Economic Benchmarking Results for the Australian Energy Regulator’s 2021 TNSP Annual Benchmarking Report

Draft report prepared for
Australian Energy Regulator

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TNSP NAME ABBREVIATIONS

The following table lists the TNSP name abbreviations used in this report and the State in which the TNSP operates.

Abbreviation	*TNSP name*	*State*
ANT	AusNet Services Transmission	Victoria
ENT	ElectraNet	South Australia
PLK	Powerlink	Queensland
TNT	TasNetworks Transmission	Tasmania
TRG	TransGrid	New South Wales

OTHER ABBREVIATIONS

Abbreviation	*Description*
AEMO	Australian Energy Market Operator
AUC	Annual user cost of capital
CAM	Cost allocation methodology
EBRIN	Economic Benchmarking Regulatory Information Notice
ENS	Energy Not Supplied
MPFP	Multilateral partial factor productivity
MTFP	Multilateral total factor productivity
MVA	Megavolt ampere
MVAkms	Megavolt ampere kilometres
NEM	National Electricity Market
PFP	Partial factor productivity
RMD	Ratcheted maximum demand
TFP	Total factor productivity
TNSP	Transmission network service provider
VCR	Value of customer reliability

1 INTRODUCTION

Economic Insights has been asked by the Australian Energy Regulator (AER) to update the electricity transmission network service provider (TNSP) multilateral total factor productivity (MTFP) and multilateral partial factor productivity (MPFP) results presented in the AER's 2020 TNSP Annual Benchmarking Report (AER 2020). This study also updates the analyses examining the contributions of each individual output and input to total factor productivity (TFP) change. The update involves including data for the 2019–20 financial and March years (as relevant) reported by the TNSPs in their latest Economic Benchmarking Regulatory Information Notice (EBRIN) returns.

1.1 Updates to Productivity Measurement Methods

The methods of analysis used in this report are the same as those used in Economic Insights (2020a) with the following exceptions:

- As with past studies, an opex price index is calculated from published ABS price indexes that approximate components of electricity TNSP costs, and it is used to deflate nominal opex to derive real opex. As applied to individual TNSPs, the approach used in this report is consistent with the previously used approach, whereby the opex price index differs depending on whether the TNSP reports data in financial March-to-April years (AusNet) or July-to-June years (all other TNSPs). For the industry as a whole, this report uses a weighted average regulatory year opex price index,[1] whereas previously the financial July-to-June year opex price index was used for the industry.

- In calculating the weight of the reliability output based on the value of customer reliability, we have recognised that the state-based value of customer reliability estimates published by the AER are the September 2019 value (AER 2019b:71), which are adjusted by CPI to the mid-point of each regulatory year of the TNSP.

- The annual user cost of capital (the return on and of capital) is used to determine the cost (and hence cost shares) of physical capital inputs. We have updated the calculation of the weighted average cost of capital for 2020 to reflect the AER's Rate of Return Instrument 2018 (AER 2018:13–16 Table 1, col. 3).[2] For earlier years (2006-2019), the annual user cost of capital calculations broadly reflect the 2013 rate of return guideline (AER 2018:13–16 Table 1, col. 2).

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[1] The weights attached to the financial and calendar years being based on the opex quantities of each of the TNSPs. The weighted average opex price index is such that both: the sum of all TNSPs' nominal opex equals industry nominal opex and the sum of all TNSPs' real opex equals industry real opex.

[2] We have applied the 2018 Rate of return Instrument in full, that is: Risk free rate – Yield from 10 year CGS; MRP – 6.1%; Equity beta – 0.6; Gamma – 0.585; Return on debt – Weighted average of A and BBB curves from RBA, Bloomberg and Thomson Reuters.

1.2 Specifications Used for Productivity Measurement

This report measures TFP using the multilateral Törnqvist TFP (MTFP) index method developed by Caves, Christensen and Diewert (1982), and explained in Appendix A. This method is used for the industry TFP indexes presented in chapter 2, the multilateral comparisons of productivity in chapter 3, and the individual TNSP indexes in chapter 4.

When the MTFP method is applied to data for a single TNSP, it provides information on the *changes over time* in productivity for the TNSP. The industry-level analysis in chapter 2 and the analysis of individual TNSPs in chapter 4, examine patterns of output, input and productivity over time. These chapters do not provide a basis for comparing productivity levels between TNSPs. An analysis of *comparative productivity levels* of TNSPs is presented in chapter 3.

1.2.1 Defining Outputs

The output index for TNSPs is defined to include five outputs:[3]

(a) Energy throughput in GWh (with 14.9 per cent share of gross revenue)

(b) Ratcheted maximum demand (RMD) in Megavolt amperes (MVA) (with 24.7 per cent share of gross revenue)

(c) End–user numbers (with 7.6 per cent share of gross revenue)

(d) Circuit length in kms (with 52.8 per cent share of gross revenue), and

(e) (minus) Energy not supplied (ENS) in MWh (with the weight based on current AER estimates of the Value of Customer Reliability (VCR) capped at a maximum absolute value of 2.5 per cent of total revenue).

Outputs (a) to (d) are referred to as the 'non-reliability outputs', and output (e) is the 'reliability' output. With the exception of RMD, the outputs are all directly reported by the TNSPs, which also report Maximum Demand for each year in MVA. RMD, in any given year t, is the maximum of the series of maximum demands from 2006 up to and including year t.

The weights applied to the non-reliability outputs are based on estimated shares of marginal cost which the provision of each output accounts for. These are derived from the coefficients of an econometrically-estimated Leontief cost function. This cost analysis was carried out by Economic Insights (2020a) and the method is described in Appendix A. This report does not repeat that analysis because the resulting weights are intended to be held constant for several years before updating them (Economic Insights 2020a, pp. 1–2).

As discussed in more detail in Appendix A (section A3.2), the weight applying to the reliability output is based on the cost to end-users caused by lost supply; the quantity of ENS for each

[3] An exception arises in relation to Figure 2.1, and Figures 4.1, 4.5, 4.9, 4.13, and 4.17, which also show, for comparison, output and TFP indexes when output is defined to include only four outputs, not including Energy Not Supplied.

TNSP multiplied by the VCR in $/kWh, which varies by State. The VCR is that estimated by the AER for 2019 (AER 2019b, p. 71), which is adjusted by CPI in all other years of the data sample.

1.2.2 Defining Inputs

There are four TNSP inputs:

(a) Opex in $'000 (2006 prices) (total opex deflated by a composite labour, materials and services price index), making up 27.4 per cent of total cost on average

(b) Overhead lines (quantity proxied by overhead MVAkms[4]), making 27.0 per cent of total cost on average

(c) Underground cables (quantity proxied by underground MVAkms), making 1.7 per cent of total cost on average, and

(d) Transformers and other capital (quantity proxied by transformer MVA), making 43.9 per cent of total cost on average.

These inputs are grouped into two broader categories: input (a) is referred to as 'non-capital inputs', or 'opex input', whilst inputs (b) to (d) are together the 'capital inputs'. The capital inputs are aggregated for the purpose of calculating indexes of capital inputs and partial factor productivities (PFPs) for capital inputs.

The weights applied to each input are based on estimated shares of total cost which each input accounts for. The cost of the non-capital input is measured by nominal Opex. For the capital inputs taken together, the annual user cost of capital (AUC) is taken to be the return on capital, the return of capital and the benchmark tax liability, all calculated in a broadly similar way to that used in forming the building blocks revenue requirement.[5] This aggregate cost of capital inputs is decomposed into the separate capital inputs using estimated shares of each capital asset type in the RAB for each TNSP in each year.

1.3 TNSP comments on draft report

The AER made the draft version of this report available to the five included TNSPs for comment. Feedback was received from three TNSPs: AusNet Services (ANT), Powerlink (PLK), and ElectraNet (ENT).

ANT expressed concern that MTFP and MPFP measures were being used to compare productivity levels of TNSPs, and not just a comparison of MTFP trend. This, it claimed, is inconsistent with the approach in Economic Insights' 2020 TNSP benchmarking report. We

[4] 'MVAkms' is an aggregate of the MVA rating of lines multiplied by their length.

[5] In this year's report the calculation of AUC has been updated to reflect the AER's Rate of Return Instrument 2018. In previous years the AUC calculations broadly reflected the 2013 rate of return guideline. See: https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/rate-of-return-instrument-2018/final-decision.

disagree with this claim because chapter 3 of that report presented the results of pooled MTFP and MPFP analysis to "allow comparisons of productivity levels as well as productivity growth to be made" (Economic Insights 2020a, p. 19), and such comparisons are made throughout chapter 3 of that report. That said, Economic Insights has previously observed:

> "We have always been cautious about using the TNSP economic benchmarking results to compare productivity levels across TNSPs given the difficulty of specifying the outputs of TNSPs in a productivity measurement context and the lack of precedent to go on. For example, Economic Insights (2014, p. 2) noted: 'While economic benchmarking of distribution network service providers (DNSPs) is relatively mature and has a long history, there have been very few economic benchmarking studies undertaken of TNSPs. Economic benchmarking of transmission activities is in its relative infancy compared to distribution. As a result, ... we ... caution against drawing strong inferences about TNSP efficiency levels from these results. However, output growth rates and opex input quantity growth rates can be calculated with a higher degree of confidence and used to forecast opex partial productivity growth for the next regulatory period which is a key component of the rate of change formula.' At the same time, it is important to progress TNSP productivity and efficiency measurement and the workstream initiated by the AER in 2013 has led to ongoing development and refinement of TNSP economic benchmarking." (2020a, p. 5)

There has been greater use of TNSP benchmarking by economic regulators since 2014. European regulators, through the Council of European Economic Regulators (CEER) have periodically conducted benchmarking studies of electricity and gas transmission system operators in Europe since 2005. The latest of these studies uses data for 46 TNSPs collected by regulators in 16 participating European jurisdictions. Several European regulators use this information, and other benchmarking exercises, in their regulatory decision-making. TNSP benchmarking is also used by some regulators elsewhere. For example, in Brazil, Agência Nacional de Energia Elétrica (ANEEL) has carried out comparative efficiency analysis of nine Brazilian TNSPs since 2007. (For a survey of benchmarking of TNSPs in regulatory contexts see: Economic Insights 2020b) Although the approaches to benchmarking differ, and each has its challenges, in our opinion the MTFP method used in Australia is at least as reliable as methods used elsewhere. (For a discussion and appraisal of methods of benchmarking in economic regulation see: Economic Insights 2017c, 2017d).

Powerlink made some specific comments on the wording in parts of the draft report, some of which have been addressed. Two specific matters of measurement were raised:

- Powerlink considered that our inflation indexation of the value of customer reliability (VCR) did not align with the approach set out in the AER's *Values of Customer Reliability: Final Decision* (2019a). Powerlink provided a spreadsheet comparing the two approaches and showing that the difference is not large. We agree that there was a shortcoming in our application of the VCR data but we do not agree with Powerlink's suggested approach, as it does not apply the AER's 2019 VCR values to the correct periods. The VCR published in 2019 should be interpreted as applying to the September quarter 2019. Powerlink applied them to the whole of the 2019-20 regulatory year (and ignoring the difference between AusNet's regulatory year from April to March, and the regulatory years of other TNSPs, which are from July to June). In the preliminary analysis, we had incorrectly taken the VCR values to represent the June quarter 2019 rather than the September quarter. We have corrected this misinterpretation, and we escalate or de-escalate to the mid-point of each regulatory year, as appropriately defined for each TNSP, to obtain VCR values for each TNSP and each year over 2006-2020.

- Powerlink suggested that the transformer input measure should not include the transformer capacity associated with Static VAR Compensators (SVCs) because, it claims, this results in double-counting.[6] The AER has advised that it will investigate this question, however this cannot be completed for the 2021 benchmarking report because it will require gathering information from TNSPs and better understanding the issues raised.

Powerlink also considered that it would be timely for the AER to reassess the suitability of the current benchmarking methodology in light of recent changes and current developments in the power system. These issues are to be addressed via a scoping paper as part of this year's benchmarking exercise. The scoping paper relating to TNSP benchmarking will address opportunities to improve the benchmarking methods especially having regard to new responsibilities of network operators arising in relation to current market reforms.

Some of ElectraNet's comments are related to the same issue. Its investments in Synchronous Condensers were made "in response to our service obligations under the National Electricity Rules (Rules) to provide system strength and inertia. The failure of the output measures to capture this increase in output shows they are not well aligned with the Rules." Again, this is a question to be addressed in the scoping paper.

ElectraNet also commented that the draft report lacks acknowledgement of prior concerns or outstanding issues in the benchmarking methodology. In the AER's 2017 review of TNSP economic benchmarking, ElectraNet remarked that "the number of downstream customers served in the distribution network does not provide a measure of the scale of the transmission task, nor does it provide a good proxy for the complexity of the task facing the TNSP. The number and size of transmission connection points provides a far more reliable indicator of the complexity of the task performed by the TNSP" (ElectraNet 2017, p. 2). The views of TNSPs differed on this question and there were concerns about the adequacy of the previous voltage-weighted connection points measure (Economic Insights 2017a, pp. 3–5, 2017b, pp. 6–12). Economic Insights observed that "the choice of outputs will involve trade–offs across a number of considerations including capturing the scale and complexity of the transmission task and having robust and unambiguous measures based on the soundest and most consistent data" (Economic Insights 2017b, p. 10).

According to ElectraNet, the analysis does not account for the length of networks normalised by MW of peak demand. However, since the study does explicitly take account of both the circuit length of networks and the (ratchetted) peak demand, it is difficult to respond to this comment without further detail on the exact limitations which ElectraNet sees with the method used here.

[6] An SVC is used to alter the electrical characteristics of a transmission line to facilitate voltage management and thereby improve transmission line rating on long transmission lines.

ElectraNet also argues that "two of the four measures currently in use, namely energy throughput and end use customer numbers, bear little or no relationship to the output of a transmission network." ElectraNet's thinking seems to be couched in terms of the concept of short-run marginal cost (SRMC) for a network with excess capacity. For such a network, an incremental increase in energy throughput or in end-user numbers at existing locations, would not add significantly to cost. However, the concept of cost which is appropriate to identifying the cost drivers or outputs in this application is long-run marginal cost (LRMC). LRMC is conceptually based on the optimal capacity to serve specified demands, so there is no excess capacity. It takes account of the impact of changes in outputs on the optimal network configuration, and hence on minimum cost in the long-run. For example, a network that carries more throughput will typically have higher capacity requirements and hence higher cost. A transmission network that serves more end-users may have more delivery points and terminal stations for a given length. As an empirical matter, the cost function analysis in Economic Insights (2020a Appendix B) did find that costs are partly related to both energy throughput and end-user numbers—there is a long-run influence of these factors on TNSP costs on average over time and across the TNSPs in the data sample, in addition to the other measured cost drivers.

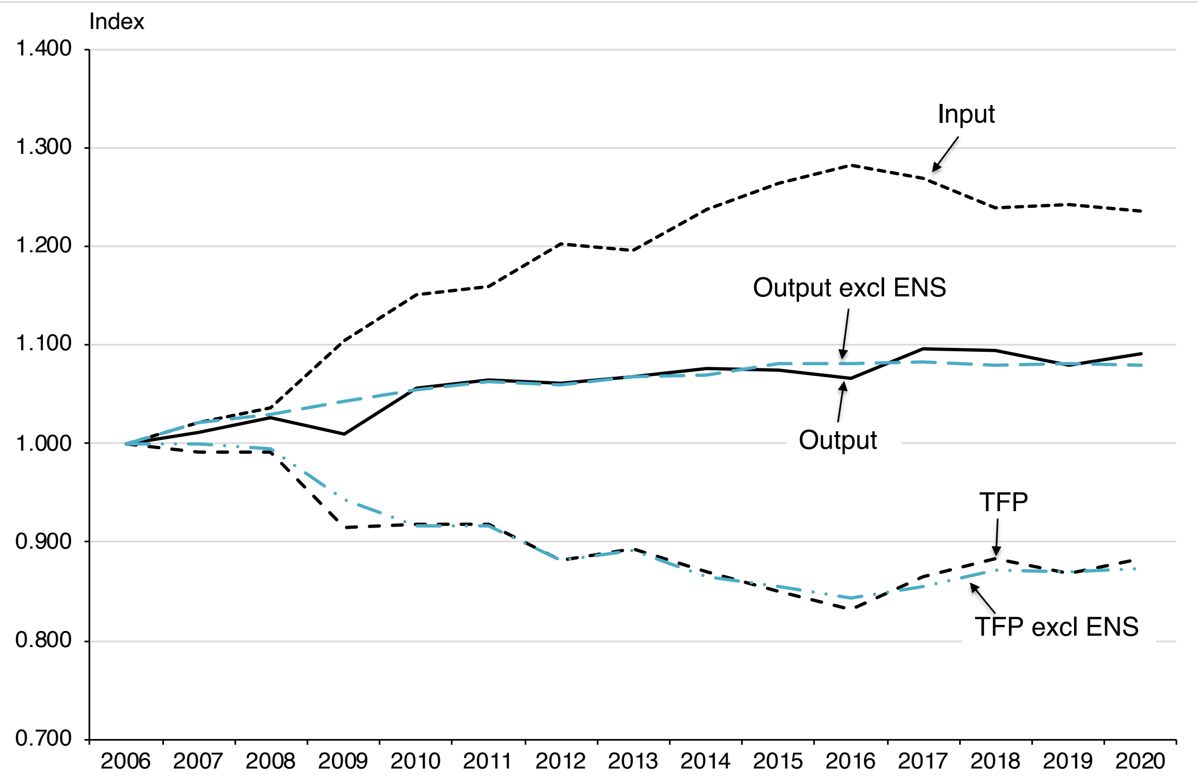
2 TRANSMISSION INDUSTRY PRODUCTIVITY RESULTS

This chapter presents output, input and TFP indexes for the electricity transmission industry after aggregating across the five TNSPs.

2.1 TFP Trends

Transmission industry-level total output, total input and TFP indexes are presented in figure 2.1 and table 2.1. Opex and capital partial productivity indexes are also presented in table 2.1. Figure 2.1 shows, for comparison, the industry output and TFP indexes if ENS were not included as an output. This highlights the effects of the ENS on movements in output and TFP.

Figure 2.1 **Transmission Industry output, input and TFP indexes, 2006–2020**



Over the 15-year period 2006 to 2020, industry level TFP declined at an average annual rate of –0.9 per cent. Although total output increased by an average annual rate of 0.6 per cent, total input use increased faster, at a rate of 1.5 per cent. Since the average rate of change in TFP is the average rate of change in total output less the average rate of change in total inputs, this produced a negative average rate of productivity change. TFP change was, however, positive in six years: 2008, 2010, 2013, 2017, 2018 and 2020. In some instances, such as 2010, there was an abnormally high growth of output which resulted in TFP growth despite increased use of inputs. In 2017, there was a combination of reduced inputs and abnormally high output growth. In recent years there has been reductions in input use which resulted in strong TFP growth. In 2020 a reduction in input use (–0.6 per cent) was coupled with a better than average output growth of 1.1 per cent. This combination implied a TFP growth of 1.7 per cent in 2020.

Table 2.1 **Transmission industry output, input, TFP and PFP indexes, 2006–2020**

Year	*Output Index*	*Input Index*	*TFP Index*	*PFP Index*	
				Opex	*Capital*
2006	1.000	1.000	1.000	1.000	1.000
2007	1.012	1.021	0.991	1.011	0.983
2008	1.027	1.035	0.992	1.031	0.977
2009	1.010	1.105	0.914	0.990	0.884
2010	1.057	1.151	0.918	0.988	0.890
2011	1.064	1.159	0.918	1.046	0.872
2012	1.061	1.202	0.882	1.014	0.836
2013	1.068	1.196	0.893	1.062	0.835
2014	1.076	1.238	0.870	0.989	0.826
2015	1.075	1.264	0.850	0.977	0.805
2016	1.066	1.282	0.832	0.953	0.788
2017	1.096	1.268	0.864	0.989	0.819
2018	1.095	1.238	0.884	1.121	0.807
2019	1.079	1.243	0.868	1.093	0.795
2020	1.091	1.236	0.883	1.119	0.805
Growth Rate 2006-2020	0.6%	1.5%	-0.9%	0.8%	-1.5%
Growth Rate 2006-2012	1.0%	3.1%	-2.1%	0.2%	-3.0%
Growth Rate 2012-2020	0.3%	0.3%	0.0%	1.2%	-0.5%
Growth Rate 2020	1.1%	-0.6%	1.7%	2.4%	1.3%

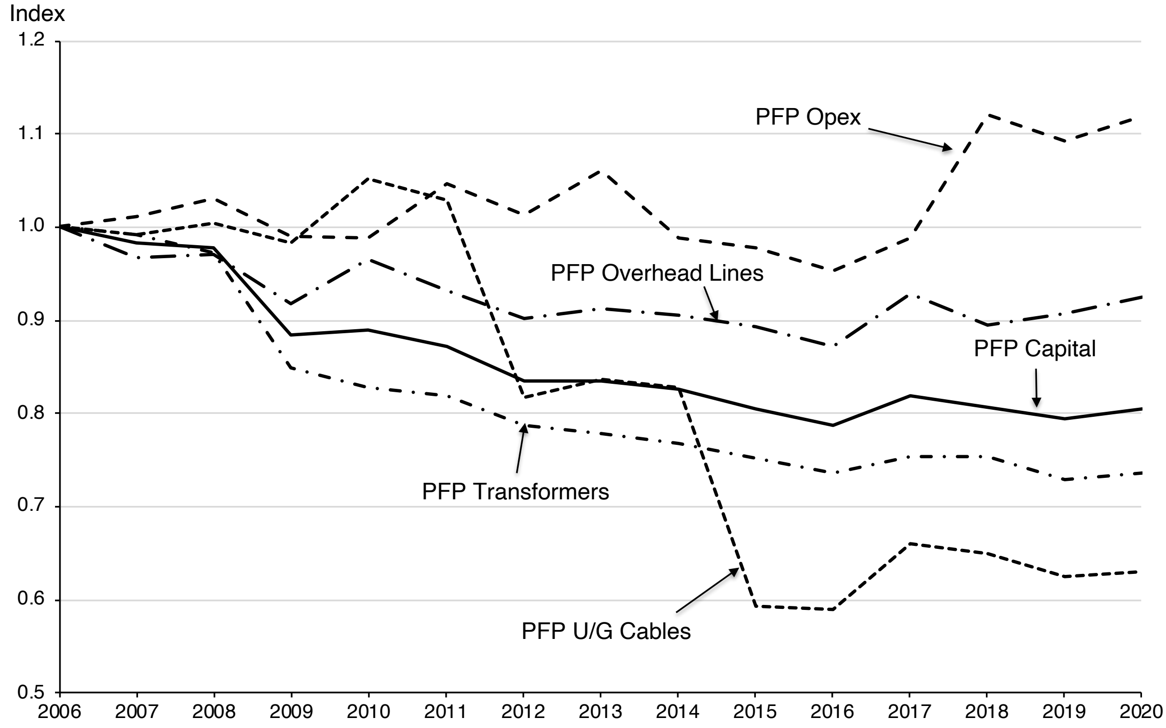
2.2 Partial Productivity Trends

Partial factor productivity (PFP) is a measure of output relative to a single input. Figure 2.2 shows transmission industry PFP indexes: (a) for two broad categories of inputs, opex inputs and capital inputs; and (b) for each of the three capital inputs individually. From figure 2.2 we see that movements in transmission industry-level PFP indexes follow an essentially inverse pattern to input quantities shown in figure 2.4. This is because outputs increased *comparatively* steadily over the 2006-2020 period (i.e. compared to movements of inputs).

Consequently, the opex PFP index is the highest, and in 2020 is 11.9 per cent above its 2006 level. The PFP of capital inputs decreased fairly steadily up to 2016, but since that time shows a small upward trend. In 2020, the capital PFP is 19.5 per cent below its 2006 level. Among the PFP indexes for specific capital inputs:

- underground cables PFP decreased sharply in 2012 and 2015, and by 2020 it was 36.9 per cent lower than in 2006;
- transformers PFP and overhead lines PFP both declined over the period to 2016, but have increased slightly since then. Transformer PFP was 26.4 per cent lower in 2020 than in 2006. Overhead lines PFP in 2020 was 7.5 per cent lower than in 2006.

Figure 2.2 **Transmission industry PFP indexes, 2006–2020**



Average growth rates for PFP by individual input are presented in Appendix B, together with average growth rates of individual outputs and inputs.

2.3 Transmission industry output and input quantity changes

To gain a more detailed understanding of what is driving these TFP changes, we need to look at the pattern of quantity change in our five transmission output components and our four transmission input components. We also need to consider the weight placed on each of these components in forming the total output and total input indexes. Later we present the contributions of each output and each input to TFP change, taking account of the quantity change in each component over time and its weight in forming the TFP index. First, however, we will look at the quantity indexes for individual outputs in figure 2.3 and for individual inputs in figure 2.4. In each case the quantities are converted to an index number with a value of one in 2006 for ease of comparison. Tables showing growth rates of outputs and inputs are included in appendix B.

In figure 2.3, energy not supplied (ENS) is not shown, because year-to-year movements are too large to show alongside the other outputs.[7] Maximum demand is shown for comparison with RMD.

[7] The largest of these movements was the upwards spike in 2009 associated with a transformer failure at ANT's South Morang Terminal Station. The next largest spike was in 2016.

From figure 2.3 we see that the total output index has moved in parallel with circuit length, which is the output with the largest weight in forming the aggregate output index. Circuit length increased steadily up to 2015 before levelling off (and decreasing slightly). It was 8.0 per cent higher in 2020 than it was in 2006. The relatively modest growth in the circuit length output compared to the growth in end-users reflects the fact that most of the increase in end-use customer numbers over the period has been able to be accommodated by 'in fill' off the existing DNSP networks without requiring large extensions of the transmission network length.

The output that increased the most over the period is end-user numbers with an increase of 20.8 per cent between 2006 and 2020. Its steady increase is because the number of electricity end-users increases roughly in line with population growth. In 2020, end-users increased by 1.2 per cent, broadly consistent with the long-term average annual growth rate of 1.3 per cent from 2006 to 2020. This suggests that the effects of COVID-19 on population growth were not yet reflected in end-user growth in 2020.[8]

By contrast to end-user numbers, we see that energy throughput for transmission peaked in 2010 and fell steadily through to 2014 before a partial recovery and then another marked fall in 2018. In 2020 transmission energy throughput was 4.7 per cent less than it was in 2006. The decline in energy throughput since around 2010 partly reflects economic conditions being more subdued since the 'global financial crisis' but, more importantly, the increasing impact of energy conservation initiatives, more energy efficient buildings and appliances and greater penetration of local distributed generation.

Maximum demand has followed a broadly analogous pattern to energy throughput although it increased more rapidly between 2006 and 2009 before levelling off and then falling markedly in 2012 and again in 2014 and 2015. Although maximum demand declined from 2011 to 2014, it has since increased significantly. Transmission networks, thus, have to service a steadily increasing number of end-users whilst electricity throughput is declining, and maximum demand levels, although variable, have not shown a sustained downward trend to match electricity throughout.

In recognition of the variable nature of maximum demand, we include ratcheted maximum demand (RMD) as our output measure rather than maximum demand so that TNSPs get credit for having had to provide capacity to service the earlier higher maximum demands than may occur in subsequent years. The RMD measure reflects the fact that the provision of capacity to service the earlier higher maximum demands does not diminish with decreases in maximum demand or necessarily vary with year-to-year variations in maximum demand. RMD is the sum of ratcheted maximum demands across the five TNSPs (rather than first summing the maximum demands and then calculating the ratcheted quantity).[9] It increased up to 2011, and has been relatively flat since then. There were incremental increases in each of the years from 2017 to 2020. In 2020, industry RMD was 12.3 per cent above its 2006 level.

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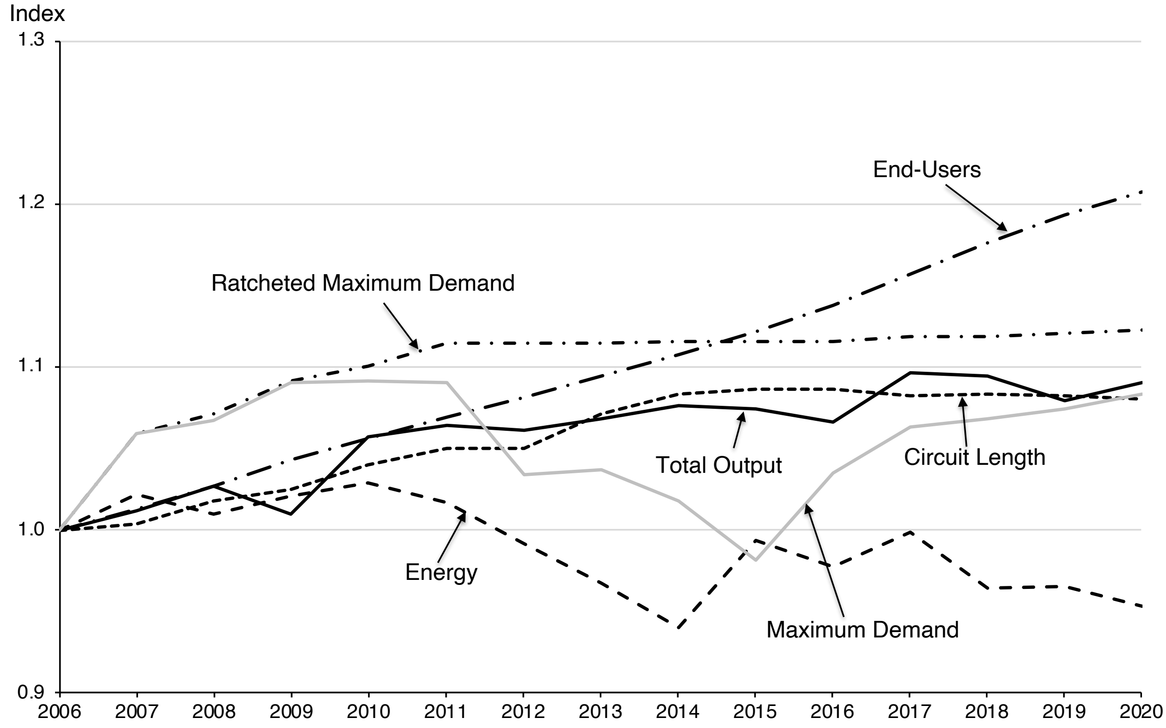
[8] See: <https://www.abs.gov.au/articles/population-and-covid-19>.

[9] For this reason, the RMD for the industry can increase in a year when aggregate maximum demands did not increase as seen for 2011 in Figure 2.3.

Figure 2.3 **Transmission industry output quantity indexes, 2006–2020**



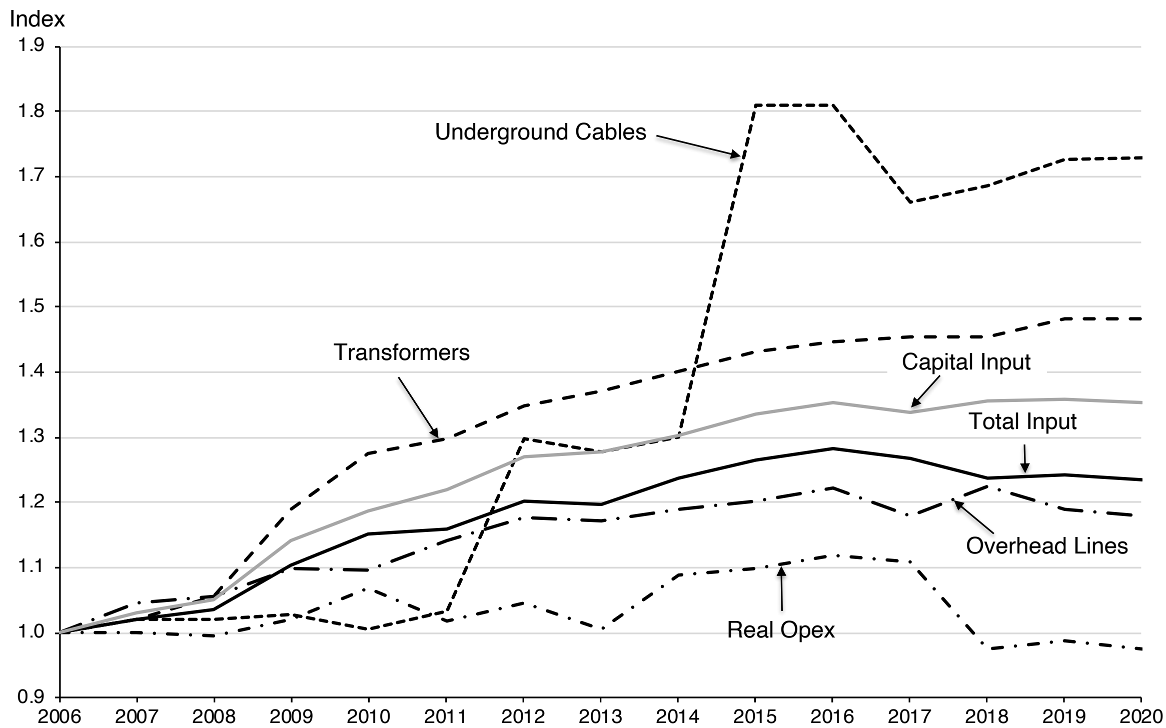
The last output is total ENS because of network limitations. This enters the total output index as a negative output since a reduction in ENS represents an improvement and a higher level of service for end-users. Conversely, an increase in ENS reduces total output as end-users are inconvenienced more by not having supply over a wider area and/or for a longer period. Despite periodic large spikes, ENS has generally trended downwards and, hence, contributed more to total output than was the case in 2006, holding all else constant. In 2020 ENS was 60.0 per cent lower than the level it had been in 2006. This needs to be viewed from the perspective that transmission outage rates are usually very low so they can appear to be very volatile in years where unusual events happen.

Circuit length, RMD and energy throughput outputs receive a combined weight on average of 93.7 per cent of total revenue (see Table A.1 in appendix A), and hence have greatest influence on total output movements. Hence we see in figure 2.3 that the total output index tends to lie close to the circuit length output index and be bounded by the RMD and energy throughput indexes. Although ENS has a comparatively small weight of –1.4 per cent of total revenue on average, the more extreme variation in ENS means that total output movements are significantly influenced by the pattern of movement in the ENS output (noting that an increase in ENS has a negative impact on total output). However, the impact of extreme ENS events on total output is limited by capping this output’s weight (in absolute terms) at 2.5 per cent of total revenue.

Turning to the input side, we present quantity indexes for the four inputs and the aggregate input index in figure 2.4. The quantity of opex (i.e. opex in constant 2006 prices) is the only input that has decreased over the 15-year period. From about 2009 to 2016, opex usage increased on balance, although at a slower rate than other inputs. Since then, opex use has declined, including a marked fall in 2018, and a subsequent smaller decline in 2020. In 2020, opex usage was 2.5 per cent lower than in 2006. Opex has the third largest average share in total costs at 27.4 per cent (see Table A.2 in appendix A).

The input with the largest average share of total cost, at 43.9 per cent, is transformers. The quantity of transformer input has increased steadily over the period to 2020, with only a marginal decrease in 2018. By 2020 transformer input was 48.2 per cent above its 2006 level. Given its large share of total costs, transformer input is an important driver of the total input quantity index.

Figure 2.4 **Industry–level transmission input quantity indexes, 2006–2020**



The next key component of TNSP input is the quantity of overhead lines. This input quantity increased the second least over the period, being 17.9 per cent higher in 2020 than it was in 2006. It should be noted that overhead line input quantities take account of both the length of lines and the overall 'carrying capacity' of the lines (in MVA). The fact that the overhead lines input quantity has increased substantially more than network length reflects the fact that the average capacity of overhead lines has increased over the period as new lines and replacement of old lines are both of higher carrying capacity than older lines. Overhead lines account for 27.0 per cent of total TNSP costs on average (see appendix A).

The fastest growing input quantity is that of underground cables whose quantity was 72.9 per cent higher in 2020 than it was in 2006. However, this growth starts from a quite small base and so a higher growth rate is to be expected. Most of the increase in length and/or capacity of transmission underground cables has occurred since 2011. The scope to put significant parts of the transmission network underground is considerably less than it is for distribution and the cost relativity greater. Underground cable inputs in transmission have an average share of total costs of only 1.7 per cent, compared to a share in total costs of 13.8 per cent for distribution.[10]

2.4 Output and input contributions to TFP change

By decomposing TFP change into its constituent parts, contributions of individual output and inputs to that change can be ascertained. Appendix A presents the methodology that allows the change in productivity (i.e. the change in the MTFP index) to be decomposed into the contributions of changes in each output and each input.

Figure 2.5 and table 2.2 present the percentage point contributions of each output and each input to the average annual rate of TFP change of –0.9 per cent over the 15-year period 2006 to 2020. In figure 2.5 the blue columns represent the percentage point contributions of each of the outputs and inputs to average annual TFP change, which is shown by the pink bar at the far right of the graph. The contributions are ranked from most positive on the left to most negative on the right. If all the positive and negative contributions (blue columns) are added together, the sum will equal the TFP change (pink column). Outputs with the largest contribution were:

- growth in circuit length provided the highest positive contribution to TFP change over the 15-year period. Although the rate of growth of circuit length was only moderate (averaging 0.6 per cent per year), it has a high weight in the output index, and thus contributed 0.3 percentage points to TFP change;
- RMD made the second highest contribution to TFP change. Despite flattening out after 2011, RMD's average annual growth rate over the period of 0.8 per cent, combined with its substantial weight, resulted in a contribution 0.2 percentage points to average TFP change.

Of the other outputs: end-user numbers have grown steadily, averaging 1.3 per cent annually over the whole period, but their relatively low weight in the output index means this output contributed just 0.1 percentage points to TFP change over the period. Although ENS declined at an average annual rate of –6.5 per cent over the same period, its small weight in the output index means that it contributed less than 0.1 percentage point to TFP change. Although energy throughput has a weight of 15.1 per cent in the output index, it had a minor decline over the 15-year period and hence made a marginal negative contribution to average TFP change.

[10] Average of the relevant cost shares of individual DNSPs.

Figure 2.5 **Transmission industry output and input percentage point contributions to average annual TFP change, 2006–2020**

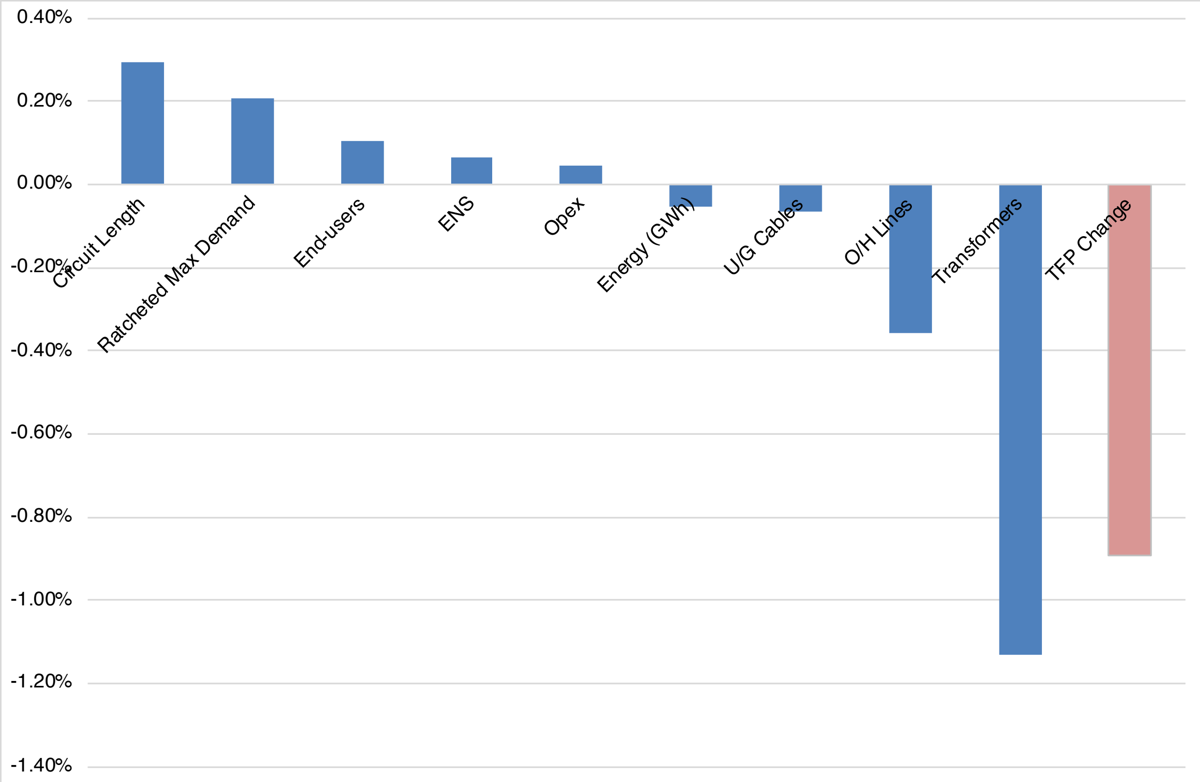


Table 2.2 **Transmission industry output and input percentage point contributions to average annual TFP change: 2006–2020, 2006– 2012, 2012–2020 and 2020**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Energy (GWh)	-0.05%	-0.02%	-0.08%	-0.20%
Ratcheted Max Demand	0.21%	0.45%	0.02%	0.04%
End-user Numbers	0.10%	0.10%	0.11%	0.09%
Circuit Length	0.30%	0.44%	0.19%	-0.10%
ENS	0.07%	0.01%	0.11%	1.27%
Opex	0.05%	-0.21%	0.24%	0.36%
O/H Lines	-0.36%	-0.84%	0.01%	0.26%
U/G Cables	-0.07%	-0.08%	-0.06%	0.01%
Transformers	-1.13%	-1.93%	-0.53%	-0.06%
TFP Change	-0.89%	-2.08%	0.00%	1.67%

Most of the inputs made a negative contribution to TFP change over the 15-year period, the only exception being non-capital input. The use of all three capital inputs increased, resulting in negative contributions to average annual TFP change. The two inputs with the largest shares in the total input index are transformers and overhead lines, which have a combined weight of 71.0 per cent. Since transformers had a comparatively high rate of growth of 2.8 per cent per annum from 2006 to 2020 (and a comparatively higher weight), this input made a large negative contribution to TFP change of –1.1 percentage points. Overhead lines had a lower average annual growth rate at 1.2 per cent, and made the second most negative contribution to TFP change at –0.4 percentage points.

Despite having the highest input average annual growth rate of 3.9 per cent, underground cables have only a small weight and so made a small negative contribution to TFP change of –0.1 percentage points. Whilst opex was the only input to reduce over the period, the reduction was small and so its positive contribution to TFP growth was only marginal.

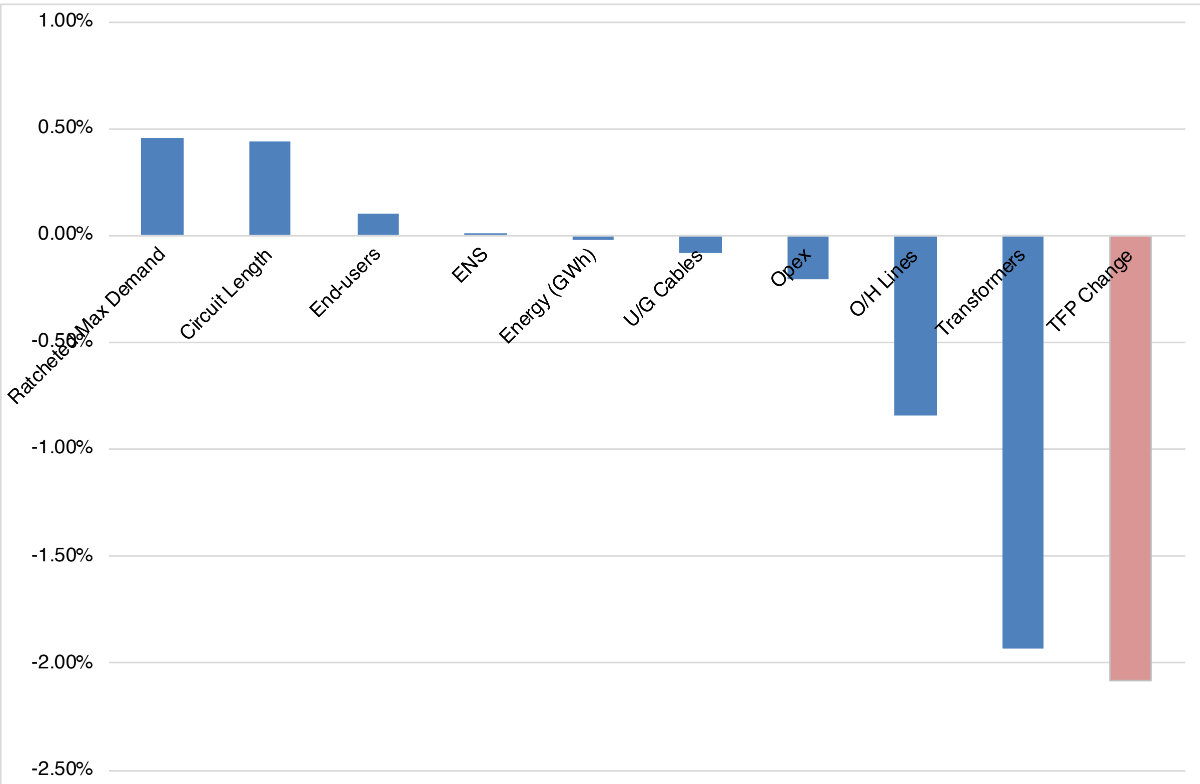
Figures 2.6 and 2.7 show the contributions of individual outputs and inputs to average TFP change in two sub-periods, from 2006 to 2012 and from 2012 to 2020 respectively. In the first of these two periods, TFP declined at an average annual rate of –2.1 per cent, whereas in the second period TFP was unchanged (an average rate of zero per cent). Figure 2.6 suggests a similar pattern of contributions to TFP change for most outputs and inputs for the period up to 2012 as for the whole period, except that:

(i) circuit length and RMD made more pronounced positive contributions;

(ii) transformers and overhead lines made much larger negative contributions; and

(iii) the contribution of opex was negative in the period up to 2012.

Figure 2.6 **Transmission industry output and input percentage point contributions to average annual TFP change, 2006–2012**



In the period from 2012 to 2020, the contributions to average annual TFP change presented in figure 2.7 indicate the following different patterns:

- opex changed from making a negative contribution up to 2012 to being a positive contributor to TFP change after 2012;
- RMD, which was a substantial contributor to TFP change in the period up to 2012 made only a marginal contribution after 2012;
- overhead lines did not have a negative contribution in the period after 2012. Although there was a reduction in the negative contribution of transformers, it remained the largest negative contributor.

Figure 2.7 **Transmission industry output and input percentage point contributions to average annual TFP change, 2012–2020**

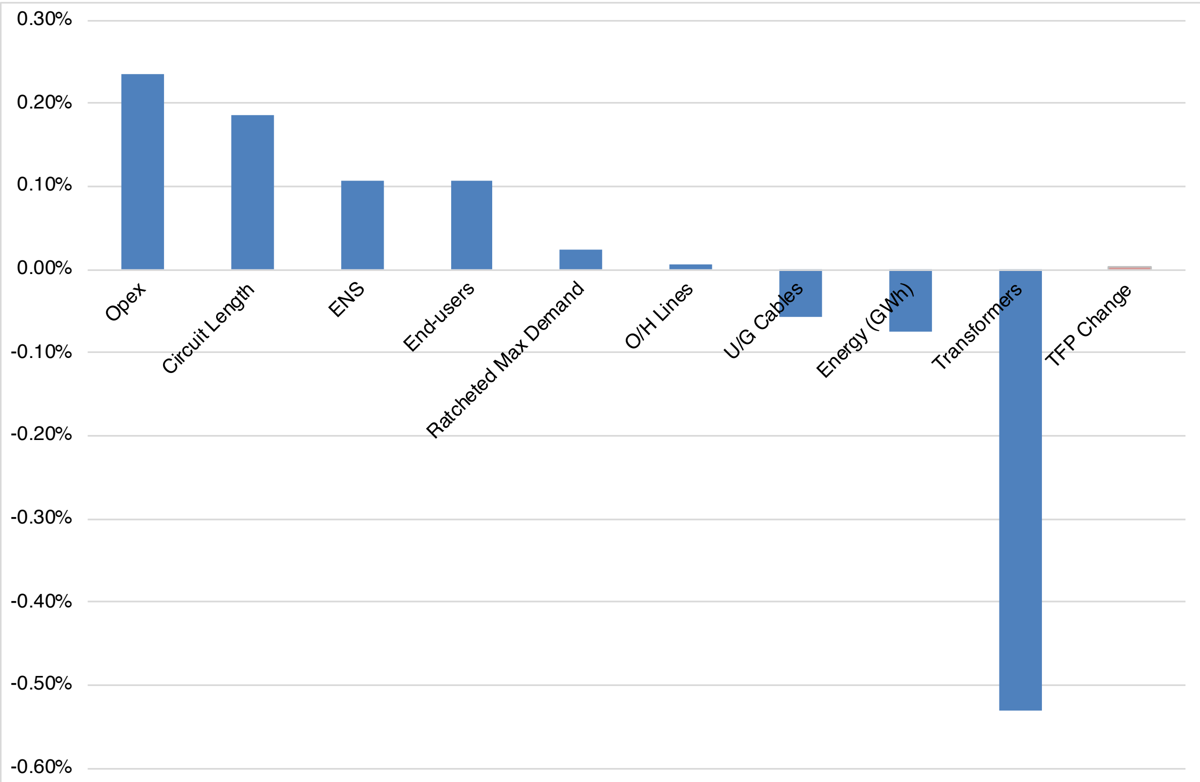


Table 2.3 presents the annual changes in each output and input from 2007 to 2020, and table 2.4 presents their percentage point contributions to annual TFP change in the same years.[11]

[11] Consistently with Economic Insights (2020), growth rates in indexes are generally expressed in this report as logarithmic growth measures. That is, the growth rate of a variable Y between period t – 1 and period t is calculated as: $g_t^Y = \ln Y_t - \ln Y_{t-1}$. It follows that some decreases in positively-valued variables can be larger (in absolute terms) than –100 per cent. For example, if $Y_{t-1} = 150$ and $Y_t = 50$, then the rate of change using the log measure is –109.9 per cent. This is because the basis for the rate of change measure is not period t – 1, but a mid-point between periods t – 1 and t. The log-difference growth rate can be related to the more common growth rate measure based on the first period as follows: $(Y_t - Y_{t-1})/Y_{t-1} = \exp(g_t^Y) - 1$.

Table 2.3 **Transmission industry output and input annual changes, 2006– 2020**

Year	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
Energy (GWh)	2.13%	-1.17%	1.12%	0.80%	-1.22%	-2.49%	-2.52%
Ratcheted Max Demand	5.72%	1.17%	1.87%	0.83%	1.21%	0.00%	0.05%
End-user Numbers	1.30%	1.32%	1.57%	1.24%	1.23%	1.19%	1.20%
Circuit Length	0.40%	1.32%	0.78%	1.39%	1.03%	0.00%	1.93%
ENS	55.43%	-28.54%	162.04%	-202.04%	5.50%	1.84%	7.40%
Opex	0.13%	-0.54%	2.42%	4.68%	-4.97%	2.82%	-3.96%
O/H Lines	4.55%	0.96%	3.98%	-0.41%	4.16%	3.05%	-0.50%
U/G Cables	1.96%	0.18%	0.56%	-2.21%	2.79%	22.73%	-1.60%
Transformers	1.97%	3.52%	11.80%	7.02%	1.79%	3.76%	1.76%
Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Energy (GWh)	-2.79%	5.49%	-1.62%	2.12%	-3.45%	0.08%	-1.30%
Ratcheted Max Demand	0.04%	0.00%	0.00%	0.29%	0.02%	0.22%	0.18%
End-user Numbers	1.13%	1.34%	1.41%	1.66%	1.61%	1.51%	1.16%
Circuit Length	1.16%	0.30%	0.01%	-0.43%	0.13%	-0.10%	-0.19%
ENS	-44.34%	96.76%	50.36%	-222.29%	-28.28%	174.11%	-119.61%
Opex	7.90%	1.01%	1.65%	-0.85%	-12.69%	1.13%	-1.27%
O/H Lines	1.51%	1.12%	1.68%	-3.50%	3.61%	-2.85%	-0.86%
U/G Cables	1.83%	33.05%	-0.01%	-8.52%	1.46%	2.43%	0.10%
Transformers	2.02%	2.14%	1.14%	0.57%	-0.12%	1.88%	0.06%

Table 2.4 **Transmission industry output and input percentage point contributions to annual TFP change, 2006–2020**

Year	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
Energy (GWh)	0.32%	-0.18%	0.17%	0.12%	-0.19%	-0.38%	-0.38%
Ratcheted Max Demand	1.43%	0.30%	0.47%	0.21%	0.30%	0.00%	0.01%
End-user Numbers	0.10%	0.10%	0.12%	0.10%	0.09%	0.09%	0.09%
Circuit Length	0.21%	0.71%	0.41%	0.75%	0.55%	0.00%	1.03%
ENS	-0.87%	0.50%	-2.80%	3.34%	-0.09%	-0.01%	-0.10%
Opex	-0.04%	0.18%	-0.74%	-1.24%	1.31%	-0.71%	1.01%
O/H Lines	-1.48%	-0.46%	-1.09%	0.11%	-1.23%	-0.93%	0.17%
U/G Cables	-0.02%	-0.04%	-0.01%	0.02%	-0.04%	-0.39%	0.03%
Transformers	-0.57%	-1.05%	-4.66%	-2.95%	-0.75%	-1.63%	-0.72%
TFP Change	-0.91%	0.06%	-8.12%	0.45%	-0.03%	-3.95%	1.15%
Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Energy (GWh)	-0.42%	0.83%	-0.24%	0.32%	-0.52%	0.01%	-0.20%
Ratcheted Max Demand	0.01%	0.00%	0.00%	0.07%	0.00%	0.06%	0.04%
End-user Numbers	0.09%	0.10%	0.11%	0.13%	0.12%	0.12%	0.09%
Circuit Length	0.62%	0.16%	0.00%	-0.24%	0.07%	-0.05%	-0.10%
ENS	0.49%	-1.24%	-0.69%	2.51%	0.19%	-1.58%	1.27%
Opex	-2.17%	-0.13%	-0.51%	0.22%	3.39%	-0.29%	0.36%
O/H Lines	-0.39%	-0.36%	-0.42%	1.00%	-1.00%	0.79%	0.26%
U/G Cables	-0.04%	-0.57%	0.03%	0.14%	-0.03%	-0.03%	0.01%
Transformers	-0.81%	-1.05%	-0.49%	-0.30%	0.02%	-0.83%	-0.06%
TFP Change	-2.62%	-2.24%	-2.22%	3.85%	2.25%	-1.81%	1.67%

Having regard to the contributions of individual outputs and inputs to TFP change in 2020, Table 2.4 shows that the following factors made a positive contribution to TFP growth:

- a substantial improvement in reliability, i.e. decrease in the ENS output, makes a large positive contribution 1.3 percentage points;
- a reduction in overhead lines (–0.9 per cent) contributes 0.3 percentage points; and
- a reduction in opex input (–1.3 per cent) contributes 0.4 percentage points.

The only negative contributors were:

- a decline in energy of –1.3 per cent made a negative contribution of –0.2 percentage points;
- a decline in circuit length of –0.2 per cent made a negative contribution of –0.1 percentage points; and
- a small increase in transformer inputs made a marginal negative contribution to TFP growth.

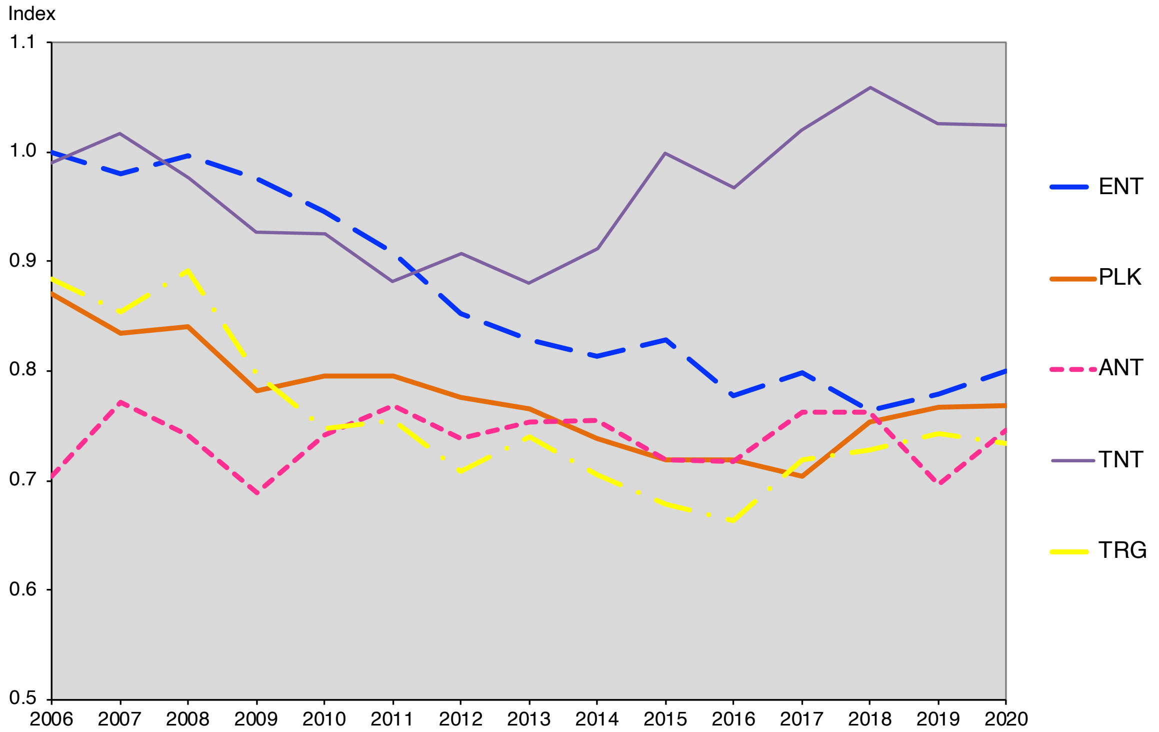
3 TNSP COMPARATIVE PRODUCTIVITY RESULTS

In this chapter we present updated comparative results for TNSPs using MTFP and MPFP indexes. As outlined in chapter 1, MTFP and MPFP indexes allow comparisons of productivity levels as well as productivity growth to be made.[12] These indexes are presented in figure 3.1 and table 3.1.

3.1 Multilateral TFP Indexes

Figure 3.1 shows that, with the exception of TNT, differences between MTFP levels narrowed in the second half of the period. The MTFP levels of three TNSPs—ENT, TRG and PLK—trended down to around 2016 before levelling out or increasing somewhat, while that of TNT generally trended down to around 2013 and has trended up since then. ANT's MTFP, on the other hand, has fluctuated over the 15-year period around a relatively low level. The MTFP levels of ANT and ENT improved somewhat in 2020 (increasing by 6.9 per cent and 2.6 per cent respectively). PLK's and TNT's MTFP levels in 2020 were not substantially changed from 2019 (PLK's increasing by 0.3 percent and TNT's decreasing by 0.2 per cent), while TRG's MTFP decreased by 1.2 per cent.

Figure 3.1 **TNSP multilateral total factor productivity indexes, 2006–2020**



[12] For convenience, index results are presented relative to ENT in 2006 having a value of one. The comparative results are invariant to which observation is used as the base.

Table 3.1 **TNSP multilateral TFP indexes, 2006–2020**

Year	*ENT*	*PLK*	*ANT*	*TNT*	*TRG*
2006	1.000	0.871	0.704	0.990	0.885
2007	0.980	0.835	0.772	1.017	0.855
2008	0.996	0.841	0.742	0.977	0.891
2009	0.975	0.782	0.689	0.927	0.797
2010	0.946	0.796	0.742	0.926	0.747
2011	0.909	0.796	0.769	0.883	0.756
2012	0.852	0.775	0.739	0.908	0.709
2013	0.828	0.765	0.754	0.881	0.741
2014	0.813	0.739	0.755	0.913	0.706
2015	0.829	0.719	0.720	1.000	0.678
2016	0.778	0.719	0.717	0.968	0.664
2017	0.798	0.704	0.763	1.019	0.719
2018	0.764	0.754	0.763	1.059	0.728
2019	0.779	0.766	0.696	1.026	0.743
2020	0.800	0.769	0.746	1.024	0.734

The MTFP of the individual TNSPs can be summarised as follows:

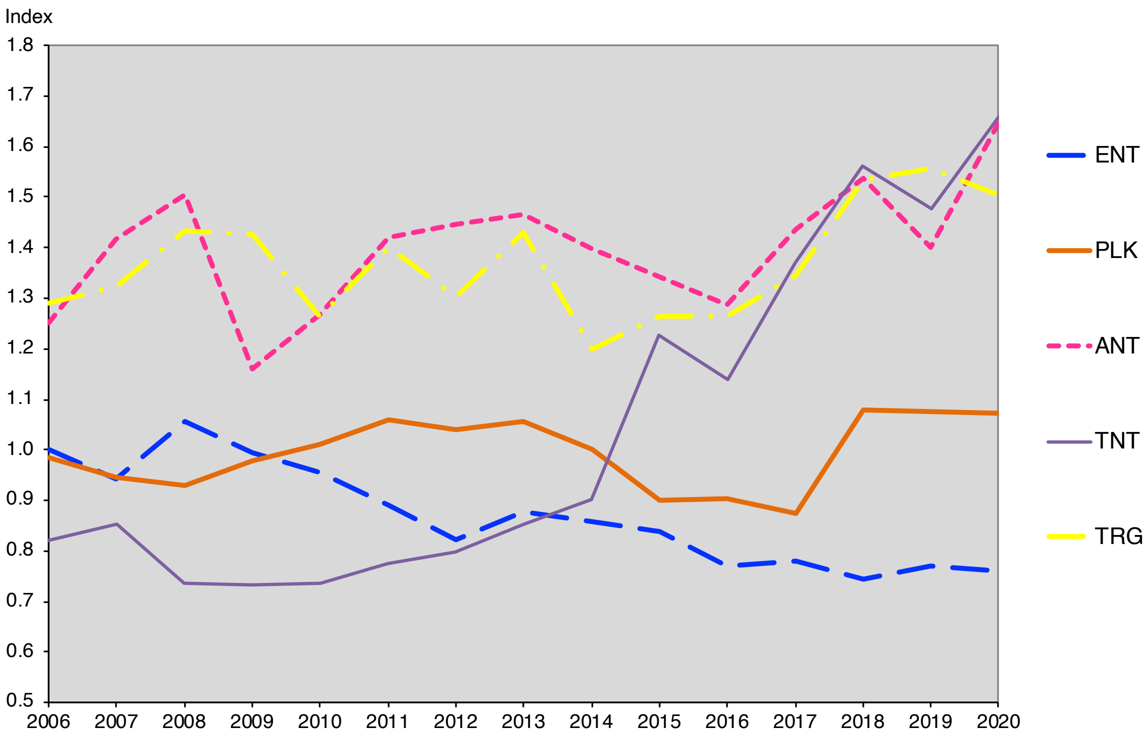
- TNT's productivity level was generally ranked second up until 2011, but increased noticeably in 2014 and 2015 with the introduction of restructuring and reform initiatives. TNT remains the highest ranked TNSP in terms of productivity level again in 2020. Its TFP level in 2020 of 1.02 (relative to ENT in 2006 equal to 1.00) was only slightly higher than TNT's productivity level in 2006 of 0.99.
- ENT started the period in 2006 having marginally the highest ranking in terms of MTFP level, slightly above that of TNT. ENT finished the period ranking second despite its MTFP index having declined to 0.80, representing an average rate of MTFP change of –1.6 per cent per annum.
- PLK had the third highest MTFP index in 2020 at 0.77. This represented a partial recovery from much lower MTFP levels, particularly from 2014 to 2017. However, PLK's MTFP level in 2020 remained below that of 2006 (0.87), representing an average rate of MTFP change of –0.9 per cent per year.
- In 2006, TRG had the third highest MTFP level, at 0.89. However, following a relatively steady decline up to 2016, with a moderate recovery since then, its MTFP level in 2020 was at 0.73. This was the lowest ranking among TNSPs in that year, and represented an average annual decline in MTFP between 2006 and 2020 of 1.3 per cent, which is similar to ENT's MTFP decrease.
- ANT started the period in 2006 with the lowest MTFP level at 0.70. It initially improved its performance before falling back in 2008 and 2009 due to increases in ENS and increases in input usage. Its MTFP subsequently improved slightly. Over the period to

2020, the rate of change in MTFP averaged 0.4 per cent per year. In 2020 it had the second lowest ranking, but at 0.75 it was not materially higher than lowest ranked TRG.

3.2 Multilateral PFP Indexes

MTFP levels are an amalgam of opex MPFP and capital MPFP levels. Opex MPFP indexes are presented in figure 3.2 and table 3.2 while capital MPFP indexes are presented in figure 3.3 and table 3.3.

Figure 3.2 **TNSP multilateral opex partial productivity indexes, 2006–2020**



From figure 3.2 we see that the two largest TNSPs—ANT and TRG—had the highest opex MPFP levels over the first half of the 15-year period but have been joined at the top by TNT since 2015. TNT had the lowest opex MPFP levels from 2006 to 2013 but marked increases in opex MPFP in 2015 and again in 2017, 2018 and 2020 have taken it to top ranking in 2020. It had an average annual opex MPFP growth rate for the full period of 5.0 per cent. ANT's, TRG's and PLK's opex MPFP average annual changes over the period were also positive at 1.9, 1.1 and 0.6 per cent, respectively. Opex MPFP average annual change for ENT was –2.0 per cent. ANT and TNT had large increases in opex MPFP in 2020 (16.1 and 11.4 per cent respectively); PLK was relatively constant (–0.2 per cent), while TRG and ENT each had a decrease (–3.4 and –1.2 per cent respectively).

From figure 3.3 we can see that capital MPFP levels have generally declined over the 15-year period. The one exception is ANT whose capital MPFP has fluctuated over time but had no trend (i.e. no underlying growth or decline). Most recently, ANT's capital MPFP level fell noticeably in 2019 but partly recovered in 2020.

In 2020, capital MPFP change was positive for ENT at 4.5 per cent; and for ANT at 4.6 per cent; and for PLK at 0.5 per cent. It was negative for TNT at –4.1 per cent and for TRG at –1.1 per cent.

Table 3.2 **TNSP Multilateral Opex PFP indexes, 2006–2020**

Year	*ENT*	*PLK*	*ANT*	*TNT*	*TRG*
2006	1.000	0.986	1.252	0.821	1.292
2007	0.941	0.947	1.417	0.852	1.322
2008	1.057	0.929	1.505	0.736	1.434
2009	0.993	0.979	1.161	0.734	1.426
2010	0.956	1.010	1.269	0.735	1.266
2011	0.889	1.058	1.421	0.776	1.400
2012	0.822	1.039	1.447	0.799	1.303
2013	0.876	1.057	1.464	0.853	1.429
2014	0.859	1.002	1.399	0.902	1.198
2015	0.837	0.900	1.342	1.226	1.265
2016	0.769	0.903	1.287	1.140	1.264
2017	0.781	0.873	1.436	1.370	1.346
2018	0.745	1.079	1.539	1.561	1.535
2019	0.770	1.076	1.400	1.478	1.558
2020	0.761	1.074	1.643	1.658	1.506

Figure 3.3 **TNSP multilateral capital partial productivity indexes, 2006–2020**

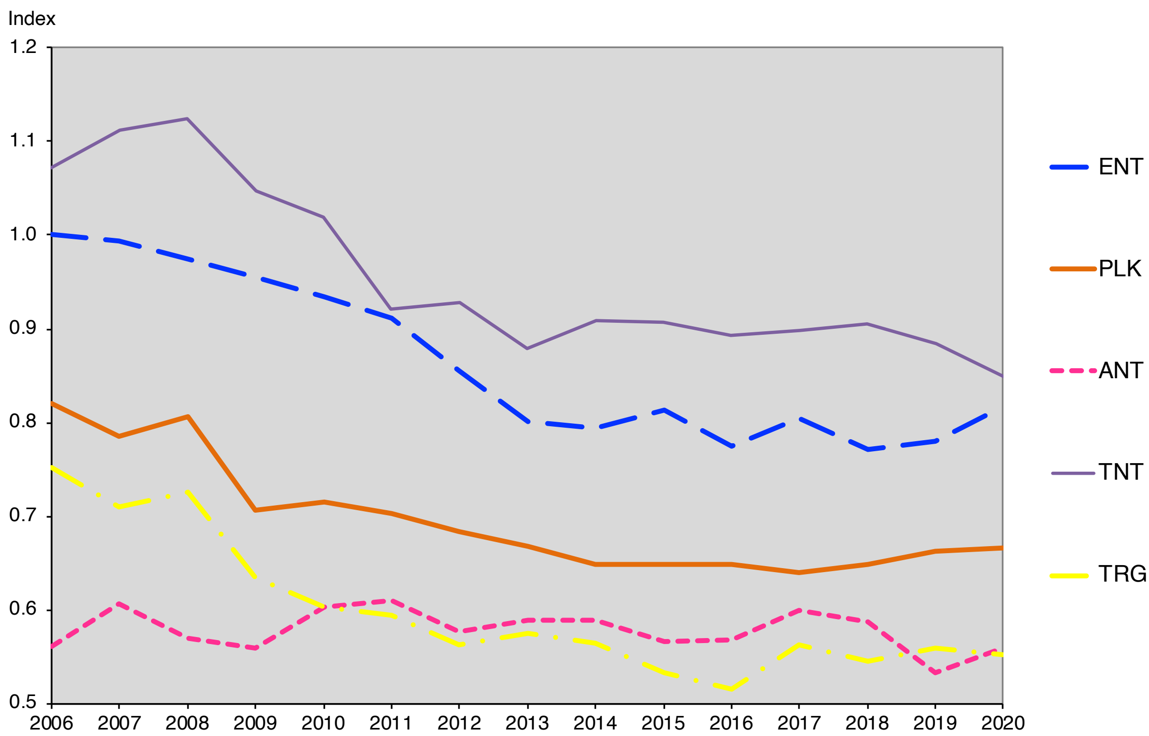


Table 3.3 **TNSP multilateral capital PFP indexes, 2006–2020**

Year	*ENT*	*PLK*	*ANT*	*TNT*	*TRG*
2006	1.000	0.821	0.561	1.072	0.752
2007	0.994	0.786	0.606	1.112	0.711
2008	0.975	0.806	0.571	1.124	0.727
2009	0.954	0.706	0.559	1.047	0.635
2010	0.934	0.715	0.603	1.020	0.604
2011	0.912	0.704	0.611	0.922	0.595
2012	0.855	0.684	0.577	0.929	0.563
2013	0.802	0.668	0.590	0.879	0.575
2014	0.795	0.648	0.590	0.908	0.565
2015	0.814	0.650	0.567	0.907	0.533
2016	0.775	0.650	0.569	0.893	0.515
2017	0.804	0.640	0.600	0.898	0.563
2018	0.772	0.648	0.587	0.906	0.546
2019	0.781	0.663	0.534	0.884	0.559
2020	0.817	0.667	0.559	0.849	0.553

4 TNSP OUTPUTS, INPUTS AND PRODUCTIVITY CHANGE

In this chapter we review the outputs, inputs and productivity change results for the five NEM TNSPs. To provide context, individual TNSP results are generally compared with the corresponding transmission industry-level result presented earlier in section 2.

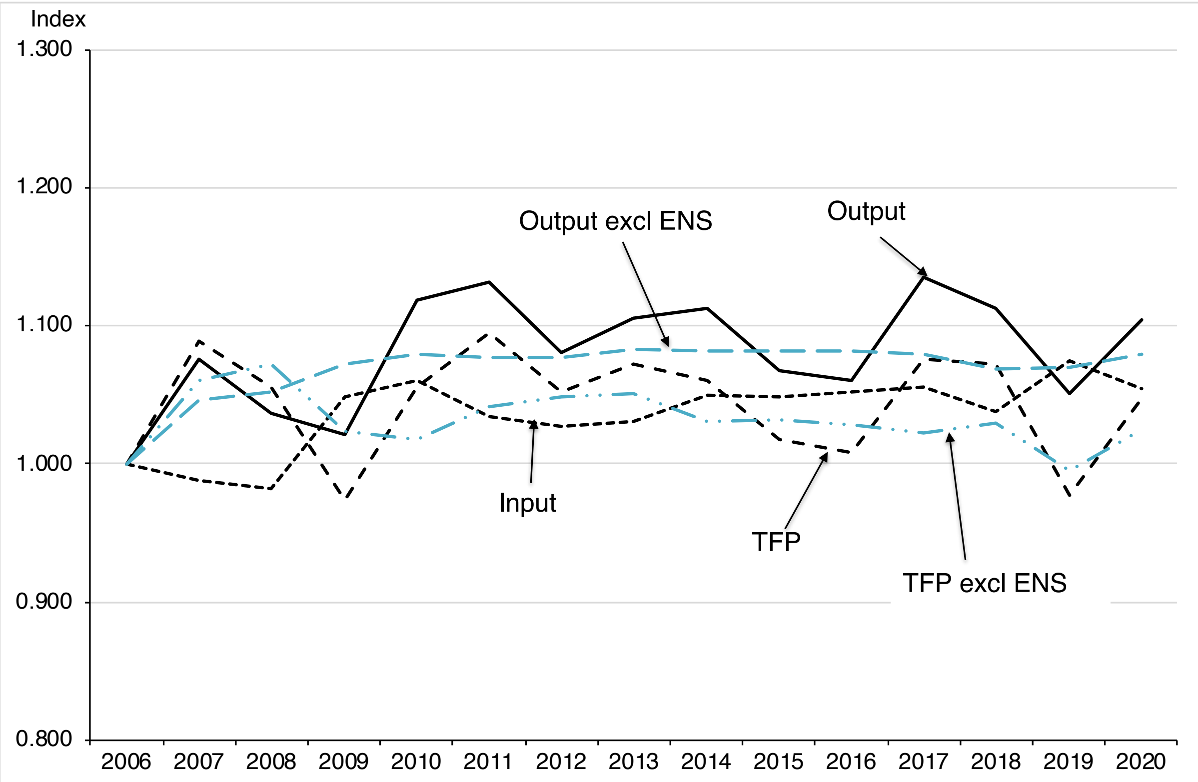
4.1 AusNet Services Transmission

In 2020 AusNet Services Transmission (ANT) transported 41,528 GWh of electricity over 6,731 circuit kilometres of lines and cables. It forms a critical part of Victoria's energy supply chain serving over 3 million end-users. ANT is the third largest TNSP in the NEM in terms of both energy throughput and circuit length but it serves the second largest number of end-users.

4.1.1 ANT's productivity performance

ANT's total output, total input and TFP indexes are presented in figure 4.1 and table 4.1. Opex and capital partial productivity indexes are also presented in table 4.1.

Figure 4.1 **ANT's output, input and TFP indexes, 2006–2020**



Over the 15-year period 2006 to 2020, ANT's TFP changed at an average annual rate of 0.3 per cent. Its total output increased by an average annual rate of 0.7 per cent, slightly more than its rate of increase in total input use of 0.4 per cent. This differs from the situation for the transmission industry as a whole where input use increased considerably more than output growth over this period.

Figure 4.1 also shows the output and TFP indexes when ENS is excluded. This highlights the effect of ENS, showing that the year-to-year volatility of output, which is apparent in figure 4.1, is almost entirely driven by ENS. Poor reliability outcomes can sharply reduce the output index. Since total input is relatively steady with a small upward trend, the effect of ENS on output is to also produce fluctuations in TFP. After a decrease in 2018 and 2019, ANT's TFP increased strongly by 6.9 per cent in 2020. Overall, productivity growth was much weaker in the second half of the period from 2006 to 2020 than in the first half of the period. On average over the period from 2012 to 2020, ANT's rate of TFP change was –0.1 per cent, which can be compared to an average rate of TFP growth of 0.8 per cent per year in the period 2006 to 2012.

Table 4.1 **ANT's output, input, TFP PFP indexes, 2006–2020**

Year	*Output Index*	*Input Index*	*TFP Index*	*PFP Index*	
				Opex	*Capital*
2006	1.000	1.000	1.000	1.000	1.000
2007	1.075	0.987	1.089	1.130	1.077
2008	1.036	0.982	1.055	1.202	1.014
2009	1.021	1.048	0.974	0.927	0.991
2010	1.118	1.060	1.055	1.012	1.068
2011	1.131	1.034	1.094	1.133	1.081
2012	1.080	1.027	1.052	1.155	1.022
2013	1.105	1.031	1.072	1.168	1.044
2014	1.113	1.050	1.060	1.116	1.043
2015	1.067	1.049	1.017	1.072	1.000
2016	1.060	1.052	1.008	1.028	1.002
2017	1.136	1.056	1.076	1.145	1.054
2018	1.113	1.037	1.073	1.227	1.029
2019	1.050	1.075	0.977	1.118	0.937
2020	1.104	1.054	1.047	1.311	0.979
Growth Rate 2006-2020	0.7%	0.4%	0.3%	1.9%	-0.2%
Growth Rate 2006-2012	1.3%	0.4%	0.8%	2.4%	0.4%
Growth Rate 2012-2020	0.3%	0.3%	-0.1%	1.6%	-0.5%
Growth Rate 2020	5.0%	-2.0%	6.9%	16.0%	4.4%

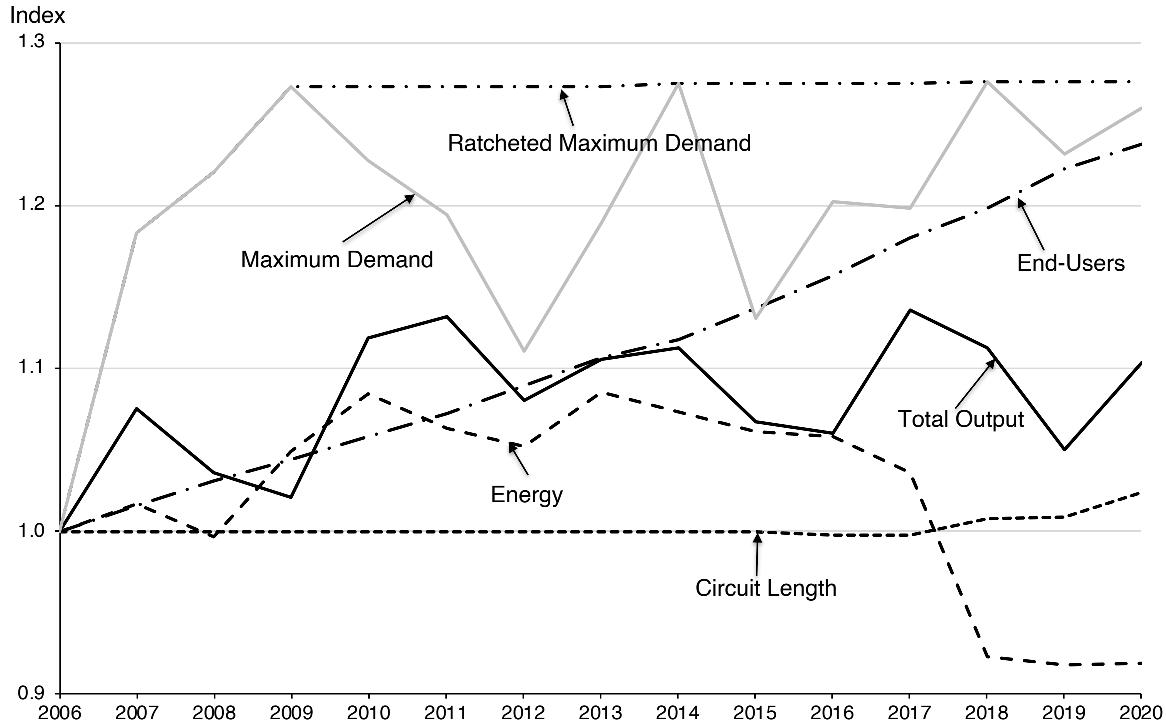
Table 4.1 also shows partial productivity indexes. The average rate of change in opex PFP in the period from 2006 to 2020 was 1.9 per cent per annum, with a slightly stronger growth in the first half of the period, and slightly weaker growth from 2012 to 2020. Capital PFP grew on average by –0.2 per cent per year between 2006 and 2020. This is the net effect of quite different trends in the period 2006 to 2012, in which capital PFP grew on average by 0.4 per cent per annum, and the period 2012 to 2020, in which capital PFP declined at –0.5 per cent per annum. This reversal of the trend in capital PFP is the most significant factor in ANT's flat TFP performance in the second half of the sample period.

4.1.2 ANT's output and input quantity changes

Quantity indexes for ANT's individual outputs are presented in figure 4.2 and for individual inputs in figure 4.3. In each case the quantities are converted to index format with a value of one in 2006 for ease of comparison. Average growth rates for selected periods are shown in appendix B.

From figure 4.2 we see that the output component that receives the largest weight in forming ANT's TFP index, circuit length, increased by 2.4 per cent in total over the 15-year period. This contrasts with the transmission industry as a whole where circuit length was 8.0 per cent higher in 2020 than it was in 2006.

Figure 4.2 **ANT's output quantity indexes, 2006–2020**



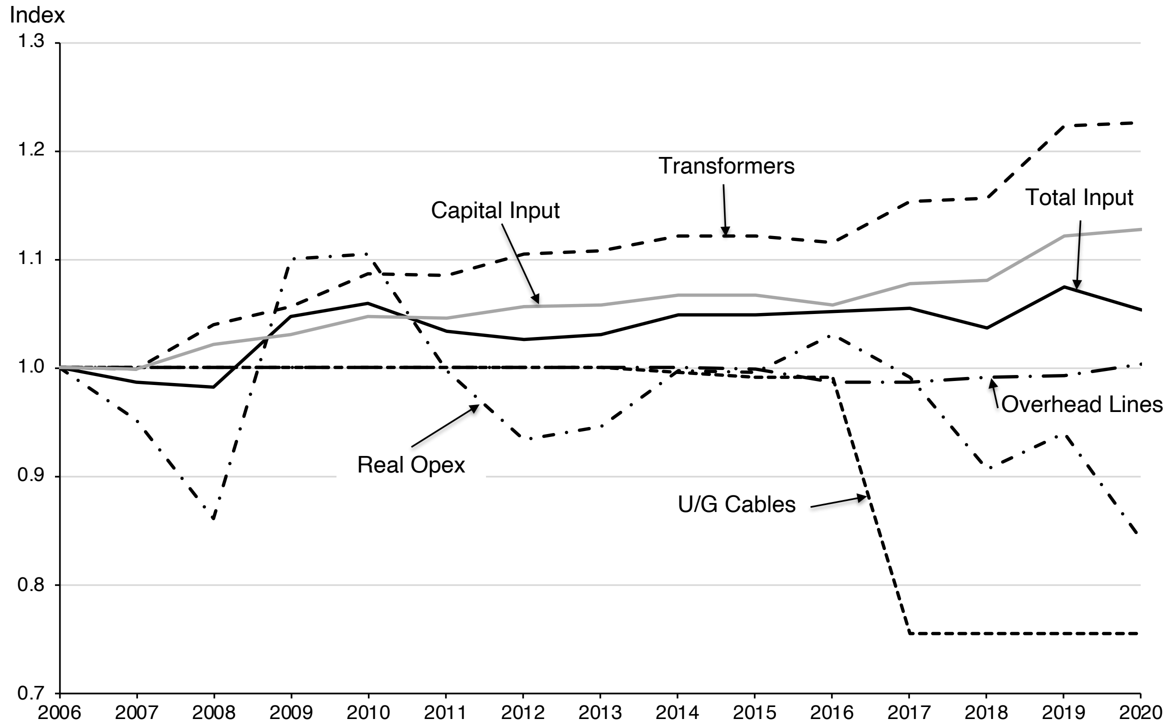
ANT's ratcheted maximum demand (RMD) output has grown at a considerably higher rate than for the industry as a whole. Between 2006 and 2020, ANT's RMD increased by 27.6 per cent in total compared to 12.3 per cent for the industry. Almost all of this growth occurred in the period from 2006 to 2009. Figure 4.2 shows that maximum demand has fluctuated in the period after 2009, with peaks in 2014 and 2018 which slightly increased RMD.

End-user numbers for ANT grew over the period 2006 to 2020 by almost the same proportion as RMD—an increase of 23.7 per cent, which is comparable to the increase of 20.8 per cent for the industry. In the period up to about 2017, ANT's energy throughput showed a steadier pattern than that for the industry as a whole, since the latter was steadily declining over the same period. However, ANT's energy throughput fell sharply in 2018 due to reduced energy exports, and has remained at the reduced level. In 2020 ANT's transmission energy throughput was 8.1 per cent below its 2006 level while for the industry it was 4.7 per cent lower than it was in 2006.

The output not shown in figure 4.2 is energy not supplied (ENS). ANT's ENS spiked upwards in 2009 to 13 times its 2006 level associated with the transformer failure at the South Morang Terminal Station. With the exception of 2009, ANT's ENS generally trended downwards to 2014 and, hence, contributed to an increase in total output relative to 2006, all else equal. However, ENS again increased in 2015 and 2016 before falling to near zero in 2017 and remaining low in 2018 before increasing significantly in 2019 and falling again in 2020. The industry's ENS has followed a broadly similar pattern to that of ANT. Despite its small weight, the size of the percentage changes in ENS means it still has a significant impact on total output and, hence, TFP growth.

Turning to the input side, quantity indexes for ANT's four input components and total input are shown in figure 4.3. In line with its near constant circuit length output, ANT's input quantities for both overhead lines and underground cables have remained virtually constant over the whole period although the (relatively small) quantity of underground cables input reduces in 2017 as cable length falls from 11 to 9 kilometres.

Figure 4.3 **ANT's input quantity indexes, 2006–2020**



After underground cables, opex input decreased the next most of ANT's inputs over the 15-year period, being 15.8 per cent lower in 2020 than in 2006 but with significant variation over the intervening years. This compares to 2.5 per cent overall reduction in opex between 2006 and 2020 for the industry. Opex has an average share of ANT's total costs at 23.6 per cent (see appendix A).

The input component with the largest average share of total cost, at 46.0 per cent for ANT on average, is transformers. ANT's quantity of transformers increased steadily, at an average rate of 1.7 per cent per year in the period 2006 to 2012, and again at an average annual rate of 1.3 per cent in the period 2012 to 2020. In 2020 ANT's transformers input was 22.6 per cent above its 2006 level; considerably smaller than the 48.2 per cent increase for the industry over the same period. Given their large share of total costs, transformer inputs are an important driver of the total input quantity index.

4.1.3 ANT's output and input contributions to TFP change

Figure 4.4 shows the contributions of outputs and inputs to ANT's average rate of TFP change in 2020. Table 4.2 shows the decomposition of ANT's average rates of TFP change into the contributions of the individual outputs and inputs for the whole 15-year period and for the periods up to and after 2012, and for 2020.

Figure 4.4 **ANT's output and input percentage point contributions to average annual TFP change, 2020**

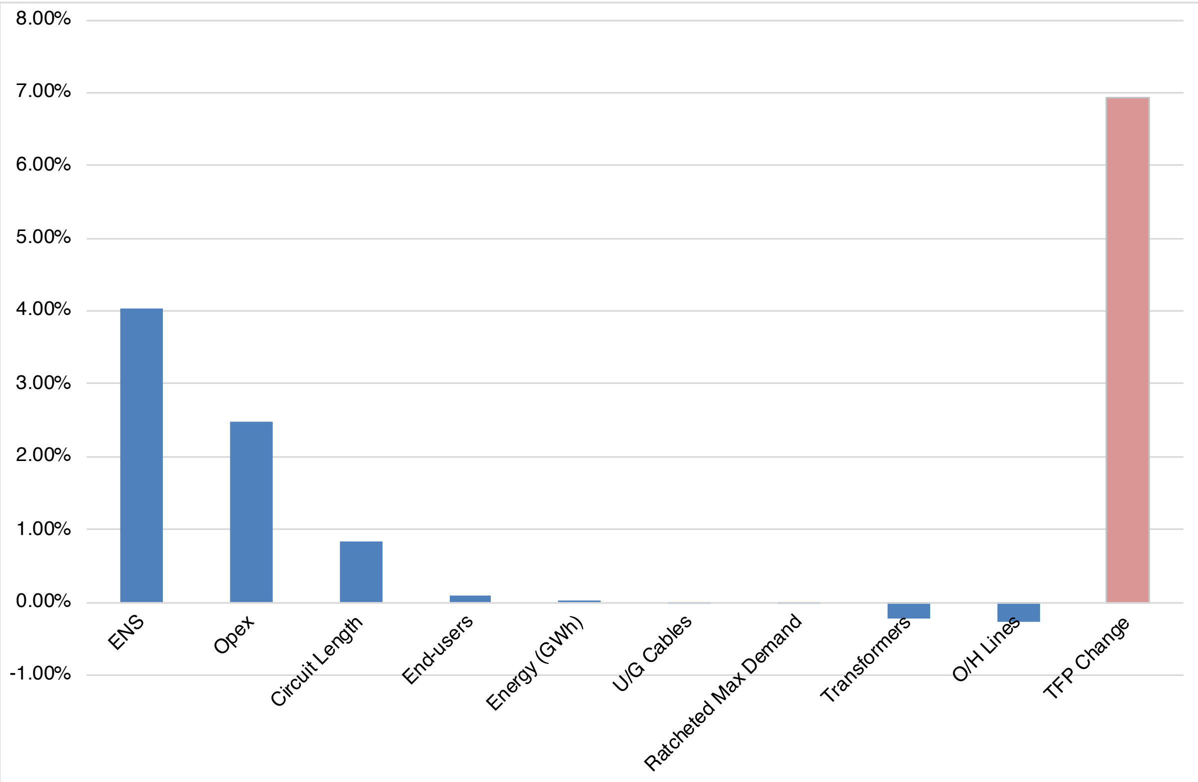


Table 4.2 **ANT output and input percentage point contributions to average annual TFP change: 2006–2020, 2006– 2012, 2012–2020 and 2020**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Energy (GWh)	-0.09%	0.13%	-0.26%	0.03%
Ratcheted Max Demand	0.44%	1.01%	0.01%	0.00%
End-user Numbers	0.12%	0.11%	0.12%	0.09%
Circuit Length	0.09%	0.00%	0.16%	0.83%
ENS	0.15%	0.04%	0.24%	4.03%
Opex	0.28%	0.26%	0.30%	2.48%
O/H Lines	-0.01%	0.00%	-0.01%	-0.28%
U/G Cables	0.02%	0.00%	0.03%	0.00%
Transformers	-0.67%	-0.71%	-0.64%	-0.23%
TFP Change	0.33%	0.84%	-0.05%	6.94%

4.2 ElectraNet

In 2020 ElectraNet (ENT) transported 13,857 GWh of electricity over 5,520 circuit kilometres of lines and cables. It forms a critical part of South Australia's energy supply chain serving 914,603 end-users. ENT is the fourth largest of the five TNSPs in the NEM in terms of energy throughput, circuit length and the number of end-users.

4.2.1 ENT's productivity performance

ENT's total output, total input and TFP indexes are presented in figure 4.5 and table 4.3. Opex and capital partial productivity indexes are also presented in table 4.3. Figure 4.5 also shows the output and TFP indexes when ENS is excluded, which highlights the effect of ENS.

Over the 15-year period 2006 to 2020, ENT's TFP decreased at an average annual rate of change of –1.6 per cent. This can be compared to the industry's average annual change of –0.9 per cent over the same period. ENT's total output increased over the same period at an average annual rate of 0.3 per cent. This is lower than the industry average rate of growth in output of 0.6 per cent per annum. ENT's average annual rate of increase in input use of 1.8 per cent was slightly higher than the rate of increase in total input use for the industry (1.5 per cent per year).

While in most years ENT's TFP has decreased, there have been some years when there was a small increase in TFP, and these include 2020, when ENT's TFP increased by 2.6 per cent. This was driven by above-average output growth of 3.4 per cent in 2020.

It is also notable that the rate of growth of input usage is much higher in the period 2006 to 2012 (averaging 2.7 per cent per year) than in the period 2012 to 2020 (averaging 1.2 per cent per year). Accordingly, the average rate of change in TFP between 2006 and 2012 was –2.9 per cent per year, while after 2012 the rate of decline was not as strong, averaging –0.6 per cent per annum between 2012 and 2020.

The partial productivity indexes in table 4.3 show that the moderation in negative average annual rates of change of TFP after 2012 were mirrored in a reduced rate of decrease in opex PFP and in capital PFP.

Figure 4.5 **ENT's output, input and TFP indexes, 2006–2020**

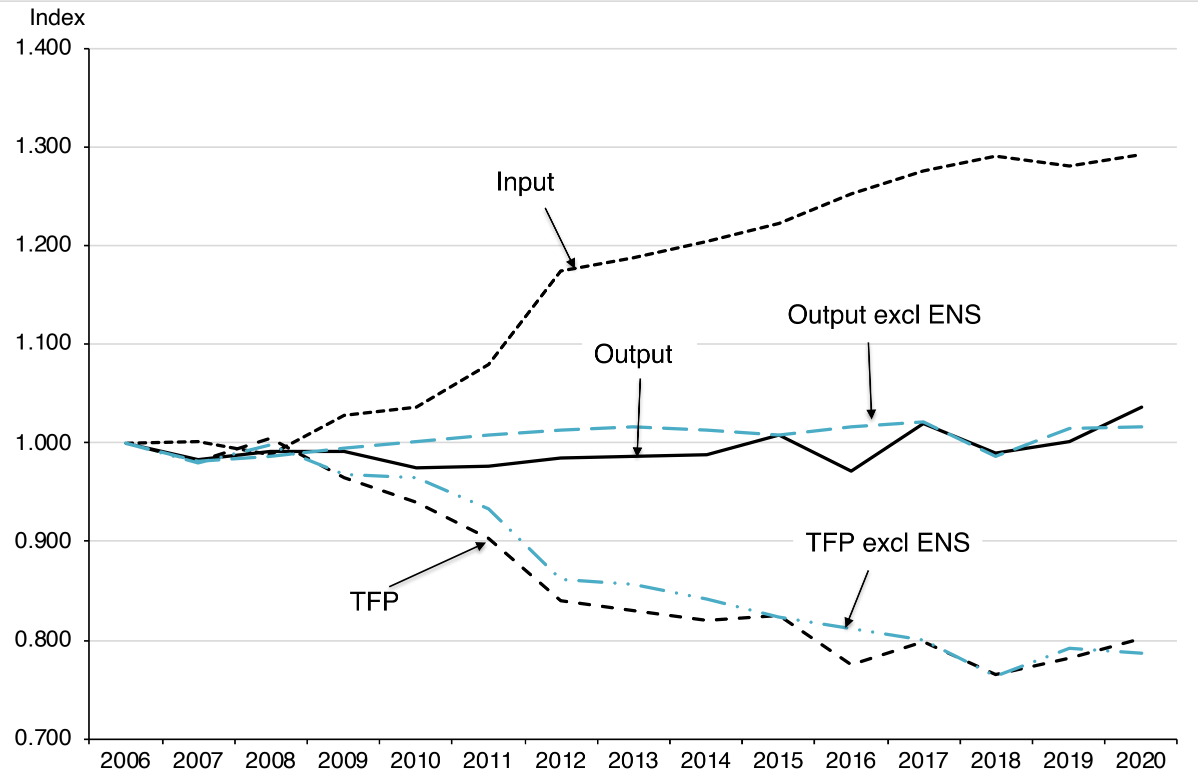


Table 4.3 **ENT's output, input, TFP and PFP indexes, 2006–2020**

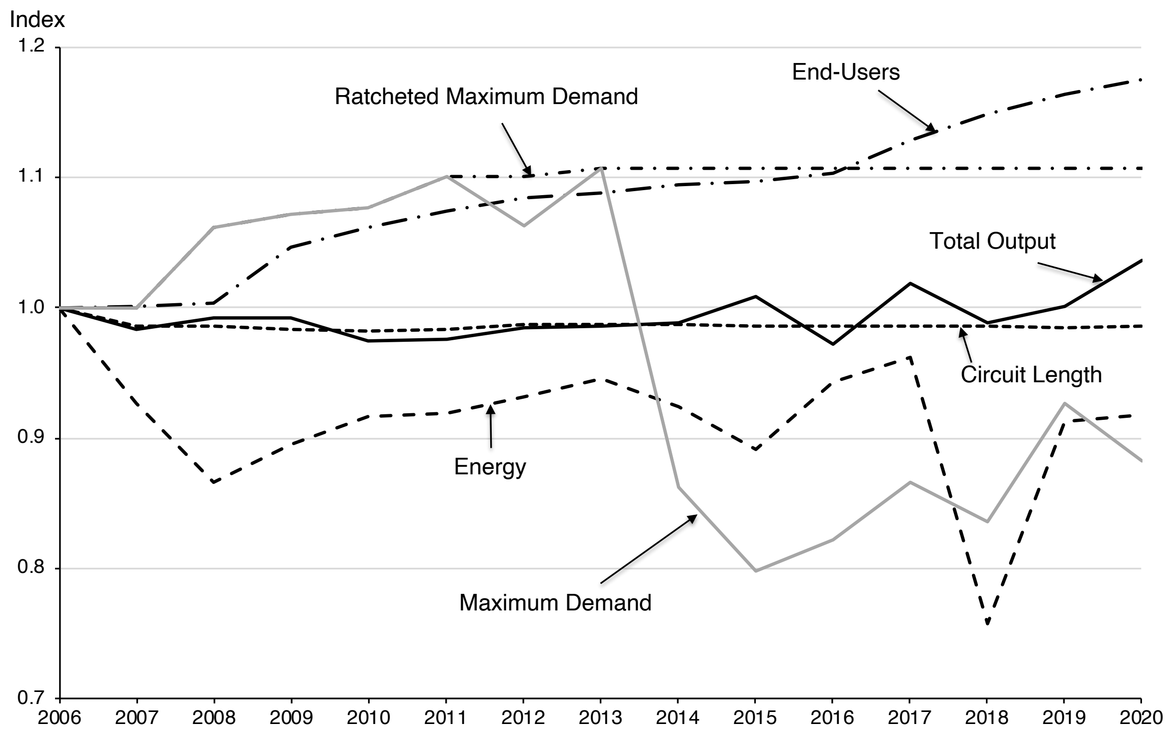
Year	*Output Index*	*Input Index*	*TFP Index*	*PFP Index Opex*	*PFP Index Capital*
2006	1.000	1.000	1.000	1.000	1.000
2007	0.983	1.002	0.981	0.941	1.001
2008	0.992	0.988	1.004	1.057	0.979
2009	0.992	1.028	0.965	0.993	0.954
2010	0.974	1.037	0.940	0.956	0.933
2011	0.976	1.080	0.904	0.889	0.911
2012	0.985	1.174	0.839	0.822	0.847
2013	0.986	1.187	0.830	0.876	0.811
2014	0.988	1.205	0.820	0.859	0.802
2015	1.008	1.223	0.824	0.836	0.820
2016	0.972	1.253	0.776	0.768	0.779
2017	1.019	1.275	0.799	0.780	0.808
2018	0.989	1.291	0.766	0.744	0.776
2019	1.001	1.280	0.782	0.771	0.787
2020	1.036	1.292	0.802	0.762	0.822
Growth Rate 2006-2020	0.3%	1.8%	-1.6%	-1.9%	-1.4%
Growth Rate 2006-2012	-0.2%	2.7%	-2.9%	-3.3%	-2.8%
Growth Rate 2012-2020	0.6%	1.2%	-0.6%	-1.0%	-0.4%
Growth Rate 2020	3.4%	0.9%	2.6%	-1.2%	4.4%

4.2.2 ENT's output and input quantity changes

Quantity indexes for ENT's individual outputs are presented in figure 4.6 and for individual inputs in figure 4.7. From figure 4.6 we see that circuit length (the output component that receives the largest weight in forming the TFP index) declined marginally in 2007 and has then remained virtually unchanged for the remainder of the 15-year period. This contrasts with the transmission industry as whole where circuit length was 8.0 per cent higher in 2020 than it was in 2006.

ENT's RMD output has shown a quite similar pattern compared to the industry as a whole. In both cases, RMD increased though to 2011 by about 10 per cent overall, and remained essentially constant thereafter. ENT's highest maximum demand was reached in 2013, after which maximum demand levels have been considerably reduced. ENT's energy throughput has decreased at a greater rate than for the industry as a whole. ENT's throughput decreased an average rate of –0.6 per cent per annum between 2006 and 2020, while industry energy throughput decreased at an annual average rate of –0.3 per cent over the same period. For ENT, energy throughput in 2020 was 8.2 per cent below its 2006 level compared to the industry's throughput then being 4.7 per cent less than it was in 2006. The output that increased most over the period for ENT is end-user numbers with an overall increase of 17.4 per cent between 2006 and 2020, which is slightly less than the increase of 20.8 per cent for the industry.

Figure 4.6 **ENT's output quantity indexes, 2006–2020**



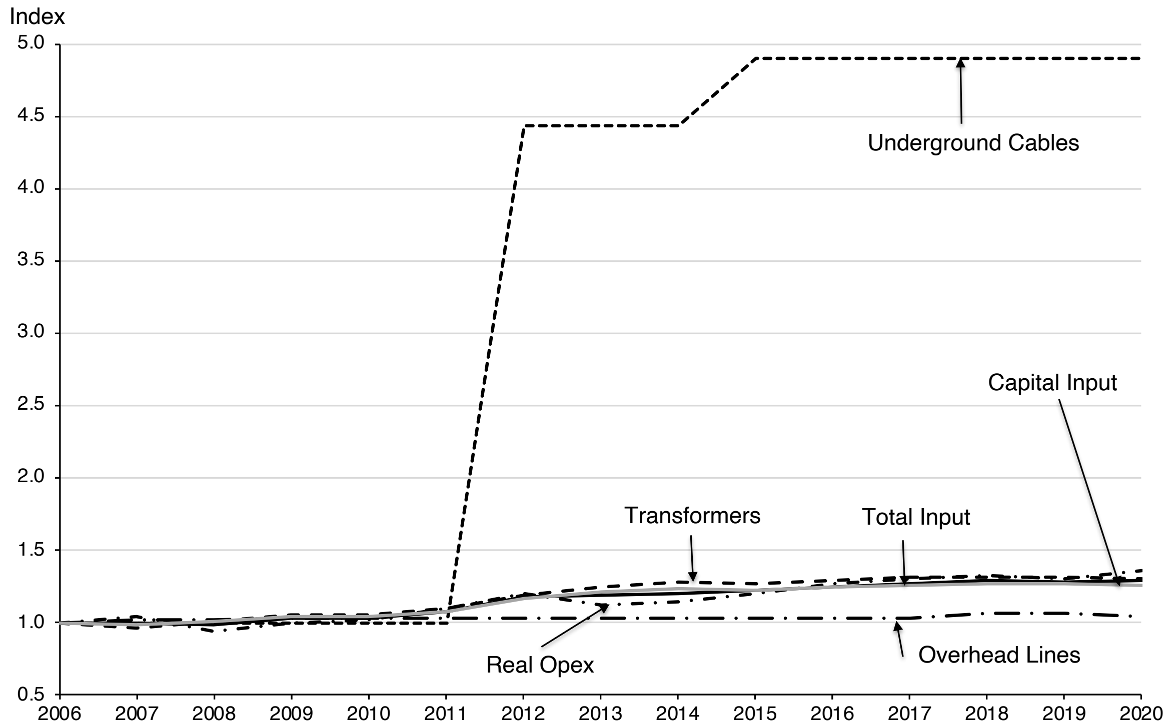
The output that is not shown in figure 4.5 is ENS. ENT's ENS has been relatively volatile and spiked upwards in 2016 to 10 times its 2006 level after having been less than its 2006 level in 2015. In 2020, ENT's ENS decreased to be only 8.6 per cent of its 2006 level (i.e. a 91.4 per cent decrease). Overall, ENS had a substantial negative impact on ENT's total output over most of the period, as shown in Figure 4.5.

Since the circuit length, end-user numbers and energy throughput outputs receive a combined weight of around 76.4 per cent in forming the total output index, in figure 4.6 we see that the total output index tends to lie close to the circuit length output index and be bounded by the end-user numbers and energy throughput indexes. Total output movements are also influenced by the pattern of movement in the ENS output, with the spike in ENS in 2016 causing a pronounced drop in output in that year, and the large reduction in ENS in 2020 causing a substantial increase in output.

Turning to the input side, quantity indexes for ENT's four inputs and aggregate inputs are shown in figure 4.7. In line with ENT's near constant circuit length output, ENT's input quantity for overhead lines increased only marginally over the whole period (4.0 per cent in total). Its underground cables input quantity increased by 389.8 per cent overall between 2006 and 2020, but the length of underground cables remains small.

The quantity of opex increased over the 15-year period to 2020 by 36.0 per cent. This was a considerably higher increase than for the industry, where opex quantity actually fell by 2.5 per cent over the same period. Opex has the second largest average share in total costs, representing 31.7 per cent of ENT's costs. Opex usage increased by 4.6 per cent in 2020.

Figure 4.7 **ENT's input quantity indexes, 2006–2020**



The input component with the largest average share of ENT's total cost, at 44.3 per cent, is transformers. ENT's quantity of transformers increased steadily over most of the 15-year period, before levelling off from 2017. By 2020, ENT's transformer inputs were 30.8 per cent above the 2006 level, which is a smaller increase than the industry's 48.2 per cent. Given their large share of total costs, transformer inputs are an important driver of the total input quantity index.

4.2.3 ENT's output and input contributions to TFP change

Figure 4.8 shows the contributions of outputs and inputs to ENT's average rate of TFP change in 2020. Table 4.4 shows the decomposition of ENT's average rates of TFP change into the contributions of the individual outputs and inputs for the whole 15-year period and for the periods up to and after 2012, and for 2020.

Figure 4.8 **ENT's output and input percentage point contributions to average annual TFP change, 2020**

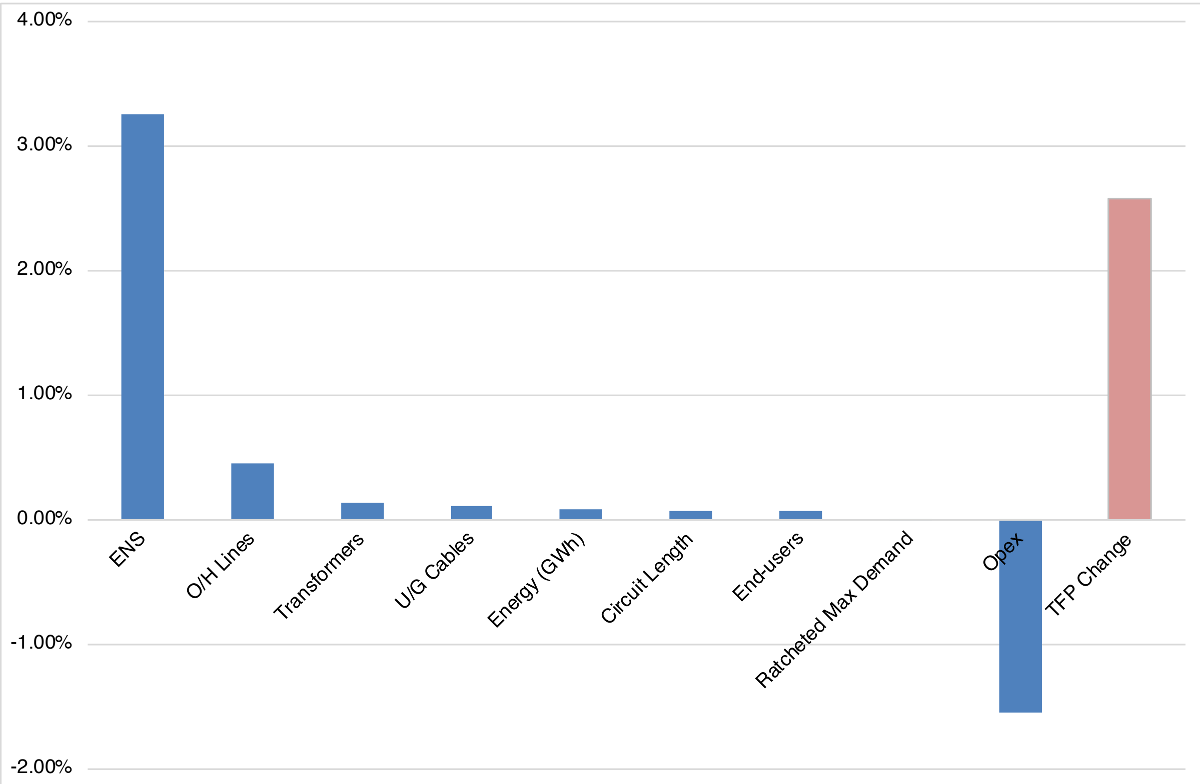


Table 4.4 **ENT output and input percentage point contributions to average annual TFP change: 2006–2020, 2006– 2012, 2012–2020 and 2020**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Energy (GWh)	-0.09%	-0.18%	-0.03%	0.08%
Ratcheted Max Demand	0.18%	0.40%	0.02%	-0.01%
End-user Numbers	0.09%	0.10%	0.08%	0.06%
Circuit Length	-0.06%	-0.12%	-0.01%	0.07%
ENS	0.13%	-0.45%	0.57%	3.25%
Opex	-0.71%	-0.96%	-0.53%	-1.55%
O/H Lines	-0.07%	-0.12%	-0.03%	0.44%
U/G Cables	-0.21%	-0.38%	-0.08%	0.10%
Transformers	-0.84%	-1.21%	-0.56%	0.14%
TFP Change	-1.58%	-2.92%	-0.57%	2.57%

4.3 Powerlink

In 2020 Powerlink (PLK) transported 53,076 GWh of electricity over 14,528 circuit kilometres of lines and cables. It forms a critical part of Queensland's energy supply chain serving around 2.3 million end-users. PLK is the second largest of the five TNSPs in the NEM in terms of energy throughput but is the largest in terms of circuit length. It serves the third largest number of end-users.

4.3.1 PLK's productivity performance

PLK's total output, total input and TFP indexes are presented in figure 4.9 and table 4.5. Opex and capital partial productivity indexes are also presented in table 4.5. Figure 4.9 also shows the output and TFP indexes when ENS is excluded, which highlights the effect of ENS.

After a steady decline over the period up to 2017, PLK's TFP increased strongly in 2018, with lesser increases in 2019 and 2020 (by 0.6 per cent in the latter year). The key to these trends is the growth rates of the input index. By 2017, the input index was 47.9 per cent higher than its level in 2006, but there was a substantial decrease in the input index in 2018. Consequently, in 2020, the input index was 39.6 per cent higher than in 2006. This remains a larger increase in inputs compared to the total industry, for which inputs increased by 23.6 per cent between 2006 and 2020. While the large increase in TFP in 2018 was driven by reduction in inputs, the increase in 2019 was due to strong output growth, which in turn was due to a reduction in ENS. PLK achieved a zero ENS in 2019. The TFP gain in 2020 was due to a reduction in inputs that more than offset a reduction in output.

Figure 4.9 **PLK's output, input and TFP indexes, 2006–2020**

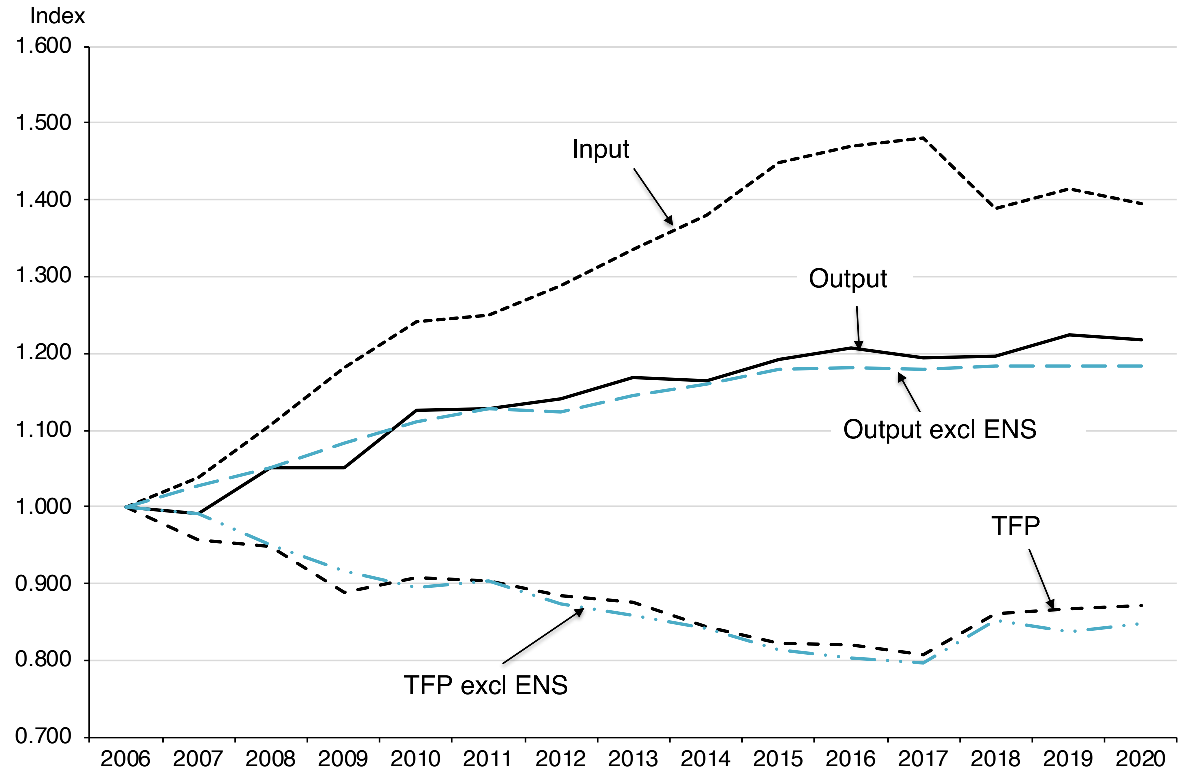


Table 4.5 **PLK's output, input, TFP and PFP indexes, 2006–2020**

Year	*Output Index*	*Input Index*	*TFP Index*	*PFP Index*	
				Opex	*Capital*
2006	1.000	1.000	1.000	1.000	1.000
2007	0.992	1.037	0.956	0.961	0.953
2008	1.050	1.107	0.949	0.942	0.956
2009	1.052	1.182	0.890	0.992	0.850
2010	1.126	1.241	0.907	1.026	0.862
2011	1.128	1.249	0.903	1.074	0.844
2012	1.140	1.288	0.885	1.056	0.828
2013	1.168	1.335	0.875	1.073	0.809
2014	1.164	1.380	0.844	1.018	0.783
2015	1.193	1.449	0.823	0.915	0.788
2016	1.207	1.470	0.821	0.915	0.785
2017	1.194	1.479	0.807	0.888	0.776
2018	1.196	1.388	0.862	1.096	0.784
2019	1.225	1.414	0.867	1.083	0.794
2020	1.217	1.396	0.872	1.085	0.799
Growth Rate 2006-2020	1.4%	2.4%	-1.0%	0.6%	-1.6%
Growth Rate 2006-2012	2.2%	4.2%	-2.0%	0.9%	-3.2%
Growth Rate 2012-2020	0.8%	1.0%	-0.2%	0.3%	-0.4%
Growth Rate 2020	-0.6%	-1.3%	0.6%	0.2%	0.7%

Over the 15-year period 2006 to 2020, PLK's TFP decreased at an average annual rate of change of –1.0 per cent. Its total output increased over the period with an average annual rate of change of 1.4 per cent. This was considerably higher than the industry average annual growth in output of 0.6 per cent. However, PLK's average annual rate of increase in input use of 2.4 per cent was above the rate of increase in total input use for the industry of 1.5 per cent. The net effect of these two differences is that PLK had a similar rate of decline in TFP than the industry average, which was –0.9 per cent per year for the 2006 to 2020 period.

For the period 2006 to 2012, PLK's rate of average annual growth in TFP was –2.0 per cent; whereas in the period from 2012 to 2020, its average annual growth in TFP was –0.2 per cent. The partial productivity indexes in table 4.7 show that in the period 2006 to 2012, the rate of capital PFP growth averaged –3.2 per cent per annum, while in the period from 2012 to 2020, the average growth of capital PFP was –0.4 per cent per annum. This stabilisation of capital PFP strongly influenced the TFP trend, but was partly offset by the reduced average annual opex PFP rate of growth, from 0.9 per cent in the period up to 2012 to 0.3 per cent in the period after 2012.

4.3.2 PLK's output and input quantity changes

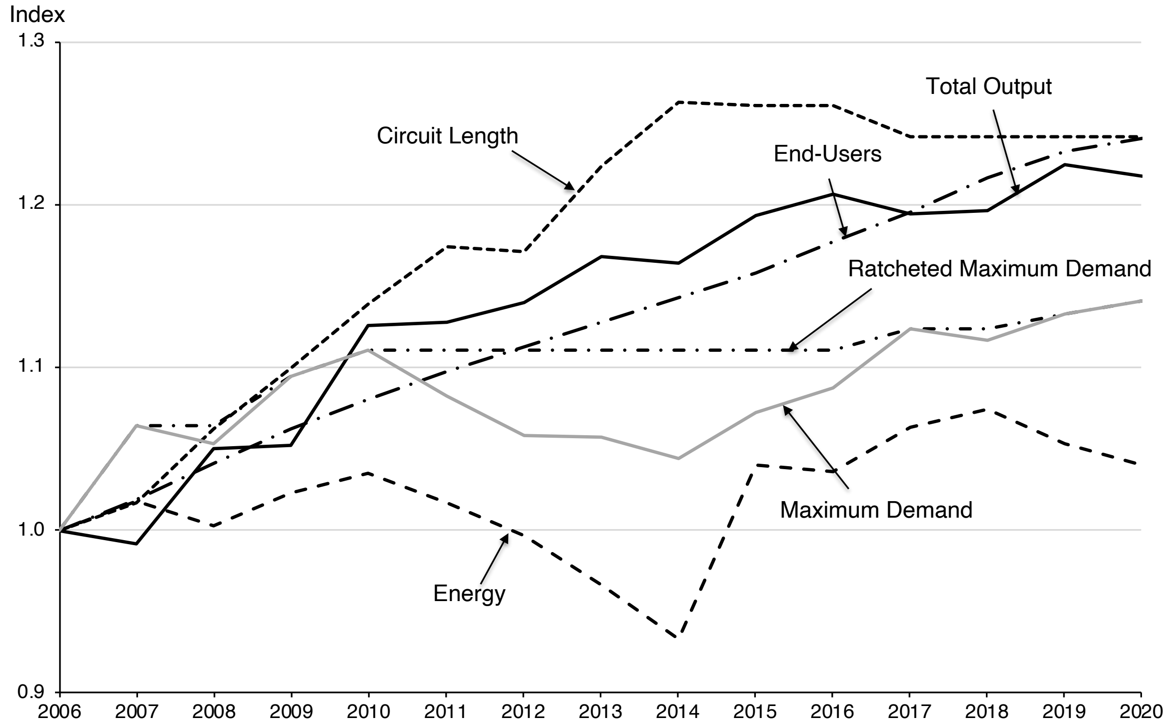
Quantity indexes for PLK's individual outputs are presented in figure 4.10 and for individual inputs in figure 4.11. The quantities are converted to index format with a value of one in 2006 for ease of comparison. Growth rates for PLK's individual outputs and inputs, and of PFPs defined in terms of individual inputs, are shown in appendix B.

From figure 4.10 we see that circuit length (the output component that receives the largest weight in forming the TFP index), increased relatively steadily through to 2014 before levelling off. In 2020, PLK's circuit length was 24.2 per cent higher than it was in 2006. This is a much larger increase than for the transmission industry as whole where circuit length was 8.0 per cent higher in 2020 than it was in 2006. PLK's ratcheted maximum demand (RMD) output initially showed a similar pattern to the industry as a whole in that it increased to about 11 per cent above the 2006 level by 2010, and was largely unchanged in following years, except in PLK's case there was further growth in recent years. Figure 4.10 shows how maximum demand and energy demand increased after 2014. In 2020, PLK's RMD was 14.1 per cent above its 2006 level (compared to 12.3 per cent for the industry).

PLK's energy throughput decreased from 2010 to 2014 but it recovered strongly. By 2020 PLK's energy throughput was 4.0 per cent above its 2006 level, compared to the industry's energy throughput then being 4.7 per cent below its level in 2006. The end-user numbers output increased over the period by a percentage approximately equal to circuit length, with an increase of 24.1 per cent between 2006 and 2020, and slightly higher than the increase in end-users of 20.8 per cent for the industry. PLK's end-user numbers have increased steadily over the period reflecting Queensland's strong rate of population growth.

The output not shown in figure 4.10 is ENS. PLK's ENS spiked upwards sharply in 2007 and 2009 to 6 times and 5 times, respectively, its 2006 level. However, since then PLK's ENS levels have tended to reduce and the peaks in the output series in figure 4.10 in 2013, 2015, 2016 and 2019 correspond to large reductions in ENS in those years. Figure 4.9 shows that the underlying output trend was smoother. As previously noted, in 2019 PLK's ENS was zero. Overall, PLK's decreasing ENS has had a positive impact on its total output over the period. Since the circuit length, end-user numbers and energy throughput outputs receive a combined weight of around 76.4 per cent of total revenue in forming the total output index, the trend of the total output index is also strongly influenced by these series.

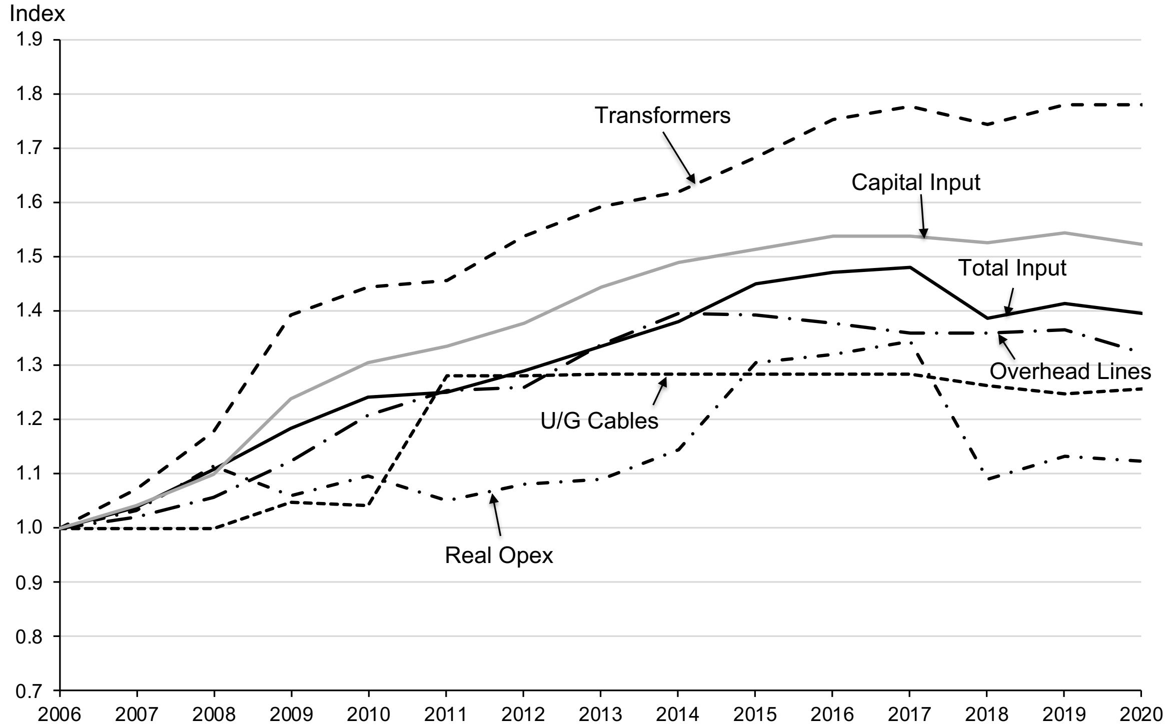
Figure 4.10 **PLK's output quantity indexes, 2006–2020**



Turning to the input side, the quantity indexes for PLK's four inputs and the total input index are shown in figure 4.11. As with its higher increase in circuit length output, PLK's input quantity for overhead lines increased more than that for the industry (2.0 per cent per year on average compared to 1.2 per cent), but its underground cables input quantity increased less than that for the industry (1.6 per cent per year compared to 3.9 per cent). PLK's overhead lines input increased by 32.2 per cent and its underground cables input quantity increased by 25.5 per cent between 2006 and 2020. This compares to corresponding respective increases for the industry of 17.9 per and 72.9 per cent over the same period.

PLK's real opex usage increased only modestly through to 2013 but increased substantially between 2015 and 2017 before returning to its previous trend in 2018 to 2020. The opex input index increased less than PLK's other three inputs over the 15-year period, and was 12.2 per cent higher in 2020 than it was in 2006. This can be compared to the decrease for the industry of 2.5 per cent over the same period. Opex has an average share in PLK's total costs at 27.1 per cent (see appendix A). The input component with the largest average share of total cost, at 36.9 per cent, is transformers. PLK's quantity of transformers increased steadily over the period and by 2020 was 77.9 per cent above its 2006 level – a much larger increase than the industry's 48.2 per cent.

Figure 4.11 **PLK's input quantity indexes, 2006–2020**



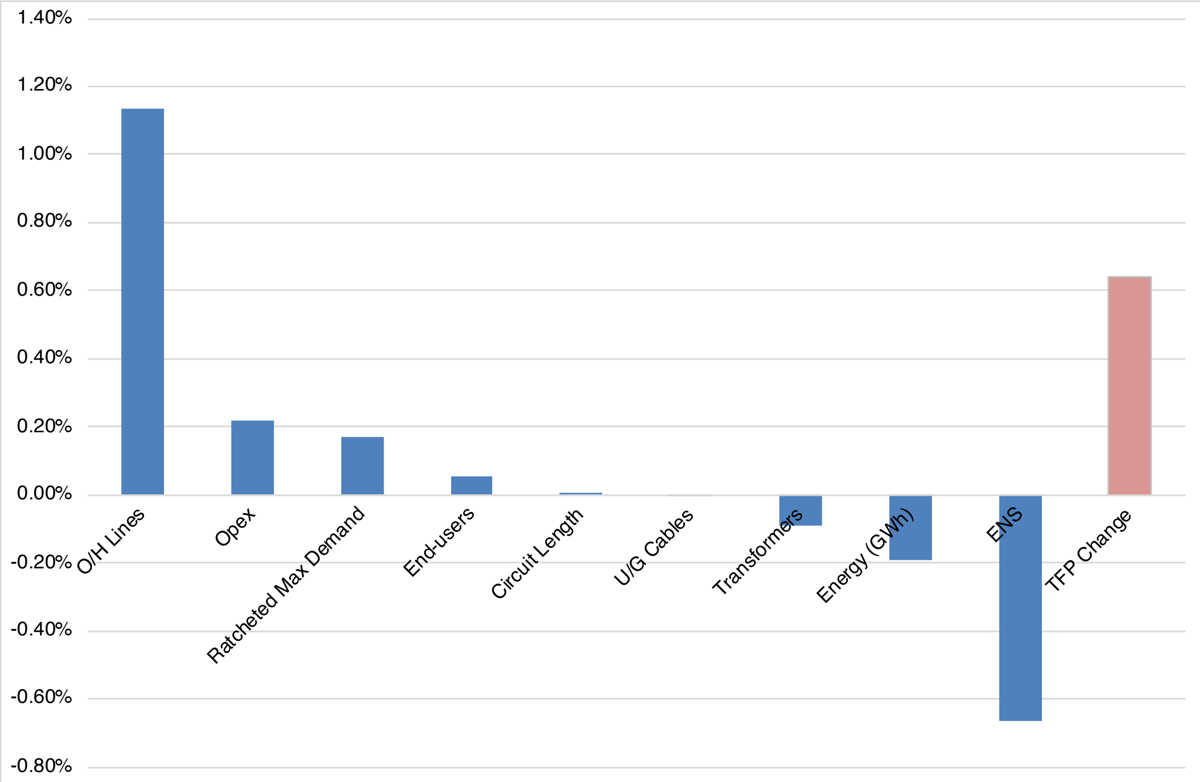
4.3.3 PLK's output and input contributions to TFP change

Table 4.6 shows the decomposition of PLK's average rates of TFP change into the contributions of the individual outputs and inputs for the whole 15-year period and for the periods up to and after 2012, and for 2020. Figure 4.12 shows the contributions of outputs and inputs to PLK's average rate of TFP change in 2020.

Table 4.6 **PLK output and input percentage point contributions to average annual TFP change: 2006–2020, 2006– 2012, 2012–2020 and 2020**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Energy (GWh)	0.04%	-0.01%	0.08%	-0.19%
Ratcheted Max Demand	0.23%	0.44%	0.08%	0.17%
End-user Numbers	0.12%	0.14%	0.10%	0.05%
Circuit Length	0.82%	1.41%	0.39%	0.01%
ENS	0.19%	0.21%	0.17%	-0.66%
Opex	-0.24%	-0.41%	-0.11%	0.22%
O/H Lines	-0.74%	-1.47%	-0.20%	1.14%
U/G Cables	-0.01%	-0.03%	0.00%	0.00%
Transformers	-1.39%	-2.31%	-0.70%	-0.09%
TFP Change	-0.98%	-2.04%	-0.18%	0.64%

Figure 4.12 **PLK's output and input percentage point contributions to average annual TFP change, 2020**



4.4 TasNetworks Transmission

In 2020 TasNetworks Transmission (TNT) transported 12,413 GWh of electricity over 3,351 circuit kilometres of lines and cables. It forms a critical part of Tasmania's energy supply chain serving 293,949 end-users. TNT is the smallest TNSP in the NEM in terms of energy throughput, circuit length and the number of end-users.

4.4.1 TNT's productivity performance

TNT's total output, total input and TFP indexes are presented in figure 4.13 and table 4.7. Opex and capital partial productivity indexes are also presented in table 4.7. Over the 15-year period 2006 to 2020, TNT's TFP increased at an average annual rate of 0.1 per cent. This outcome was the combined effect of its total output having increased by an average annual rate of 0.2 per cent while its total input use had zero net growth over the same period. This differs from the situation for the transmission industry as a whole where input use increased faster (1.5 per cent per annum on average from 2006 to 2020) and output also increased faster (0.6 per cent per annum), resulting in a decline in TFP (–0.9 per cent per annum).

Figure 4.13 **TNT's output, input and TFP indexes, 2006–2020**

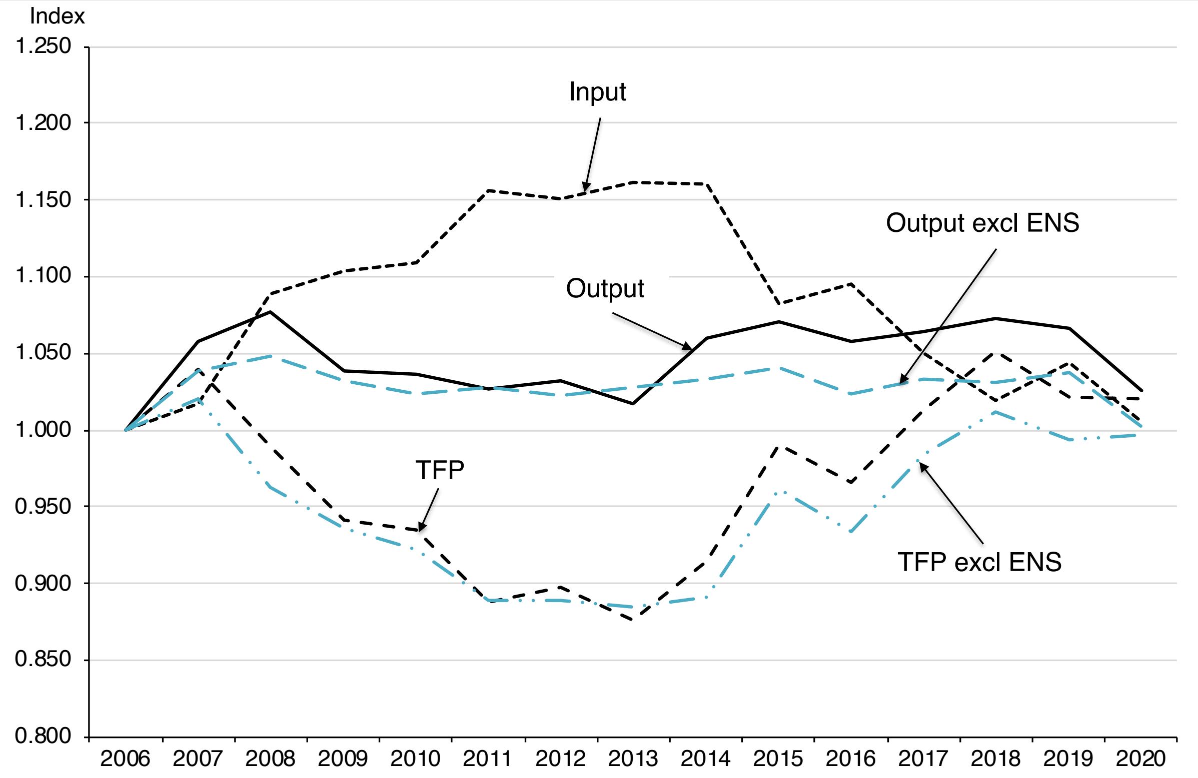


Table 4.7 **TNT's output, input, TFP and PFP indexes, 2006–2020**

Year	*Output Index*	*Input Index*	*TFP Index*	*PFP Index Opex*	*PFP Index Capital*
2006	1.000	1.000	1.000	1.000	1.000
2007	1.058	1.017	1.040	1.041	1.047
2008	1.077	1.089	0.990	0.896	1.044
2009	1.039	1.104	0.941	0.895	0.974
2010	1.037	1.109	0.934	0.896	0.951
2011	1.026	1.156	0.888	0.945	0.860
2012	1.032	1.150	0.898	0.975	0.856
2013	1.018	1.162	0.876	1.038	0.811
2014	1.060	1.160	0.914	1.097	0.843
2015	1.071	1.082	0.990	1.491	0.845
2016	1.058	1.095	0.966	1.385	0.834
2017	1.064	1.051	1.013	1.667	0.841
2018	1.072	1.019	1.052	1.898	0.847
2019	1.066	1.044	1.022	1.802	0.827
2020	1.026	1.006	1.020	2.024	0.793
Growth Rate 2006-2020	0.2%	0.0%	0.1%	5.0%	-1.7%
Growth Rate 2006-2012	0.5%	2.3%	-1.8%	-0.4%	-2.6%
Growth Rate 2012-2020	-0.1%	-1.7%	1.6%	9.1%	-1.0%
Growth Rate 2020	-3.8%	-3.7%	-0.1%	11.7%	-4.2%

TNT's average output growth over the period 2006 to 2012 of 0.5 per cent per year compares to the average rate of change in the period 2012 to 2020 of –0.1 per cent. Input usage and TFP also had different trends in these two sub-periods. The input index increased in the period from 2006 to 2012 at an average rate of 2.3 per cent, whereas in the period from 2012 to 2020 the average annual rate of change was –1.7 per cent. Conversely, the TFP index average rate of from 2006 to 2012 was –1.8 per cent, and increased at an average rate of 1.6 per cent from 2012 to 2020.

The partial productivity indexes in table 4.7 show a substantial improvement in opex PFP in the latter half of the period, from an average change of –0.4 per cent per annum before 2012 to 9.1 per cent per annum after 2012. There was also a small improvement in capital PFP from a rate of change of –2.6 per cent up to 2012, to a rate of –1.0 per cent after 2012. These were important reasons for the improvement in TFP performance in the period from 2012 to 2020.

4.4.2 TNT's output and input quantity changes

Quantity indexes for TNT's individual outputs are presented in figure 4.14 and for individual inputs in figure 4.15. Growth rates of individual outputs and individual inputs, and of partial productivities defined in terms of individual inputs, are presented in appendix B.

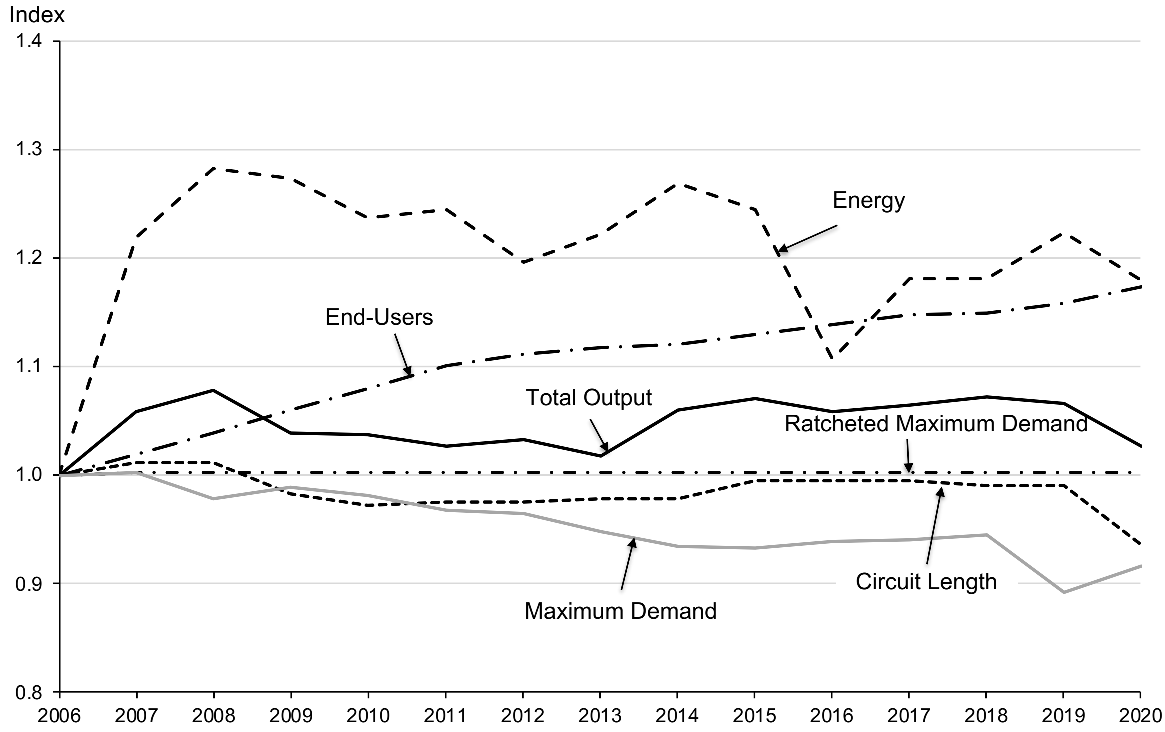
From figure 4.14 we see that circuit length (the output that receives the largest weight in the output index) has fluctuated somewhat but remained largely unchanged except for a large decrease in 2020 by –5.6 per cent. This contrasts with the transmission industry as a whole where circuit length was 8.0 per cent higher in 2020 than it was in 2006. TNT's RMD has essentially remained constant over the whole of the 15-year period. This contrasts with the industry, where the 2020 RMD was 12.3 per cent above its 2006 level.

The outputs that had the largest increases over the period for TNT were energy throughput and end-user numbers, at average annual rates of 1.2 per cent and 1.1 per cent, respectively. TNT's energy throughput has had a very different pattern to that for the industry as a whole. It increased by 28.2 per cent between 2006 and 2008 before trending downward somewhat over the remainder of the period to 2020. In 2020 energy throughput for TNT was 17.9 per cent above its 2006 level, whereas for the transmission industry it was 4.7 per cent lower than it was in 2006. TNT's energy throughput is particularly affected by exports to the mainland and demand from large industrial users.

TNT's end-user numbers increased by 17.3 per cent between 2006 and 2020, a little less than that for the industry (20.8 per cent). Again, this steady increase is to be expected as the number of electricity end-users will increase roughly in line with population growth.

The output not shown in figure 4.14 is ENS. TNT's ENS has been relatively volatile but within a much smaller range than most other TNSPs. ENS fell from 2006 through to 2009 before trending up to be approximately 60 per cent above its 2006 level in 2013. Since then it has reduced in most years and was 34.3 per cent of its 2006 level in 2020.

Figure 4.14 **TNT's output quantity indexes, 2006–2020**



Turning to the input side, figure 4.15 presents quantity indexes for TNT's four inputs and for its total input index, and the combined capital input index. TNT's input usage trends are similar to those for the industry, except that opex input decreases much more for TNT over the period and transformer and overhead lines inputs grow less for TNT than for the industry.

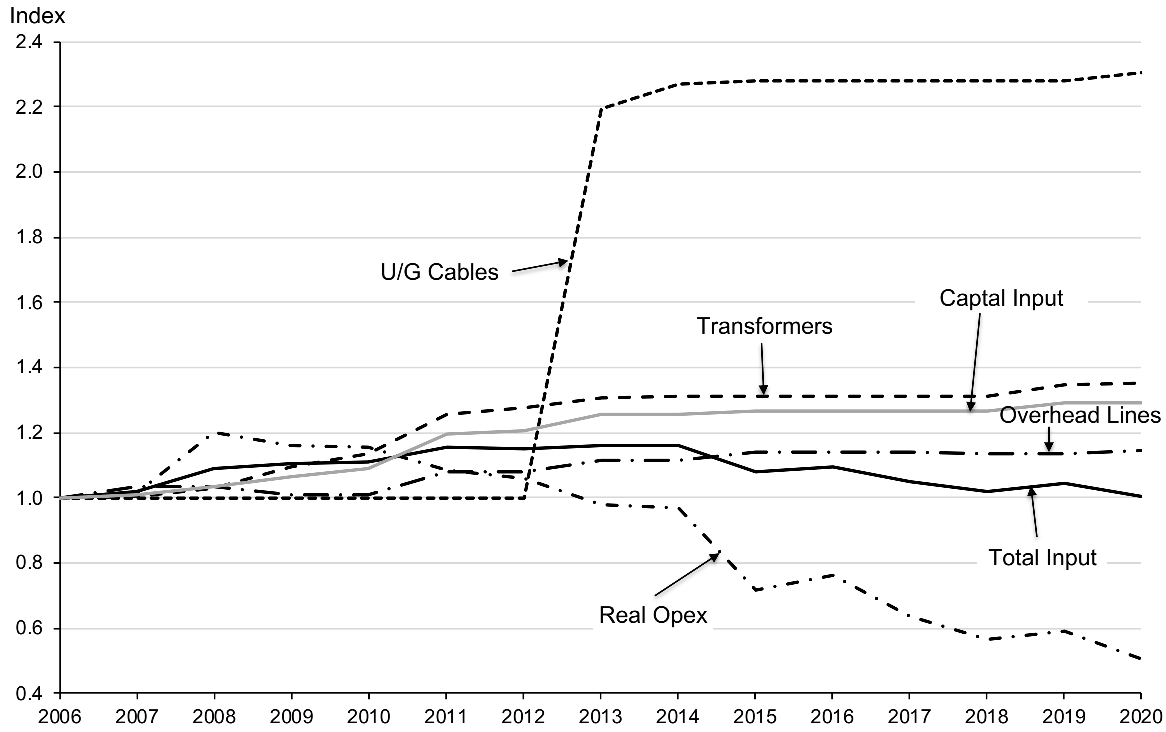
The quantity of TNT's opex input had a large decrease between 2006 and 2020, so that the 2020 level was 49.3 per cent lower than the 2006 level. This contrasts with the industry's decrease in opex usage of only 2.5 per cent over the same period. Opex has the second largest average share in TNT's total costs at 28.0 per cent.

Despite TNT's relatively steady circuit length output (excepting 2020), TNT's input quantity for overhead lines has increased reflecting the use of higher capacity lines. Underground cables input more than doubled in 2013 but the length of underground cables goes from only 13 kilometres to 23 kilometres with the new cables being of considerably higher capacity.

The input component with the largest average share of TNT's total cost, at 48.0 per cent, is transformers. TNT's quantity of transformers increased steadily to 2012 at an average annual rate of 4.1 per cent. It then largely levelled off, increasing at an average annual rate of 0.7 per cent per year between 2012 and 2020. By 2020 the quantity of transformers was 35.2 per cent above its 2006 level – a smaller increase than the industry's 48.2 per cent. Given its large share of total costs, transformer inputs are an important driver of the total input quantity index.

From figure 4.15 we see that TNT's total input quantity index generally lies close to the quantity indexes for transformers and overhead lines (which have a combined weight of 70.6 per cent of TNT's total costs), and fluctuations in the total inputs index are mainly driven by variations in opex use.

Figure 4.15 **TNT's input quantity indexes, 2006–2020**



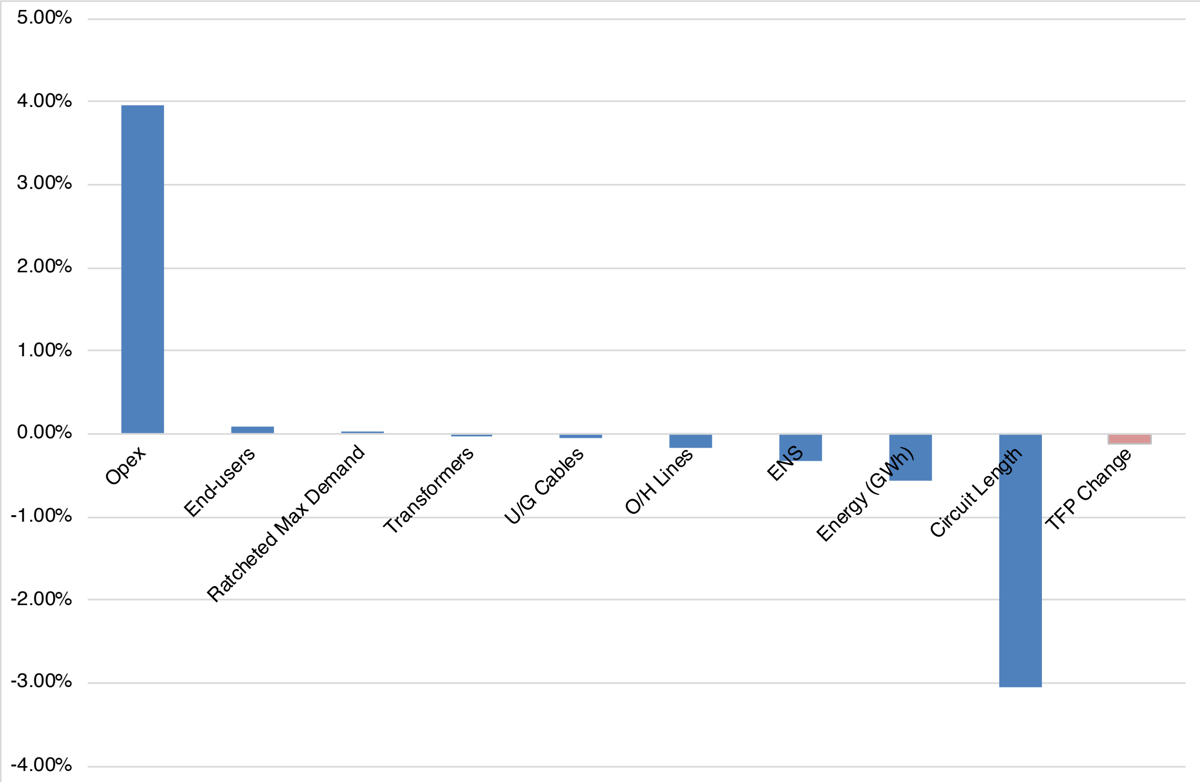
4.4.3 TNT's output and input contributions to TFP change

Table 4.8 shows the decomposition of TNT's average rates of TFP change into the contributions of the individual outputs and inputs for the whole 15-year period and for the periods up to and after 2012, and for 2020. Figure 4.16 shows the contributions of outputs and inputs to TNT's average rate of TFP change in 2020.

Table 4.8 **TNT output and input percentage point contributions to average annual TFP change: 2006–2020, 2006– 2012, 2012–2020 and 2020**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Energy (GWh)	0.18%	0.45%	-0.03%	-0.57%
Ratcheted Max Demand	0.00%	0.01%	0.00%	0.00%
End-user Numbers	0.09%	0.14%	0.05%	0.09%
Circuit Length	-0.26%	-0.22%	-0.28%	-3.05%
ENS	0.17%	0.16%	0.18%	-0.32%
Opex	1.27%	-0.15%	2.34%	3.96%
O/H Lines	-0.22%	-0.28%	-0.17%	-0.17%
U/G Cables	-0.08%	0.00%	-0.13%	-0.05%
Transformers	-1.02%	-1.90%	-0.36%	-0.03%
TFP Change	0.14%	-1.80%	1.60%	-0.13%

Figure 4.16 **TNT's output and input percentage point contributions to average annual TFP change, 2020**



4.5 TransGrid

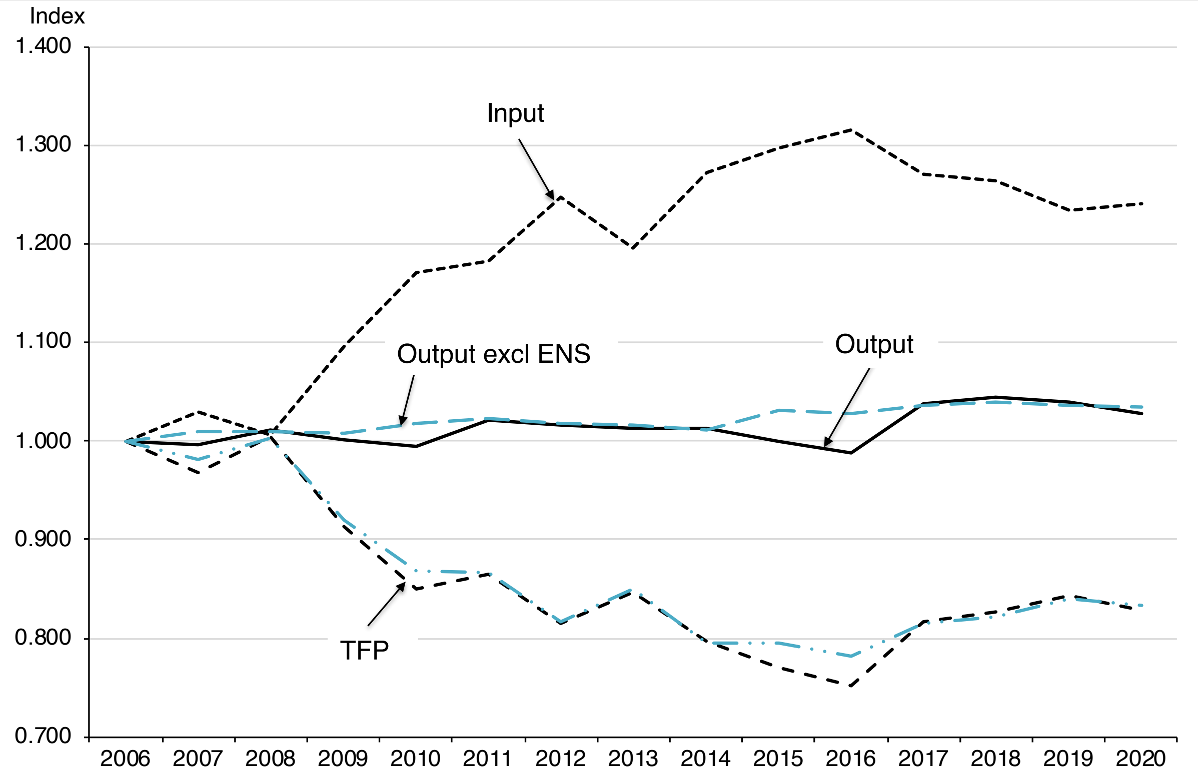
In 2020 TransGrid (TRG) transported 72,900 GWh of electricity over 13,052 circuit kilometres of lines and cables. It forms a critical part of New South Wales' energy supply chain serving around 3.9 million end-users. TRG is the largest of the five TNSPs in the NEM in terms of energy throughput and the number of end-users and the second largest in terms of circuit length.

4.5.1 TRG's productivity performance

TRG's total output, total input and TFP indexes are presented in figure 4.17 and table 4.9. Opex and capital partial productivity indexes are also presented in table 4.9.

Over the 15-year period 2006 to 2020, TRG's TFP decreased at an average annual rate of change of –1.3 per cent. Its total output increased over the period with an average annual rate of change of 0.2 per cent. This compares to an industry growth in output of 0.6 per cent per annum on average. TRG's average annual rate of increase in input use of 1.5 per cent was the same as that for the industry. The net effect of the output and input movements—TRG's annual rate of change in TFP of –1.3 per cent—was a more pronounced decline than the industry's average annual TFP change of –0.9 per cent over the 2006 to 2020 period.

Figure 4.17 **TRG's output, input and TFP indexes, 2006–2020**



Over the period from 2006 to 2012, the average growth rate of TRG's output was 0.3 per cent per annum. Over the same period the average annual growth rate of inputs was 3.7 per cent. The net effect was a decline of TFP, averaging –3.4 per cent per year in this sub-period. For the period after 2012, the rate of average annual growth in output was even smaller (0.1 per cent per year) while the average annual change in input use reduced marginally (–0.1 per cent per year). The net effect was a small TFP increase averaging 0.2 per cent per annum. During this sub-period, TFP fell significantly from 2012 to 2016. In 2017, TRG had very strong TFP growth of 8.3 per cent, mainly as the result of an increase in output associated with reduced outages following unusually high levels of outages in 2015 and, in particular, 2016. Input use was also reduced in 2017 and 2018 and again in 2019. This led to the stabilisation and partial recovery of TRG's TFP over the period from 2012 to 2020, taken as a whole.

The partial productivity indexes in table 4.9 show that the improvement in average annual rates of change of TFP after 2012 was associated with both:

(i) an improvement in the trend of capital PFP; and

(ii) stronger growth in the opex PFP index.

The average rate of change in opex PFP between 2006 and 2012 was 0.2 per cent per annum, and this increased between 2012 and 2020 to an average of 1.8 per cent. On the other hand, the rate of change per annum in capital PFP between 2006 and 2012 was –4.8 per cent, but this improved to an average rate of –0.4 per cent from 2012 to 2020.

Table 4.9 **TRG's output, input, TFP and PFP indexes, 2006–2020**

Year	*Output Index*	*Input Index*	*TFP Index*	*PFP Index*	
				Opex	*Capital*
2006	1.000	1.000	1.000	1.000	1.000
2007	0.996	1.029	0.968	1.022	0.944
2008	1.011	1.006	1.005	1.110	0.966
2009	1.001	1.096	0.913	1.104	0.845
2010	0.995	1.171	0.850	0.978	0.800
2011	1.022	1.182	0.865	1.084	0.790
2012	1.017	1.247	0.815	1.009	0.748
2013	1.013	1.195	0.847	1.107	0.763
2014	1.013	1.272	0.797	0.928	0.748
2015	0.999	1.297	0.770	0.978	0.701
2016	0.988	1.315	0.752	0.978	0.678
2017	1.038	1.270	0.817	1.042	0.742
2018	1.045	1.264	0.826	1.189	0.720
2019	1.040	1.234	0.843	1.207	0.736
2020	1.028	1.240	0.829	1.166	0.727
Growth Rate 2006-2020	0.2%	1.5%	-1.3%	1.1%	-2.3%
Growth Rate 2006-2012	0.3%	3.7%	-3.4%	0.2%	-4.8%
Growth Rate 2012-2020	0.1%	-0.1%	0.2%	1.8%	-0.4%
Growth Rate 2020	-1.1%	0.5%	-1.6%	-3.4%	-1.2%

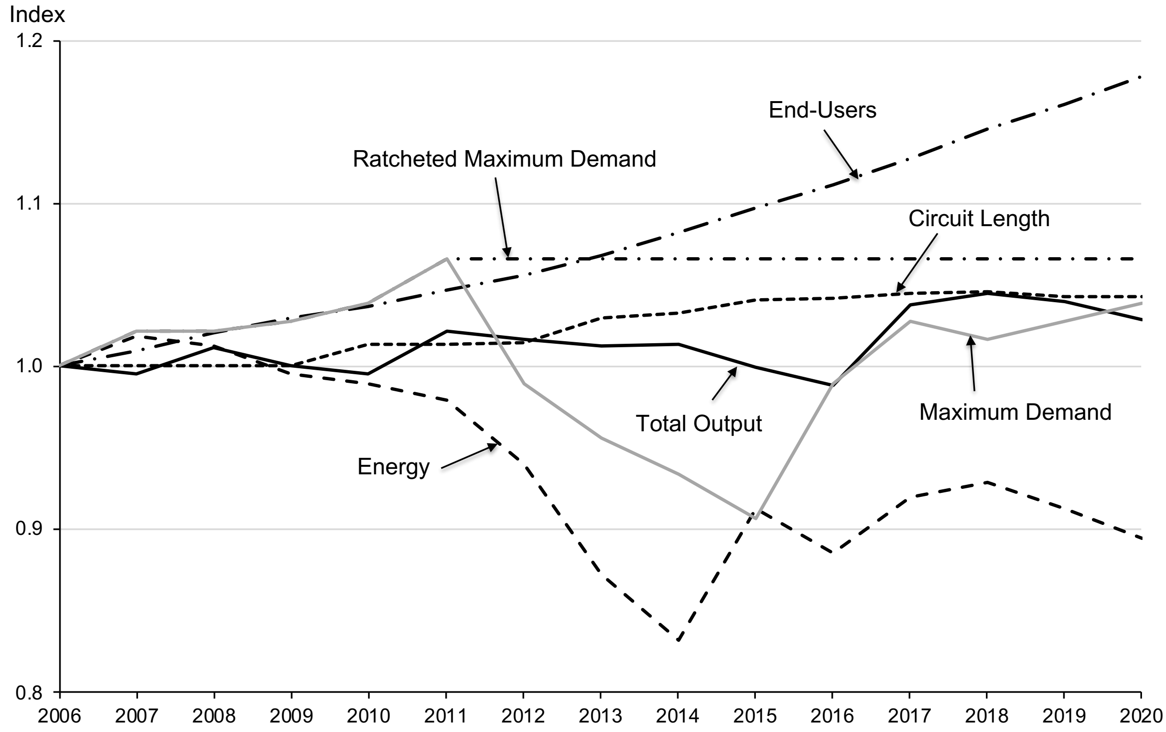
4.5.2 TRG's output and input quantity changes

Quantity indexes for TRG's individual outputs are presented in figure 4.18 and for individual inputs in figure 4.19 (where the index base is 1.0 in 2006). From figure 4.18 we see that circuit length (the output component that receives the largest weight in forming the TFP index), has increased gradually over the 15-year period. By 2020 TRG's circuit length was only 4.3 per cent above its 2006 level. This compares to the transmission industry's corresponding increase in circuit length of 8.0 per cent.

TRG's RMD showed a broadly similar pattern to the industry as a whole. TRG's RMD increased through to 2011 but then remained constant thereafter at 6.6 per cent above the 2006 level (a smaller increase than that for the industry). Figure 4.18 also shows the maximum demand, which declined from 2011 to 2015, and subsequently increased, but did not reach its 2011 level.

TRG's energy throughput decreased*,* with an average rate of –0.8 per cent per year from 2006 to 2020. This trend was reasonably consistent over the whole period, being only a slightly stronger rate of decline in the period up to 2012 than in the period after 2012. Between 2006 and 2012, the annual rate of change of TRG's energy throughput was –1.0 per cent, and from 2012 to 2020 it was –0.6 per cent per year. In 2020, TRG's energy throughput was 10.6 per cent below its 2006 level compared to the industry's throughput then being 4.7 per cent lower than it was in 2006.

Figure 4.18 **TRG's output quantity indexes, 2006–2020**



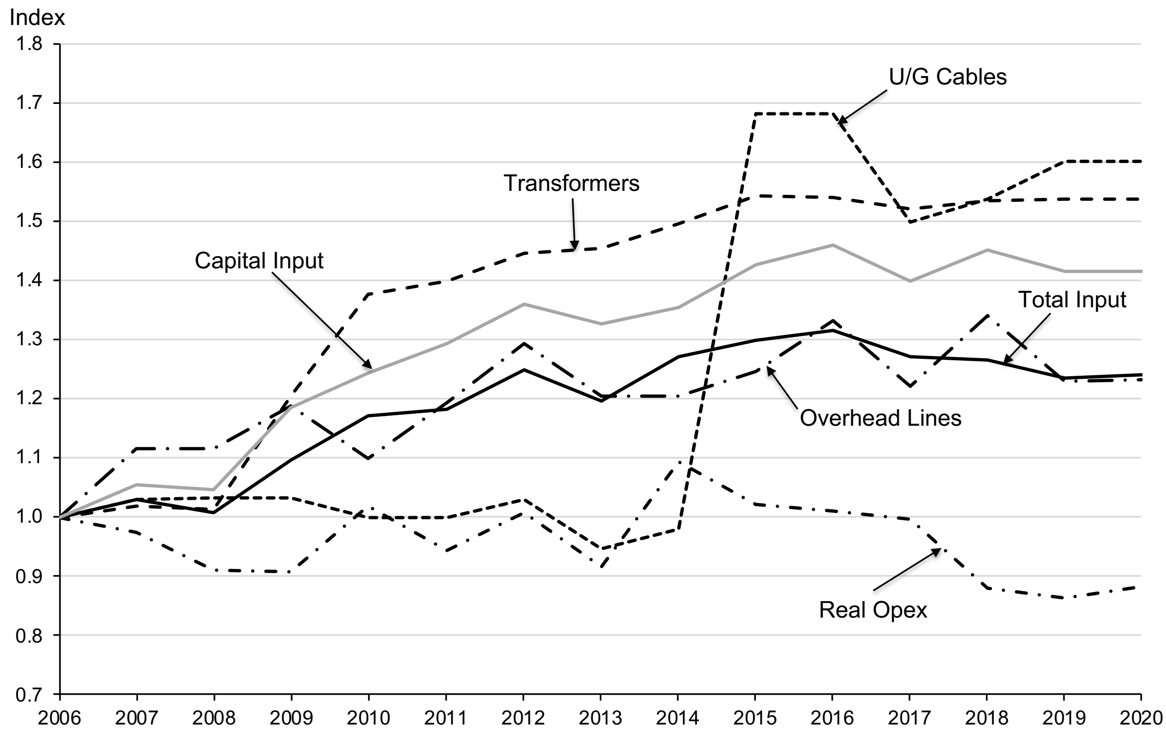
The output that increased the most over the period for TRG is end-user numbers with an increase of 17.8 per cent between 2006 and 2020, only slightly less than the increase of 20.8 per cent for the industry. TRG's end-user numbers increase has been reasonably steady over the whole period, in line with NSW's population growth.

The output not shown in figure 4.18 is ENS. TRG's ENS fluctuated around its 2006 level through to 2014, with the main exception being that in 2010 it spiked to be four times its 2006 level. TPG's ENS increased sharply in both 2015 and 2016. In 2015 it was 6 times and in 2016 it was 10 times its 2006 level after having been less than its 2006 level in 2014. In 2017, ENS returned to 18.0 per cent below its 2006 level and in 2018 and 2019 to 51.7 and 40.9 per cent, respectively, below the 2006 level. However, in 2020, it was 76.1 per cent above the 2006 level.

TRG's total output index tends to lie close to the circuit length, with the main exceptions being in 2015 and 2016, the years that ENS had its largest spikes. In these two years output decreased significantly, reflecting the impact of the ENS outcomes. This can be seen clearly in figure 4.17, which also shows the output index when ENS is excluded. Total output has been relatively flat since 2017, although it decreased by 1.1 per cent in 2020.

Turning to the input side, figure 4.19 presents quantity indexes for TRG's four inputs and for the total input index. We see that TRG's input quantity for overhead lines increased steadily in the first half of the period before levelling off somewhat. This input has tended to fluctuate depending on whether TRG has measured capacity at the time of summer, spring or winter peak, whichever is higher in the relevant year. Between 2006 and 2012, overhead lines increased at an average annual rate of 4.3 per cent. From 2012 to 2020, TRG's overhead lines decreased at an annual average rate of –0.6 per cent.

Figure 4.19 **TRG's input quantity indexes, 2006–2020**



TRG's underground cables input quantity increased by 54.1 per cent in 2015 although the length of underground cables increased from only 47 to 78 kilometres in that year. This input has a very small share of total costs.

The quantity of opex was the only one of TRG's four inputs to decrease over the 15-year period, being 11.8 per cent lower in 2020 than it was in 2006 (compared to a reduction for the industry of only 2.5 per cent). Over the period from 2006 to 2020, opex usage averaged an annual rate of change of –0.9 per cent. Between 2006 and 2012 there was a small 0.1 per cent annual average rate of increase, but from 2012 to 2020 the annual average rate of change was –1.7 per cent. In 2020 opex usage increased by 2.3 per cent. Opex has the second largest average share in TRG's total costs at 26.4 per cent (see appendix A).

The input component with the largest average share of TRG's total cost, at 44.5 per cent, is transformers. TRG's transformer input quantity increased more quickly in the first half of the period and more slowly thereafter. In the period from 2006 to 2012, TRG's transformer inputs increased at an average rate of 6.1 per cent per annum. From 2012 to 2020, transformer inputs increased at a rate of 0.8 per cent. By 2020, TRG's transformer input was 53.7 per cent above its 2006 level—a slightly larger increase than the industry's 48.2 per cent increase. Given its large share of total costs, transformer inputs are an important driver of the total input quantity index.

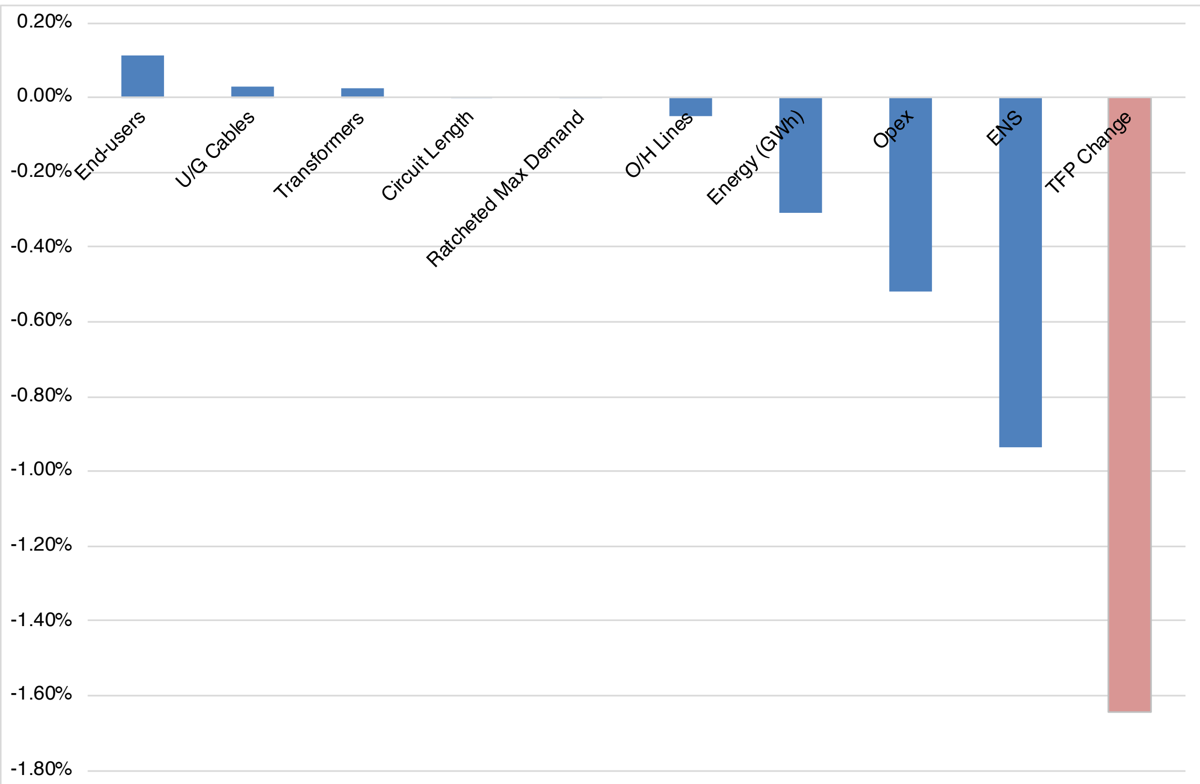
4.5.3 TRG's output and input contributions to TFP change

Table 4.10 shows the decomposition of TRG's average rates of TFP change into the contributions of the individual outputs and inputs for the whole 15-year period and for the periods up to and after 2012, and for 2020. Figure 4.20 shows the contributions of outputs and inputs to TRG's average rate of TFP change in 2020.

Table 4.10 **TRG output and input percentage point contributions to average annual TFP change: 2006–2020, 2006– 2012, 2012–2020 and 2020**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Energy (GWh)	-0.12%	-0.16%	-0.09%	-0.31%
Ratcheted Max Demand	0.11%	0.27%	0.00%	0.00%
End-user Numbers	0.09%	0.07%	0.10%	0.11%
Circuit Length	0.16%	0.13%	0.18%	0.00%
ENS	-0.04%	-0.03%	-0.05%	-0.94%
Opex	0.24%	0.00%	0.43%	-0.52%
O/H Lines	-0.41%	-1.19%	0.17%	-0.05%
U/G Cables	-0.11%	-0.03%	-0.17%	0.03%
Transformers	-1.26%	-2.46%	-0.36%	0.02%
TFP Change	-1.34%	-3.40%	0.21%	-1.64%

Figure 4.20 **TRG's output and input percentage point contributions to average annual TFP change, 2020**



APPENDIX A: METHODS

A1 Indexing Methods

Productivity refers to the quantitative relationship between the outputs produced (by a firm, industry or economy) and the inputs used to produce those outputs. This report concerns the outputs produced and inputs used by electricity transmission businesses, and the relationship of outputs to inputs is measured using an index of outputs produced and an index of inputs used. 'Total factor productivity' (TFP) refers to the ratio of an index of all outputs produced by a business to an index of all inputs consumed in producing those outputs. 'Partial factor productivity' (PFP) refers to a ratio of a measure of all or some outputs to a measure of a single input. This report measures TFP using the multilateral Törnqvist TFP (MTFP) index method developed by Caves, Christensen and Diewert (1982).

A1.1 Multilateral Törnqvist TFP index

The method for calculating time series TFP rates of change for individual TNSPs is the same method as that used for calculating the comparative levels of TFP between TNSPs, namely the multilateral Törnqvist TFP index (MTFP) of Caves, Christensen and Diewert (1982):

$$\begin{aligned} \ln (TFP_m/TFP_n) = \; & \Sigma_i (R_{im}+R_i^*) (\ln Y_{im} - \ln Y_i^*)/2 - \\ & \Sigma_i (R_{in}+R_i^*) (\ln Y_{in} - \ln Y_i^*)/2 - \\ & \Sigma_j (S_{jm}+S_j^*) (\ln X_{jm} - \ln X_j^*)/2 + \\ & \Sigma_j (S_{jn}+S_j^*) (\ln X_{jn} - \ln X_j^*)/2 \end{aligned} \qquad (1)$$

where m and n are two adjacent observations;[13] i denotes individual outputs; j denotes individual inputs; and

- R_{im} is the revenue share of the ith output at observation m;
- S_{jm} is the cost share of the jth input at observation m;
- R_i^* is the revenue share of the ith output averaged over the whole sample;[14]
- S_j^* is the cost share of the jth input averaged over the whole sample;

[13] A sequence of observations will be ordered by firm and by time-period. When the sample includes more than one firm, m might represent the period after n for the same firm, or n might represent the last observation for one firm and m would then represent the first observation of the next firm. If there is only one firm in the sample, the m is the period after n.

[14] If there is more than one firm in the sample, it is the average over all firms and all periods. If there is only one firm in the sample, it is the average over all periods.

- Y_{im} is the quantity of the ith output at observation m;
- X_{jm} is the quantity of the jth input at observation m;
- Y_i^* is the average quantity of the ith output over the whole sample;
- X_j^* is the average quantity of the jth input over the whole sample.

To derive the TFP index, an arbitrarily chosen observation is set equal to 1.0. Here the first observation in the sample is used, and the rates of change for every subsequent observation in the sample, calculated using (1), are applied sequentially from this base.

The MTFP allows comparisons of the absolute levels as well as growth rates of productivity. It satisfies the technical properties of transitivity and characteristicity which are required to accurately compare TFP levels within panel data. Transitivity states that direct comparisons between observations m and n should be the same as indirect comparisons of m and n via any intermediate observation k. 'Characteristicity' says that when comparing two observations, the index should use sufficient information relating to those two observations. The multilateral Törnqvist index satisfies these properties for the whole sample by making comparisons through the sample mean.

Because the multilateral Törnqvist productivity indexes focus on preserving comparability of productivity levels across NSPs and over time by doing all comparisons through the sample mean, there may sometimes be minor changes in historical results as the sample is updated in each annual benchmarking report and, hence, the sample mean changes over time. This is a necessary trade-off for the MTFP index to satisfy the technical properties of transitivity and characteristicity which allow comparability of productivity levels across NSPs and over time.

A1.2 Output and Input Indexes

The rate of change in TFP is equal to the rate of change in the output index minus the rate of change in the input index. Equation (1) can be separated into these two components. The rate of change in the output index is given by:

$$\ln (Y_m/Y_n) = \Sigma_i (R_{im}+R_i^*) (\ln Y_{im} - \ln Y_i^*)/2 - \Sigma_i (R_{in}+R_i^*) (\ln Y_{in} - \ln Y_i^*)/2 \qquad (2)$$

Similarly, the rate of change in the input index is given by:

$$\ln (X_m/X_n) = \Sigma_j (S_{jm}+S_j^*) (\ln X_{jm} - \ln X_j^*)/2 - \Sigma_j (S_{jn}+S_j^*) (\ln X_{jn} - \ln X_j^*)/2 \qquad (3)$$

Again these are converted into output and input indexes by setting the value for the index at the first observation of the sample as equal to 1.0 and applying the rates of change specified by (2) or (3), as appropriate, sequentially for every subsequent observation in the sample.

A1.3 Partial Factor Productivity Indexes

Analysis of partial factor productivity (PFP) trends, where total output is expressed relative to individual inputs, assists to interpret the sources of TFP trends. A partial factor productivity measure is obtained by dividing the index of all outputs over an index of one input, or over an index of a sub-group of inputs. Also note that for the construction of partial productivity indexes, we may need inputs indexes for individual inputs, or for sub-groups of inputs. For a sub-group of inputs, equation (3) applies, but the summation is only over the inputs in the sub-group, and the cost shares need to be re-scaled to sum to 1 for the sub-group. For an individual input k, the growth rate is given simply by: $\ln(X_{km}/X_{kn})$. Again, the index is obtained by setting the first observation in the data set to 1.0.

A1.4 Growth Rates of Indexes

Growth rates in productivity indexes have generally been reported in earlier Economic Insights reports as logarithmic measures, and this report uses the same method of calculation for growth rates presented in tables. That is, the growth rate of a variable Y between period t – 1 and period t is calculated as: $g_t^Y = \ln Y_t - \ln Y_{t-1}$.[15] The log-difference growth rate can be related to the more common growth rate measure based on the first period as follows: $(Y_t - Y_{t-1})/Y_{t-1} = \exp(g_t^Y) - 1$. That is, the relative index values are: $Y_t/Y_{t-1} = \exp(g_t^Y)$.

Although reported annual growth rates are measured as log-differences, the discussion in this report also refers to total percentage changes over the whole period from 2006 to 2020, and these comparisons are not expressed in terms of log growth rates. Economic Insights (2020a) also included, as supplementary information, trend measures of growth rates based on linear regression.[16] This report also presents regression-based trend estimates for TFP indexes in Appendix C.

A2 Output and input contributions to TFP change

Analysis of contributions to TFP change of the individual outputs and inputs, which involves decomposing TFP change into its constituent parts. Since TFP change is the change in total output quantity less the change in total input quantity, the contribution of an individual output (input) will depend on the change in the output's (input's) quantity and the weight it receives in forming the total output (total input) quantity index. However, this calculation has to be done in a way that is consistent with the index methodology to provide a decomposition that is consistent and robust.

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[15] It follows that some decreases in positively-valued variables can be larger (in absolute terms) than –100 per cent. For example, if $Y_{t-1} = 150$ and $Y_t = 50$, then the rate of change using the log measure is –109.9 per cent. This is because the basis for the rate of change measure is not period t – 1, but at a mid-point between periods t – 1 and t.

[16] For the linear regression model: $\ln Y_t = a + b.t + \varepsilon_t$, the estimated coefficient $\hat{b}$ is a measure of the average growth rate of Y over the sample period.

The analysis of contributions to TFP change is carried out only for individual firm and industry TFP trends. In this case subscripts *n* and *m* in equation (1) refer only to successive periods. To emphasise this, *m* is denoted *t* and *n* is denoted *t*–1.

This analysis involves decomposing TFP change into its constituent parts. Since TFP change is the change in total output quantity less the change in total input quantity, the contribution of an individual output (input) will depend on the change in the output's (input's) quantity and the weight it receives in forming the total output (total input) quantity index. However, this calculation has to be done in a way that is consistent with the index methodology to provide a decomposition that is consistent and robust. The multilateral Törnqvist index methodology allows us to readily decompose productivity change into the contributions of changes in each output and each input. The *percentage point contribution* of output *i* to productivity change between years *t* and *t–1* ($Cont_{i,t}^{Y}$) is given by the following equation:

$$Cont_{i,t}^{Y} = (R_{i,t}+R_i^*)(\ln Y_{i,t} - \ln Y_i^*)/2 - (R_{i,t-1}+R_i^*)(\ln Y_{i,t-1} - \ln Y_i^*)/2 \qquad (4)$$

And, the *percentage point contribution* of input *j* to productivity change between years *t* and *t*–1 ($Cont_{j,t}^{X}$) is given by the following equation:

$$Cont_{j,t}^{X} = -(S_{j,t}+S_j^*)(\ln X_{j,t} - \ln X_j^*)/2 + (S_{j,t-1}+S_j^*)(\ln X_{j,t-1} - \ln X_j^*)/2 \qquad (5)$$

where all variables in equations (4) and (5) have the same definition as those in equation (1). Using these consistent equations ensures the sum of the percentage point contributions of all outputs and all inputs equals the rate of TFP change obtained in equation (1).

A3 Output weights & Leontief Cost Function Estimation

This section explains the method by which output weights are calculated. The value shares applied to outputs are shadow prices based on estimates of the marginal cost of producing each output. For four of the outputs, an econometric cost analysis was used to derive the marginal cost estimates for each output used as the basis for value-share weights. Economic Insights (2020a Appendix B) estimated the costs attributable to each output using the data and method described below. Those estimates are intended to apply for several years and are used in this study.

A3.1 Leontief Cost Function Estimation

The study used multi–output Leontief cost functions to estimate the output cost shares used in the index number methodology, using a similar procedure to that used in Lawrence (2003). This functional form essentially assumes that TNSPs use inputs in fixed proportions for each output and is given by:

$$C(y^k, w^k, t) = \sum_{i=1}^{M} w_i^k \left[\sum_{j=1}^{N} (a_{ij})^2 y_j^k (1+b_i t)\right] \qquad (6)$$

where there are *M* inputs and *N* outputs, w_i is an input price, y_j is an output, *t* is a time trend representing technological change and there are *k* observations. The input/output coefficients

a_{ij} are squared to ensure the non–negativity requirement is satisfied; i.e. increasing the quantity of any output cannot be achieved by reducing an input quantity. This requires the use of non–linear regression methods. To conserve degrees of freedom a common rate of technological change for each input across the four outputs was imposed but this can be either positive or negative.

The estimating equations were the *M* input demand equations:

$$x_i^k = \sum_{j=1}^{N} (a_{ij})^2 y_j^k (1 + b_i t) \tag{7}$$

where the *i*'s represent the *M* inputs, the *j*'s the *N* outputs and *t* is a time trend representing the 13 years, 2006 to 2018. The input demand equations were estimated separately for each of the 5 TNSPs using the non–linear regression facility in Shazam (Northwest Econometrics 2007) and data for the years 2006 to 2018. Given the absence of cross equation restrictions, each input demand equation is estimated separately. We then derive the estimated output cost shares, s_j^k, for each output *j* and each observation *k* from the 5 firm–specific cost functions as follows:

$$s_j^k = \{\sum_{i=1}^{M} w_i^k [(a_{ij}^f)^2 y_j^k (1 + b_i^f t)]\} / \{\sum_{i=1}^{M} w_i^k [\sum_{j=1}^{N} (a_{ij}^f)^2 y_j^k (1 + b_i^f t)]\} \tag{8}$$

where *f*=1,..,5.

We then form a weighted average of the estimated output cost shares across all observations to form an overall estimated output cost share ($\bar{s}_j$) where the weight in the weighted average, g^k, for each observation, *k*, is given by that observation's estimated total cost divided by the overall sum of estimated total costs across all observations:

$$g^k = C_f(b, y^k, w^k, t) / \sum_k C_f(b, y^k, w^k, t) \tag{9}$$

A3.2 Weight of ENS

The fifth output is energy not supplied (ENS), the negative of which is a measure supply reliability. The formal way in which reliability is incorporated into the analysis is to treat ENS as an undesirable output. The method of incorporating undesirable outputs into the multilateral productivity index originates with Pittman (1983), and the method used here is consistent with that approach.

The weight applied to the reliability output is based on the estimated (negative) value of energy not supplied (i.e. the cost imposed on consumers) as measured by the Values of Customer Reliability (VCR) published by the AER (2019a, 2019b). Since direct data are not readily available on the cost of improving TNSP reliability, economic benchmarking has relied on the VCR, which is a measure of how consumers value energy not supplied. The VCR, expressed on a per MWh basis, is multiplied by the quantity of ENS. That is, the cost of ENS is based on: $ENS \times VCR$. The VCR used is that estimated by the AER for 2019 (AER 2019b, p. 71), which is adjusted by CPI in all other years of the data sample.

In theory this measure could be expected to provide a proxy for TNSP costs of improving reliability since in equilibrium reliability would be improved to the point where the marginal cost of further improvement equals the marginal benefit of further improvement. However, unconstrained reliance on the VCR can produce some very large weights for the reliability output where unusual one-off outages occur. As a result, the 2017 review introduced a cap of 5.5 per cent of gross revenue (total revenue plus the value of the reliability output) on the reliability output weight. This cap was derived from statistical analysis of the energy not served (ENS) series. In 2020 this approach was reviewed and revised, to take account of incentives under the regulatory framework, which limits the 'value at risk' to a business under the Service Target Performance Incentive Scheme (STPIS).[17] Having regard to this, the cap on the reliability output weight was reduced to 2.5 per cent of total revenue. This study uses the same cap.

A cap applies to the reliability output weight equal to 2.5 per cent of total revenue. The cap is needed because ENS can be highly volatile off a low base, and because TNSP's potential penalties for poor reliability, and rewards for improved reliability, under the regulatory framework are capped (Economic Insights, 2020).

A3.3 Re-calibration of weights

Weights are then re-calibrated as shares of 'gross revenue', which is defined as the sum of total revenue plus the value of energy not served. Since reliability carries a negative weight in the output index, this ensures that all of the weights sum to unity. This is shown in Table 1.1, using sample average values; weights as shares of total revenue vary across observations in the sample because both revenue and the value of ENS vary.

Table A.1 **Output cost-based weights (industry average*)**

Output	*Shares of gross revenue (%)*	*Shares of revenue (%)*
Energy throughput	14.91[(a)]	15.12
Ratcheted max. demand	24.71[(a)]	25.06
End-user numbers	7.59[(a)]	7.70
Circuit length	52.79[(a)]	53.54
Energy not supplied (minus)	-1.40	-1.43
Total		100.00

Note: Percentages shown may not sum to 100.00 due to rounding.
* Average across all TNSPs and years; (a) Derived from Leontief cost function analysis.

[17] The STPIS for transmission has three key components: (i) a service component designed to incentivise TNSPs to reduce unplanned circuit outage events and outage duration; (ii) market-impact component to incentivise TNSPs to reduce the impact of planned and unplanned outages on wholesale market outcomes; and (iii) a network-capability component to encourage TNSPs to undertake operational and minor capital expenditure projects to improve reliability (AER 2015). The first component is capped at ±1.25 per cent of annual maximum allowed revenue, and it is this component that is relevant to the capping of the cost of ENS for the purpose of benchmarking.

The ENS output has become very low, but also volatile, and is zero in some cases (specifically, for PLK in 2019). A minimum value of ENS equal to 1 MWh is imposed here, consistent with Economic Insights (2020a). Also, sensitivity analysis on output and TFP indexes is carried out to show results when the reliability output, ENS, is excluded.[18]

A4 Input weights & Asset Unit Costs

The input weights are the estimated cost shares of each input. The cost of the opex input is nominal opex. The cost of the capital inputs, in aggregate, is calculated by the AER from the other components of the building block calculation, namely: (a) the return on capital – i.e. the weighted average cost of capital (WACC) applied to the opening regulatory asset base (RAB); (b) the return of capital – the straight line depreciation of the RAB less the inflation indexation of the RAB; and (c) benchmark tax liability. This aggregate cost of capital inputs is decomposed by the AER into the separate capital inputs using estimated shares of each capital asset type in the RAB for each TNSP in each year. The decomposed capital-related costs are referred to as the annual user cost (AUC) for each capital input. Table 1.2 shows the average cost shares of each input for each TNSP.

Table A.2 **Input cost share weights by TNSP (%, average 2006 to 2020)**

Input	*ENT*	*PLK*	*ANT*	*TNT*	*TRG*	*Industry*
Real opex	31.65	27.12	23.57	28.02	26.37	27.35
Overhead lines	21.86	35.36	29.36	22.67	25.95	27.04
Underground cables	2.15	0.63	1.06	1.37	3.23	1.69
Transformers & other capital	44.34	36.89	46.01	47.95	44.45	43.93
Total	100.00	100.00	100.00	100.00	100.00	100.00

Note: Percentages shown may not sum to 100.00 due to rounding.

[18] In this report, unless otherwise specifically stated, ENS is included in the measurement of total outputs and TFP and PFP indexes.

APPENDIX B: INDIVIDUAL OUTPUTS & INPUTS: GROWTH RATES & PFP

Table B.1 **Transmission industry individual output, input and PFP growth rates**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Outputs:				
Energy (GWh)	-0.3%	-0.1%	-0.5%	-1.3%
Ratcheted Max Demand (MVA)	0.8%	1.8%	0.1%	0.2%
End-user Numbers	1.3%	1.3%	1.4%	1.2%
Circuit Length (km)	0.6%	0.8%	0.3%	-0.2%
ENS (MWh)*	-6.5%	-1.0%	-10.7%	-119.6%
Inputs:				
Real Opex ($'000 2006)	-0.2%	0.8%	-0.9%	-1.3%
O/H Lines (MVA-kms)	1.2%	2.7%	0.0%	-0.9%
U/G Lines (MVA-kms)	3.9%	4.3%	3.6%	0.1%
Transformers (MVA)	2.8%	5.0%	1.2%	0.1%
All Capital inputs	2.2%	4.0%	0.8%	-0.2%
Partial productivity:				
Output / Real Opex	0.8%	0.2%	1.2%	2.4%
Output / OH Lines	-0.6%	-1.7%	0.3%	2.0%
Output / UG Lines	-3.3%	-3.4%	-3.2%	1.0%
Output / Transformers	-2.2%	-4.0%	-0.8%	1.0%
Output / Capital	-1.5%	-3.0%	-0.5%	1.3%

Table B.2 **ANT's individual output, input and PFP growth rates**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Outputs:				
Energy (GWh)	-0.6%	0.8%	-1.7%	0.1%
Ratcheted Max Demand (MVA)	1.7%	4.0%	0.0%	0.0%
End-user Numbers	1.5%	1.4%	1.6%	1.2%
Circuit Length (km)	0.2%	0.0%	0.3%	1.5%
ENS (MWh)*	-7.8%	-1.8%	-12.3%	-206.5%
Inputs:				
Real Opex ($'000 2006)	-1.2%	-1.1%	-1.3%	-11.0%
O/H Lines (MVA-kms)	0.0%	0.0%	0.1%	1.0%
U/G Lines (MVA-kms)	-2.0%	0.0%	-3.5%	0.0%
Transformers (MVA)	1.5%	1.7%	1.3%	0.3%
All Capital inputs	0.9%	0.9%	0.8%	0.6%
Partial productivity:				
Output / Real Opex	1.9%	2.4%	1.6%	16.0%
Output / OH Lines	0.7%	1.3%	0.2%	3.9%
Output / UG Lines	2.7%	1.3%	3.8%	5.0%
Output / Transformers	-0.7%	-0.4%	-1.0%	4.7%
Output / Capital	-0.2%	0.4%	-0.5%	4.4%

Table B.3 **ENT's individual output, input and PFP growth rates**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Outputs:				
Energy (GWh)	-0.6%	-1.2%	-0.2%	0.5%
Ratcheted Max Demand (MVA)	0.7%	1.6%	0.1%	0.0%
End-user Numbers	1.1%	1.3%	1.0%	0.9%
Circuit Length (km)	-0.1%	-0.2%	0.0%	0.1%
ENS (MWh)*	-17.5%	23.8%	-48.5%	-326.6%
Inputs:				
Real Opex ($'000 2006)	2.2%	3.0%	1.6%	4.6%
O/H Lines (MVA-kms)	0.3%	0.5%	0.1%	-2.4%
U/G Lines (MVA-kms)	11.3%	24.8%	1.3%	0.0%
Transformers (MVA)	1.9%	2.9%	1.2%	-0.4%
All Capital inputs	1.7%	2.5%	1.0%	-0.9%
Partial productivity:				
Output / Real Opex	-1.9%	-3.3%	-1.0%	-1.2%
Output / OH Lines	0.0%	-0.7%	0.5%	5.8%
Output / UG Lines	-11.1%	-25.1%	-0.6%	3.4%
Output / Transformers	-1.7%	-3.2%	-0.5%	3.8%
Output / Capital	-1.4%	-2.8%	-0.4%	4.4%

Table B.4 **PLK's individual output, input and PFP growth rates**

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Outputs:				
Energy (GWh)	0.3%	-0.1%	0.5%	-1.3%
Ratcheted Max Demand (MVA)	0.9%	1.7%	0.3%	0.7%
End-user Numbers	1.5%	1.8%	1.4%	0.7%
Circuit Length (km)	1.5%	2.6%	0.7%	0.0%
ENS (MWh)*	-28.7%	-18.4%	-36.4%	152.2%
Inputs:				
Real Opex ($'000 2006)	0.8%	1.3%	0.5%	-0.8%
O/H Lines (MVA-kms)	2.0%	3.8%	0.6%	-3.1%
U/G Lines (MVA-kms)	1.6%	4.1%	-0.3%	0.7%
Transformers (MVA)	4.1%	7.2%	1.8%	0.1%
All Capital inputs	3.0%	5.3%	1.3%	-1.3%
Partial productivity:				
Output / Real Opex	0.6%	0.9%	0.3%	0.2%
Output / OH Lines	-0.6%	-1.7%	0.2%	2.5%
Output / UG Lines	-0.2%	-1.9%	1.1%	-1.3%
Output / Transformers	-2.7%	-5.0%	-1.0%	-0.7%
Output / Capital	-1.6%	-3.2%	-0.4%	0.7%

Table B.5 TNT's individual output, input and PFP growth rates

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Outputs:				
Energy (GWh)	1.2%	3.0%	-0.2%	-3.7%
Ratcheted Max Demand (MVA)	0.0%	0.0%	0.0%	0.0%
End-user Numbers	1.1%	1.8%	0.7%	1.2%
Circuit Length (km)	-0.5%	-0.4%	-0.5%	-5.6%
ENS (MWh)*	-7.7%	-7.1%	-8.1%	20.5%
Inputs:				
Real Opex ($'000 2006)	-4.9%	1.0%	-9.2%	-15.5%
O/H Lines (MVA-kms)	1.0%	1.3%	0.7%	0.6%
U/G Lines (MVA-kms)	6.0%	0.0%	10.4%	1.1%
Transformers (MVA)	2.2%	4.1%	0.7%	0.2%
All Capital inputs	1.8%	3.1%	0.9%	0.4%
Partial productivity:				
Output / Real Opex	5.0%	-0.4%	9.1%	11.7%
Output / OH Lines	-0.8%	-0.7%	-0.8%	-4.5%
Output / UG Lines	-5.8%	0.5%	-10.5%	-4.9%
Output / Transformers	-2.0%	-3.6%	-0.8%	-4.1%
Output / Capital	-1.7%	-2.6%	-1.0%	-4.2%

Table B.6 TRG's individual output, input and PFP growth rates

Year	*2006 to 2020*	*2006 to 2012*	*2012 to 2020*	*2020*
Outputs:				
Energy (GWh)	-0.8%	-1.0%	-0.6%	-2.0%
Ratcheted Max Demand (MVA)	0.5%	1.1%	0.0%	0.0%
End-user Numbers	1.2%	0.9%	1.4%	1.4%
Circuit Length (km)	0.3%	0.2%	0.3%	0.0%
ENS (MWh)*	4.0%	2.4%	5.2%	109.1%
Inputs:				
Real Opex ($'000 2006)	-0.9%	0.1%	-1.7%	2.3%
O/H Lines (MVA-kms)	1.5%	4.3%	-0.6%	0.3%
U/G Lines (MVA-kms)	3.4%	0.5%	5.5%	0.0%
Transformers (MVA)	3.1%	6.1%	0.8%	0.0%
All Capital inputs	2.5%	5.1%	0.5%	0.1%
Partial productivity:				
Output / Real Opex	1.1%	0.2%	1.8%	-3.4%
Output / OH Lines	-1.3%	-4.0%	0.8%	-1.4%
Output / UG Lines	-3.2%	-0.2%	-5.4%	-1.1%
Output / Transformers	-2.9%	-5.9%	-0.6%	-1.1%
Output / Capital	-2.3%	-4.8%	-0.4%	-1.2%

APPENDIX C: REGRESSION–BASED TREND GROWTH RATES

Table C.1 **Transmission output, input, total factor productivity and partial productivity index trend annual growth rates, 2006–2020**

TNSP	*Output*	*Input*	*TFP*	*PFP Index*	
Period	*Index*	*Index*	*Index*	*Opex*	*Capital*
Industry					
Growth Rate 2006–20	0.6%	1.7%	-1.0%	0.5%	-1.6%
Growth Rate 2006–12	1.1%	3.3%	-2.2%	0.2%	-3.1%
Growth Rate 2012–20	0.3%	0.4%	-0.1%	1.2%	-0.5%
ANT					
Growth Rate 2006–20	0.4%	0.4%	0.0%	1.0%	-0.4%
Growth Rate 2006–12	1.5%	0.9%	0.6%	1.0%	0.4%
Growth Rate 2012–20	0.0%	0.4%	-0.4%	1.0%	-0.8%
ENT					
Growth Rate 2006–20	0.2%	2.3%	-2.1%	-2.3%	-1.9%
Growth Rate 2006–12	-0.3%	2.4%	-2.7%	-2.9%	-2.6%
Growth Rate 2012–20	0.4%	1.3%	-0.9%	-1.7%	-0.5%
PLK					
Growth Rate 2006–20	1.5%	2.5%	-1.1%	0.3%	-1.6%
Growth Rate 2006–12	2.6%	4.4%	-1.9%	1.7%	-3.3%
Growth Rate 2012–20	0.8%	0.9%	-0.1%	0.4%	-0.3%
TNT					
Growth Rate 2006–20	0.2%	-0.2%	0.3%	6.0%	-1.8%
Growth Rate 2006–12	0.0%	2.5%	-2.5%	-1.0%	-3.4%
Growth Rate 2012–20	0.2%	-1.9%	2.1%	9.6%	-0.4%
TRG					
Growth Rate 2006–20	0.2%	1.7%	-1.5%	0.7%	-2.3%
Growth Rate 2006–12	0.3%	3.9%	-3.6%	0.1%	-5.1%
Growth Rate 2012–20	0.4%	0.1%	0.3%	2.3%	-0.4%

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