour cost index LCI-ADMIN 2020 by country.

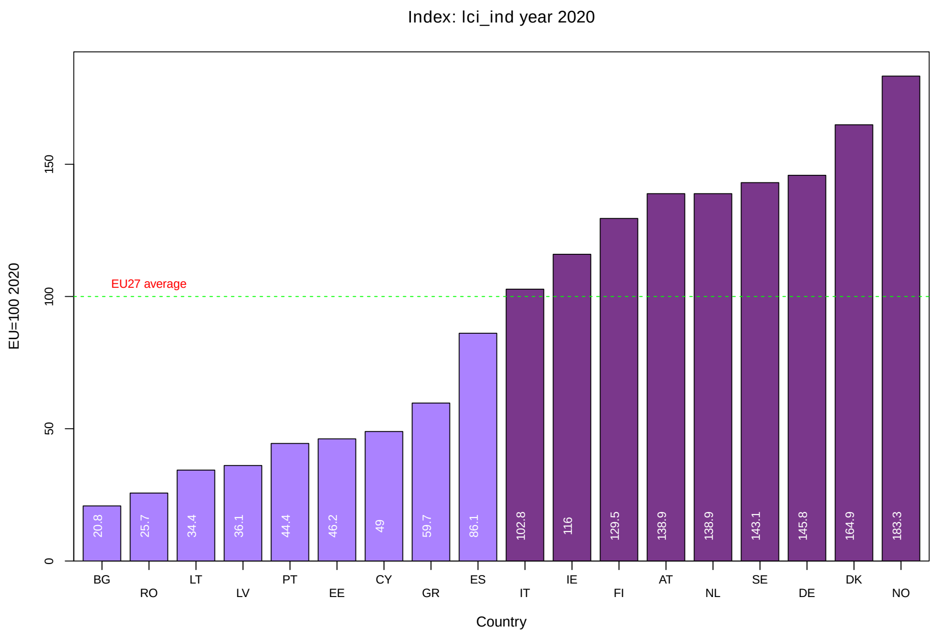

Figure A.6: Labour cost index LCI-IND 2020 by country.

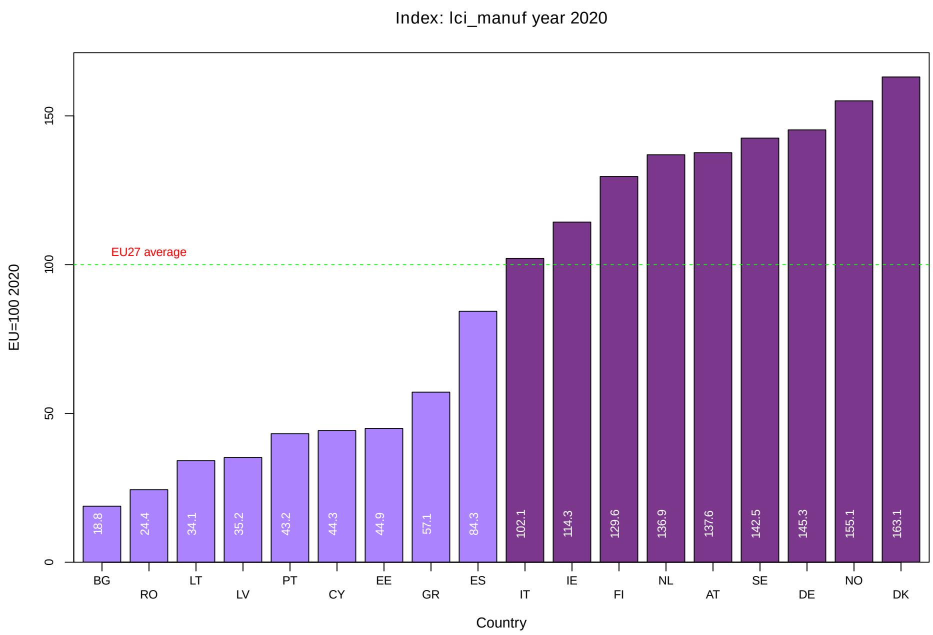

Figure A.7: Labour cost index LCI-MANUF 2020 by country.

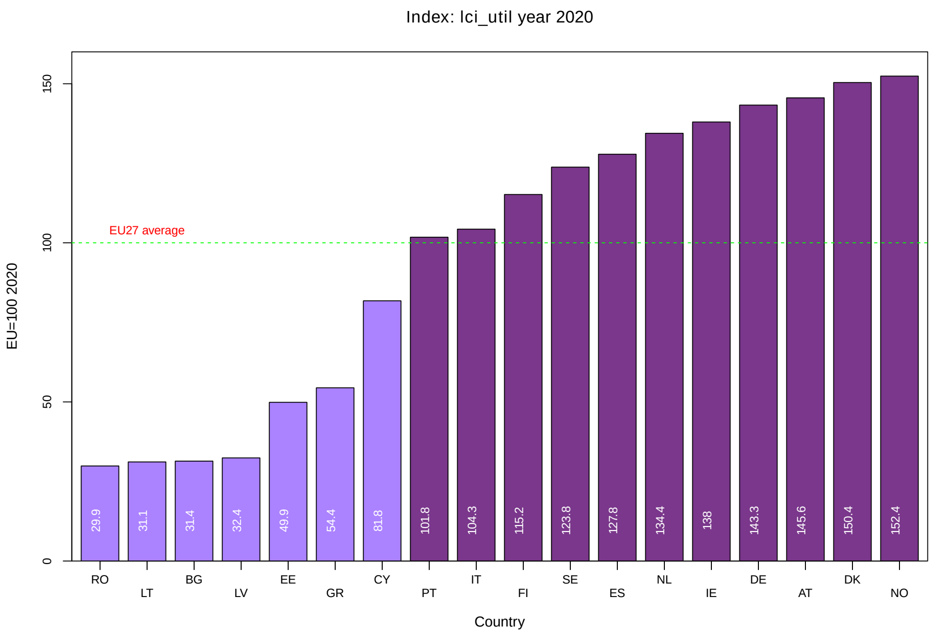

Figure A.8: Labour cost index LCI-UTIL 2020 by country.

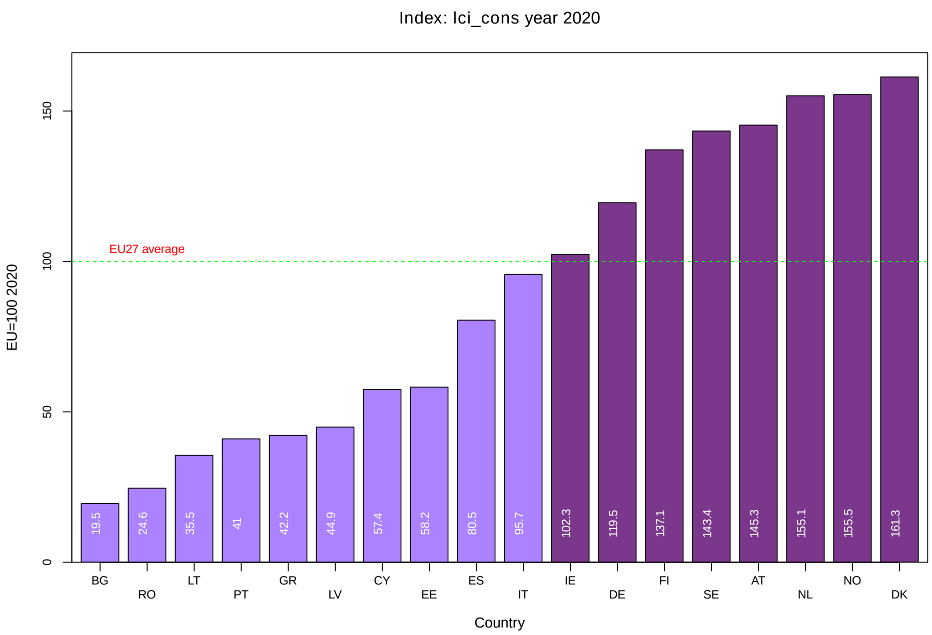

Figure A.9: Labour cost index LCI-CONS 2020 by country.

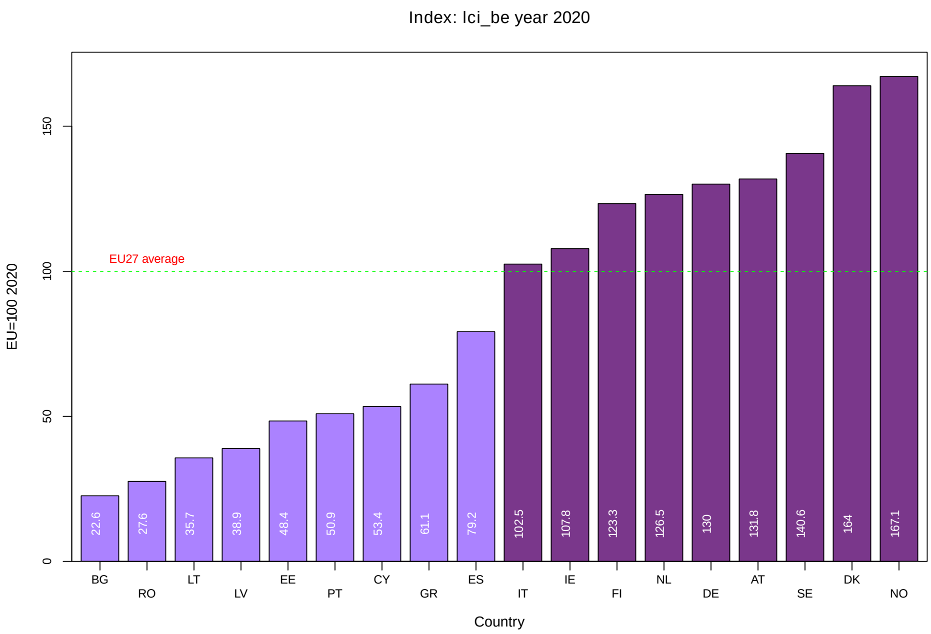

Figure A.10: Labour cost index LCI-BE 2020 by country.

A.5 Sensitivity analysis: interest rate

Table A.11: Sensitivity analysis rate model E2388.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
0.006	0.884	0.872
0.007	0.880	0.874
0.008	0.876	0.876
0.009	0.872	0.878
0.01	0.868	0.879
0.011	0.865	0.881
0.012	0.861	0.881
0.013	0.857	0.882
0.014	0.853	0.882
0.015	0.849	0.882
0.016	0.845	0.882
0.017	0.841	0.882
0.018	0.837	0.882
0.019	0.833	0.882
0.02	0.829	0.881
0.021	0.825	0.881
0.022	0.821	0.880
0.023	0.817	0.880
0.024	0.813	0.879
0.025	0.809	0.879
0.026	0.806	0.878
0.027	0.802	0.878
0.028	0.798	0.877
0.029	0.795	0.876
0.03	0.791	0.876
0.031	0.787	0.875
0.032	0.784	0.875
0.033	0.780	0.874
0.034	0.777	0.874
0.035	0.773	0.873
0.036	0.770	0.872
0.037	0.767	0.872
0.038	0.764	0.871
0.039	0.760	0.871
0.04	0.757	0.870
0.041	0.754	0.870
0.042	0.751	0.869
0.043	0.748	0.869
0.044	0.745	0.868
0.045	0.742	0.868
0.046	0.739	0.867
0.047	0.736	0.867
0.048	0.733	0.866
0.049	0.730	0.865
0.05	0.727	0.865

Table A.12: Sensitivity analysis rate model E2388.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
0.006	0.766	0.912
0.007	0.762	0.911
0.008	0.758	0.910
0.009	0.754	0.908
0.01	0.750	0.907
0.011	0.746	0.906
0.012	0.742	0.905
0.013	0.738	0.904
0.014	0.734	0.902
0.015	0.730	0.901
0.016	0.726	0.900
0.017	0.723	0.899
0.018	0.719	0.898
0.019	0.715	0.897
0.02	0.712	0.896
0.021	0.708	0.895
0.022	0.704	0.894
0.023	0.701	0.893
0.024	0.697	0.891
0.025	0.694	0.890
0.026	0.690	0.889
0.027	0.687	0.888
0.028	0.683	0.887
0.029	0.680	0.887
0.03	0.677	0.886
0.031	0.673	0.885
0.032	0.670	0.884
0.033	0.667	0.883
0.034	0.664	0.882
0.035	0.661	0.881
0.036	0.658	0.880
0.037	0.655	0.879
0.038	0.652	0.878
0.039	0.649	0.878
0.04	0.646	0.877
0.041	0.643	0.876
0.042	0.640	0.875
0.043	0.637	0.874
0.044	0.634	0.874
0.045	0.632	0.873
0.046	0.629	0.872
0.047	0.626	0.871
0.048	0.624	0.871
0.049	0.621	0.870
0.05	0.619	0.869

Table A.13: Sensitivity analysis rate model E3395.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
0.006	0.745	0.885
0.007	0.742	0.885
0.008	0.739	0.885
0.009	0.736	0.884
0.01	0.733	0.884
0.011	0.731	0.884
0.012	0.728	0.884
0.013	0.725	0.883
0.014	0.722	0.883
0.015	0.719	0.883
0.016	0.717	0.883
0.017	0.714	0.882
0.018	0.711	0.882
0.019	0.708	0.882
0.02	0.706	0.881
0.021	0.703	0.881
0.022	0.701	0.880
0.023	0.698	0.880
0.024	0.696	0.880
0.025	0.693	0.879
0.026	0.691	0.879
0.027	0.688	0.879
0.028	0.686	0.878
0.029	0.683	0.878
0.03	0.681	0.878
0.031	0.679	0.877
0.032	0.676	0.877
0.033	0.674	0.876
0.034	0.672	0.875
0.035	0.670	0.874
0.036	0.667	0.873
0.037	0.665	0.872
0.038	0.663	0.871
0.039	0.661	0.871
0.04	0.659	0.870
0.041	0.657	0.869
0.042	0.655	0.868
0.043	0.653	0.868
0.044	0.651	0.867
0.045	0.649	0.866
0.046	0.647	0.865
0.047	0.645	0.865
0.048	0.644	0.864
0.049	0.642	0.864
0.05	0.640	0.863

Table A.14: Sensitivity analysis rate model E3395.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
0.006	0.745	0.887
0.007	0.742	0.887
0.008	0.739	0.887
0.009	0.736	0.886
0.01	0.733	0.886
0.011	0.731	0.886
0.012	0.728	0.886
0.013	0.725	0.886
0.014	0.722	0.886
0.015	0.719	0.885
0.016	0.717	0.885
0.017	0.714	0.885
0.018	0.711	0.884
0.019	0.708	0.884
0.02	0.706	0.884
0.021	0.703	0.883
0.022	0.701	0.883
0.023	0.698	0.883
0.024	0.696	0.882
0.025	0.693	0.882
0.026	0.691	0.882
0.027	0.688	0.881
0.028	0.686	0.881
0.029	0.683	0.881
0.03	0.681	0.881
0.031	0.679	0.880
0.032	0.676	0.879
0.033	0.674	0.879
0.034	0.672	0.878
0.035	0.670	0.877
0.036	0.667	0.876
0.037	0.665	0.875
0.038	0.663	0.874
0.039	0.661	0.874
0.04	0.659	0.873
0.041	0.657	0.872
0.042	0.655	0.871
0.043	0.653	0.871
0.044	0.651	0.870
0.045	0.649	0.869
0.046	0.647	0.869
0.047	0.645	0.868
0.048	0.644	0.867
0.049	0.642	0.867
0.05	0.640	0.866

A.6 Standardized age assumptions

Table A.15: Sensitivity analysis std-age model E2388.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
Age-Low	0.813	0.874
Age-Base	0.845	0.882
Age-High	0.797	0.869

Table A.16: Sensitivity analysis std-age model E2388.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
Age-Low	0.685	0.862
Age-Base	0.726	0.900
Age-High	0.679	0.876

Table A.17: Sensitivity analysis std-age model E3395.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
Age-Low	0.656	0.877
Age-Base	0.717	0.883
Age-High	0.685	0.879

Table A.18: Sensitivity analysis std-age model E3395.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
Age-Low	0.656	0.877
Age-Base	0.717	0.885
Age-High	0.685	0.879

A.7 Impact of labour cost indexes (LCI)

Table A.19: Sensitivity analysis lci model E2388.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
lci_lev	0.943	0.887
lci_gen	0.810	0.871
lci_admin	0.785	0.871
lci_ind	0.812	0.870
lci_manuf	0.830	0.865
lci_util	0.845	0.882
lci_cons	0.998	0.883
lci_be	0.794	0.870

Table A.20: Sensitivity analysis lci model E2388.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
lci_lev	0.825	0.914
lci_gen	0.722	0.907
lci_admin	0.702	0.905
lci_ind	0.732	0.910
lci_manuf	0.758	0.917
lci_util	0.726	0.900
lci_cons	0.888	0.927
lci_be	0.709	0.904

Table A.21: Sensitivity analysis lci model E3395.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
lci_lev	0.761	0.875
lci_gen	0.699	0.866
lci_admin	0.683	0.864
lci_ind	0.697	0.860
lci_manuf	0.703	0.857
lci_util	0.717	0.883
lci_cons	0.769	0.863
lci_be	0.689	0.863

Table A.22: Sensitivity analysis lci model E3395.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
lci_lev	0.761	0.876
lci_gen	0.699	0.868
lci_admin	0.683	0.866
lci_ind	0.697	0.862
lci_manuf	0.703	0.859
lci_util	0.717	0.885
lci_cons	0.769	0.866
lci_be	0.689	0.865

A.8 Salary corrections for capitalized labor in investments

The notation denotes the proportion for adjustment ψ, i.e., $\psi = 0.25 = 25$ percent of nominal investment is adjusted.

Table A.23: Sensitivity analysis caplab model E2388.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
0	0.845	0.882
0.05	0.861	0.887
0.1	0.878	0.891
0.15	0.894	0.896
0.2	0.911	0.901
0.25	0.928	0.906
0.3	0.945	0.911
0.35	0.963	0.915
0.4	0.981	0.921
0.45	0.999	0.926
0.5	1.000	0.930

Table A.24: Sensitivity analysis caplab model E2388.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
0	0.726	0.900
0.05	0.740	0.904
0.1	0.754	0.907
0.15	0.768	0.911
0.2	0.782	0.915
0.25	0.797	0.919
0.3	0.812	0.924
0.35	0.827	0.928
0.4	0.842	0.932
0.45	0.857	0.936
0.5	0.873	0.940

Table A.25: Sensitivity analysis caplab model E3395.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
0	0.717	0.883
0.05	0.724	0.883
0.1	0.733	0.883
0.15	0.741	0.883
0.2	0.749	0.884
0.25	0.757	0.884
0.3	0.766	0.885
0.35	0.775	0.885
0.4	0.784	0.886
0.45	0.793	0.886
0.5	0.793	0.886

Table A.26: Sensitivity analysis caplab model E3395.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
0	0.717	0.885
0.05	0.724	0.885
0.1	0.733	0.885
0.15	0.741	0.886
0.2	0.749	0.886
0.25	0.757	0.886
0.3	0.766	0.886
0.35	0.775	0.887
0.4	0.784	0.887
0.45	0.793	0.888
0.5	0.793	0.888

A.9 Impact of inflation indexes (PI)

Table A.27: Sensitivity analysis cpi model E2388.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
cpiw	0.808	0.877
hicp_cpiw	0.815	0.878
hicpg_cpiw	0.832	0.882
hicpig_cpiw	0.835	0.882
hicpne_cpiw	0.817	0.878
hicpigned_cpiw	0.864	0.893
hicpigne_cpiw	0.845	0.882
hicpnhu_cpiw	0.824	0.879
hicps_cpiw	0.789	0.875

Table A.28: Sensitivity analysis cpi model E2388.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
cpiw	0.694	0.888
hicp_cpiw	0.699	0.890
hicpg_cpiw	0.714	0.895
hicpig_cpiw	0.718	0.896
hicpne_cpiw	0.701	0.890
hicpigned_cpiw	0.743	0.902
hicpigne_cpiw	0.726	0.900
hicpnhu_cpiw	0.707	0.891
hicps_cpiw	0.678	0.884

Table A.29: Sensitivity analysis cpi model E3395.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
cpiw	0.697	0.875
hicp_cpiw	0.704	0.876
hicpg_cpiw	0.711	0.879
hicpig_cpiw	0.713	0.879
hicpne_cpiw	0.704	0.876
hicpigned_cpiw	0.726	0.884
hicpigne_cpiw	0.717	0.883
hicpnhu_cpiw	0.707	0.877
hicps_cpiw	0.693	0.875

Table A.30: Sensitivity analysis cpi model E3395.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
cpiw	0.697	0.878
hicp_cpiw	0.704	0.879
hicpg_cpiw	0.711	0.882
hicpig_cpiw	0.713	0.882
hicpne_cpiw	0.704	0.879
hicpigned_cpiw	0.726	0.884
hicpigne_cpiw	0.717	0.885
hicpnhu_cpiw	0.707	0.880
hicps_cpiw	0.693	0.877

A.10 Overhead allocation rules

Table A.31: Sensitivity analysis alloc model E2388.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
Alloc ETD	0.845	0.883
Alloc ETDI	0.846	0.882
Base: ET	0.845	0.882
Alloc 0	0.698	0.866
Alloc 100	0.852	0.877

Table A.32: Sensitivity analysis alloc model E2388.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
Alloc ETD	0.727	0.900
Alloc ETDI	0.727	0.900
Base: ET	0.726	0.900
Alloc 0	0.608	0.887
Alloc 100	0.732	0.899

Table A.33: Sensitivity analysis alloc model E3395.V2.4 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
Alloc ETD	0.717	0.883
Alloc ETDI	0.717	0.883
Base: ET	0.717	0.883
Alloc 0	0.660	0.873
Alloc 100	0.755	0.892

Table A.34: Sensitivity analysis alloc model E3395.V2.4.env2 TenneT

	DEA.ndrs.exo.20 TenneT	Mean.DEA.ndrs.exo.20
Alloc ETD	0.717	0.885
Alloc ETDI	0.717	0.885
Base: ET	0.717	0.885
Alloc 0	0.660	0.875
Alloc 100	0.755	0.892

A.11 Environmental correction factors

The change is the ratio of the score for the alternative environmental correction Z to the base score for the environmental variant of the corresponding environmental model, i.e.:

$$change.Z = \frac{DEA(ndrs, 2020, Z)}{Base.DEA.env(ndrs, 2020)}$$

The operators 'max' and 'min' denote the maximum and minimum corresponding ratios, respectively.

The notation in the name (X.Y) indicates the correction applied to term1 (X) and term 2 (Y), respectively. A zero (0) denotes no correction term. For the model specifications, see Tables 2.2 to 2.5.

Table A.35: Sensitivity analysis env model E2388.V2.4.env2 TenneT

	TenneT score	TenneT change	mean.change	max.change	min.change
E2388.V2.4.env2	0.726	1.000	1.000	1.000	1.000
E2388.V2.4.env.cLGG.LSW	0.823	1.133	1.018	1.133	1.000
E2388.V2.4.env.cGG.LW	0.823	1.133	0.975	1.133	0.844
E2388.V2.4.env.cLGG.LSGGW	0.823	1.133	1.020	1.133	0.993
E2388.V2.4.env.cLSGG.LSGGHW	0.726	1.000	1.005	1.047	1.000
E2388.V2.4.env.cLGG.LSGGHW	0.823	1.133	1.042	1.324	1.000
E2388.V2.4.env.cLGG.LGGW	0.823	1.133	1.006	1.133	0.934
E2388.V2.4.env.0.LSGGHW	0.845	1.164	1.045	1.342	1.000

Table A.36: Sensitivity analysis env model E3395.V2.4.env2 TenneT

	TenneT score	TenneT change	mean.change	max.change	min.change
E3395.V2.4.env2	0.717	1.000	1.000	1.000	1.000
E3395.V2.4.env.W	0.717	1.000	0.999	1.036	0.950
E3395.V2.4.env.SW	0.717	1.000	1.005	1.116	0.941
E3395.V2.4.env.SGGW	0.717	1.000	1.007	1.144	0.950
E3395.V2.4.env.WGG	0.717	1.000	1.002	1.038	0.965
E3395.V2.4.env.csSGGW	0.717	1.000	1.007	1.145	0.953