EMPIRICAL ANALYSIS OF TOTAL FACTOR PRODUCTIVITY TRENDS IN THE NORTH AMERICAN HYDROELECTRIC GENERATION INDUSTRY

Prepared for

Ontario Power Generation Inc.

By

LE

LONDON ECONOMICS

London Economics International LLC

390 Bay Street, Suite 1702

Toronto, ON, M5H 2Y2

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Julia Frayer

Managing Director

Ian Chow

Senior Consultant

Kelima Yakupova

Consultant

Adam Hariri

Research Associate

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London Economics International LLC
390 Bay Street, Suite 1702
Toronto, ON, M5H 2Y2
www.londoneconomics.com

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Figure 1. Select Acronyms

AF	Availability Factor
AWE	Average Weekly Earnings
BEA	Bureau of Economic Analysis
BLS	Bureau of Labour Statistics
BPA	Bonneville Power Administration
CA	Canada/Canadian
CMS	Cubic Meters per Second
COS	Cost of Service
DEA	Data Envelopment Analysis
EIA	Energy Information Administration
EUCG	Electric Utility Cost Group
FERC	Federal Energy Regulatory Commission
FF1	FERC Form 1
FDD	Final Domestic Demand
GDP	Gross Domestic Product
GRC	Gross Revenue Charge
HOEP	Hourly Ontario Energy Price
ICE	Intercontinental Exchange
IR	Incentive Ratemaking
IRM	Incentive Rate Mechanisms
ISO	Independent System Operator
LADWP	Los Angeles Department of Water and Power
LEI	London Economics International
MCR	Maximum Continuous Rating
MFP	Multi- Factor Productivity
MW	Megawatt
MWh	Megawatt hour
NERC	North American Electric Reliability Corporation
NL	Non-Labour
NYPA	New York Power Authority
OEB	Ontario Energy Board
OECD	Organization for Economic Co-operation and Development
O&M	Operations and Maintenance
OM&A	Operations, Maintenance and Administration
OPG	Ontario Power Generation
PG	Plant Group
PFP	Partial Factor Productivity
PI	Price Index
ROE	Return on Equity
RTO	Regional Transmission Organization
SEPA	Southeastern Power Administration
SFA	Stochastic Frontier Analysis
SNL	SNL Financial

SWPA	Southwestern Power Administration
TFP	Total Factor Productivity
TVA	Tennessee Valley Authority
WACC	Weighted Average Cost of Capital
WAPA	Western Area Power Administration

1 Executive Summary

On March 28, 2013, the Ontario Energy Board ("OEB") published a report outlining its policy for implementing incentive ratemaking ("IR") for OPG's prescribed assets. With this in mind, London Economics International ("LEI") was engaged by OPG to perform a Total Factor Productivity ("TFP") study. The purpose of this report is to share findings from LEI's TFP study, which estimated TFP trends for a select group of peers from the North American hydroelectric generation industry.

This report is structured as follows: Section 2 presents a background into the key events that led to this study. Section 3 presents an overview of the various methods of measuring productivity, and explains why the TFP index method was selected for this study. Section 4 introduces the different inputs and outputs that could be used in the TFP index, and explains LEI's choice. Section 5 goes over the data gathering process for the peers that made up the industry used in the TFP study. Section 6 presents the results of the TFP study, and Section 7 provides concluding remarks.

1.1   What is TFP?

Total factor productivity measures the total quantity of outputs of a firm relative to the quantity of inputs it employs. TFP must cover all material inputs to production, and core outputs of a firm. TFP focuses on quantities, not costs,[1] and measures the year-on-year changes in overall productivity for the firm and its peers. It is important to note that it does not consider efficiency levels, and is therefore not a benchmarking study. An industry TFP study by definition will **not** focus on the regulated firm. The TFP study, by its nature, is also backward looking – reporting historical growth rates or trends in productivity for selected firms or the industry as a whole. A growth rate reflecting multiple years (preferably 10 years or longer) is the primary result reported in an industry TFP study.[2]

1.2   What data was used for the TFP study?

Based on best practices of estimating TFP for generation companies, and after considering issues related to data availability, LEI defined the TFP study output as generation in megawatt hours ("MWh"), and inputs as physical capital measured in megawatts ("MW"), as well as

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[1] While costs are not the focus of a TFP study, they are still needed to form input weights; this is described further in Section 4.2.2.

[2] LEI notes that there is no precedent for TFP studies of hydroelectric generation businesses for purposes of regulatory ratemaking. This is not surprising as generation is not typically regulated using IRM. However, TFP based empirical studies do exist for generation in academia.

annual operations and maintenance ("O&M") costs measured in dollars and deflated by an appropriate index in order to isolate productivity trends.[3]

The data selection and gathering process was the most significant challenge in conducting the TFP study. Primary data sources include FERC Form 1, EIA, US BEA, US BLS, StatsCan, and company public reports, as well as data provided directly by OPG. The final TFP study includes 17 firms in total: OPG, 14 US investor-owned firms that file FERC Form 1 data, and 2 US federal and municipal operators. Data for this study covered an eleven year period from 2002-2012. [4]

1.3 What are the results of the TFP study?

For the industry consisting of OPG and 16 US peers, using data from 2002-2012, the TFP growth rate was estimated to be -1.02% per annum using the 'average growth' method. Under the 'trend regression' method, the industry TFP growth rate was estimated to be –1.00% per annum.[5] As explained further in Section 6.2.1, negative TFP results can be expected for mature hydroelectric businesses, because of fixed production assets, fixed production capabilities, and rising asset maintenance costs over time.

To determine these TFP figures, LEI used a Chained Fisher Ideal index method with a model consisting of two inputs (capital and O&M) and a single output (generation), as described further in Section 6.1.

1.4 How should the results of the TFP study be used for rate setting?

An industry TFP study measures the changes in overall productivity for a particular industry or peer group over a specified time period. Because an industry TFP study reports historical productivity growth rates, care must be applied to ensure that going forward business conditions are similar to those that prevailed historically. An industry TFP is **not** a benchmarking study, as it does not focus on efficiency levels; therefore, it is important that TFP results are not viewed in the same way as a benchmarking study. This also means that individual TFP results should not be viewed self-referentially or compared to the industry result.[6]

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[3] See Section 4 for details on how this data is used and Section 4.2.1 for details on the deflation index.

[4] At the time LEI began this study, 2013 data was not yet available.

[5] See Section 3.2.2 for description of the two different methods of measuring TFP growth trends.

[6] The use of an industry rate as opposed to an individual rate is important due to the fact that it has better incentive properties. This is because the regulated firm in question cannot readily influence the result, and also because it reduces data error risk.

In the OEB report on Rate Setting Parameters and Benchmarking (EB-2010-0379) issued on November 21, 2013, the Board stated that the it will continue with a price cap formula and the use of an I-X regime.[7] Specifically, the Board has stated it would continue to rely on an index-based approach to determine productivity gains or the X-factor. In this respect, the methodology used by LEI employs an index-based methodology. The results from this study will be useful to inform the productivity growth rate assumptions under an I-X regime.[8]

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[7] OEB. *Rate Setting Parameters and Benchmarking under the Renewed Regulatory Framework for Ontario's Electricity Distributors*. Issued November 21, 2013, corrected December 4, 2013.

[8] This process through which TFP studies could be used to inform growth rate assumptions under an I-X regime is explained further in section 3.1.

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390 Bay Street, Suite 1702
Toronto, ON, M5H 2Y2
www.londoneconomics.com

2 Background

Under *Regulation 53/05* pursuant to Section 78.1 of the *Ontario Energy Board Act,* 1998, the OEB's mandate includes setting payments for prescribed assets (nuclear and hydroelectric) of OPG which to date have been under a cost of service ("COS") regulation.[9] In 2012, the OEB started stakeholder consultations to consider incentive regulation options for OPG's prescribed assets. On March 28, 2013, the OEB published a report outlining its policy directive and next steps for implementing IR for OPG's prescribed assets.[10] One of these directives to OPG was to file a work plan and a status report for an independent productivity study in the next application to set payment amounts.

To fulfill the OEB mandate, OPG retained LEI in late 2013 to perform an industry productivity study for OPG's prescribed hydroelectric assets. LEI's scope of work included identification of appropriate methodologies of data compilation and peer selection, as well as empirical analysis. This report addresses all sections of the work plan.

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[9] OEB. *Ontario Energy Board Act, 1998.* < http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_98o15_e.htm>

[10] OEB. *Incentive Rate-making for Ontario Power Generation's Prescribed Generation Assets EB-2012-0340.* March 28, 2013.

3 Basics of Total Factor Productivity

3.1 What is productivity?

Productivity is the ratio of the quantity of outputs produced by a firm, to the quantity of inputs used by the firm. Productivity growth is a trend variable, based on the year-on-year change in the productivity ratio, or the rate of growth in quantity of outputs relative to the rate of growth in the quantity of inputs. For purposes of IR, and specifically in the design of price caps and revenues caps, regulators are interested in changes in productivity over time. For example, historical productivity growth can inform regulators and the regulated utility on the level of productivity change, to guide the choice of an explicit productivity target or X factor under an I-X price cap or revenue cap.

Note that there are multiple methods for measuring productivity. In a practical sense, productivity measures the output quantity relative to input quantity, while productivity growth defines changes in this measurement over time. Common drivers of increased productivity include technological progress, economies of scale, and scope. When attempting to measure productivity, one would seek to capture as many drivers as possible. It should be noted that while TFP indexing techniques can be relied upon to measure total productivity, a TFP value cannot be decomposed to analyze the individual components or drivers of productivity.

There are also multiple categories of productivity that could be measured – for example, for assessing labour productivity, one would look at the ratio that represents the quantity of labour relative to the quantity of output. Labour productivity is a partial measure of productivity, also known as partial factor productivity ("PFP"). In contrast, a TFP measure would attempt to cover all types of inputs relative to all types of outputs.[11] The distinction between the TFP measure and the PFP measures therefore lies in the number of inputs analyzed – single factor productivity measures (or PFPs) relate output to a single input, whereas TFP considers output relative to all inputs. PFP measures can be misleading if considered in isolation.

Figure 2. Generalized concept of a TFP growth rate

$$\text{TFP growth rate} = \frac{\%\,\Delta \text{ weighted sum of the quantities of all outputs}}{\%\,\Delta \text{ weighted sum of the quantities of all inputs}}$$

An industry TFP study measures the changes in overall productivity for the firm and its peers over a specified time period – it is not a benchmarking study, as it does not focus on efficiency levels. In addition, an industry TFP study by definition will not focus on the regulated firm, but rather the industry as a whole. An industry TFP study is backward looking – reporting

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[11] OECD. *Measuring Productivity: Measurement of aggregate and industry-level productivity growth.* 2001.

historical growth rates; the industry's long-term TFP growth rate over the study period timeframe is the primary result or finding of the study.[12]

3.2   Overview of TFP methods

The following section is an overview of the various methods of performing a TFP study. TFP methods can be broadly categorized into deterministic methodologies, which "calculate" TFP, and econometric methodologies, which "estimate" TFP. Figure 3 below gives an overview of some of the methods LEI considered; for more detail see Appendix B Section 9.1.1. LEI chose to use a TFP index method, as discussed further below.

Figure 3. Empirical techniques for estimating TFP

Parameters	Non-Frontier technique	Frontier techniques	
	Index Method	Data Envelopment Analysis ("DEA")	Stochastic Frontier Analysis ("SFA")
Description	Index number measures the ratio of all outputs (weighted by revenue shares) to all inputs (weighted by cost shares)	Linear programming technique which identifies best practice within a sample by fitting a frontier over the top of the data points and measures relative inefficiencies	Same as DEA but following econometric methods to estimate the efficiency frontier
Data needs	Quantity and price data on inputs and outputs for 2 or more firms	Quantity data on inputs and outputs for a sample of firms; price data required to get information on allocative efficiency	Quantity data on inputs and outputs for a sample of firms; price data required to get information on allocative efficiency
Advantages	Relatively simple and robust technique. Can incorporate many inputs and outputs with few observations	Can decompose cost efficiency into component parts, breaking down allocative and technical efficiencies. Can easily handle multiple outputs	Can decompose cost efficiency into component parts, breaking down allocative and technical efficiencies. Accounts for "data noise" (data errors, omitted variables, etc.) and allows for the use of standard statistic tests
Drawbacks	Does not allow for identification of various factors of TFP change such as technical efficiency, scale efficiency, etc.	Requires a large dataset. Sensitive to the way outputs and inputs specified. Can be difficult to explain in a regulatory setting	Requires large sample size for robust estimates. Requires specification of production or cost function. Can be difficult to explain in a regulatory setting

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[12] It is preferable to have 10 or more years of growth rate figures; see Section 3.3 for discussion of the appropriate length of TFP study.

TFP index methods are deterministic and do not measure performance relative to an efficient frontier;[13] they measure the ratio of all outputs to all inputs, where input and output indexes are constructed using both quantities and prices of outputs and inputs. Traditionally, TFP indexing can be used to compare rates of change of productivity but not absolute levels (although more complicated multilateral index methods do also allow levels comparisons). The benefits of TFP indexing are that it is a relatively simple, easy to communicate, and robust technique that requires significantly fewer observations than the other measuring techniques, and thus it is often used for regulatory proceedings. TFP indexing is also more transparent when dealing with outliers, unlike DEA and econometric techniques. It is important to note that the TFP index method, because it is a numerical technique as opposed to a statistical technique, does not give a forecast error measure. Therefore, interpreting differences in index values requires qualitative considerations. Finally, LEI notes that the OEB and other regulators are familiar with the index approach,[14] and in the RRFE proceedings the Board stated its preference to continue to rely on productivity factors that were determined using the index-based approach.[15]

3.2.1 Selecting an indexing technique

The TFP index methodology requires selection of an indexing technique in order to calculate TFP growth rates. To determine which indexing technique was best suited for TFP calculations, LEI considered Diewert and Nakamura's 2005 review of the four most popular alternate index number formulations: Laspeyres index, Paasche index, Fisher Ideal index, and Törnqvist index (see Appendix B Section 9.1.1 for description of each index).[16] Diewert and Nakamura used the 'axiomatic' approach to the selection of an appropriate index formulation which specifies a number of desirable properties an index formulation should possess: constant quantities test,

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[13] Deterministic methodologies "calculate" TFP values, as opposed to econometric methodologies which "estimate" TFP values. Non-frontier methods assume production is always efficient in their use of existing technology, and equates potential level of production at each moment in time. Non-frontier methods do not provide separate estimates of technical change and efficiency change. Further discussion regarding methods of measuring productivity can be found in Section 9.1.1.

[14] The TFP Index method has also been used in previous industry productivity studies before the OEB, and is a preferred method among practitioners for I-X regimes.

[15] OEB. *Rate Setting Parameters and Benchmarking under the Renewed Regulatory Framework for Ontario's Electricity Distributors.* Issued November 21, 2013, corrected December 4, 2013.

[16] Diewert and Nakamura. *Concepts and Measures of Productivity: An Introduction.* 2005.

constant basket test, proportional increase in outputs test, and time reversal test. Only the Fisher Ideal index satisfied all four criteria that an index number method needs to meet.[17]

Figure 4. Fisher Ideal index

$$\text{Fisher Ideal Index} = \sqrt{(\text{Laspeyres Index}) * (\text{Paasche Index})}$$

The Chained Fisher Ideal index is a geometric mean of the Laspeyres and the Paasche indices (Figure 4).[18] The Fisher Ideal index overcomes the classic 'index number problem' suffered by the Laspeyres and Paasche indices, where as one moves further away from the set of prices used, the representative quality of the index decreases (since prices change over time). The Chained Fisher Ideal index overcomes the "index number problem" as follows: instead of using one base observation for the whole period, it calculates the Fisher Ideal index for each period using the previous period's observation as the base, linking these different calculations together to form an index number series which uses the most representative weights possible for each observation.

Based on the mathematical properties and needs of TFP calculations, the Chained Fisher Ideal index ranked highest and therefore is theoretically superior to all other index methods. For this reason, LEI determined that the Chained Fisher Ideal index was most appropriate for the purposes of this study.

3.2.2   Measuring TFP growth rates

The key finding of an industry TFP study is a numerical estimate of the TFP growth rate over the study period timeframe. LEI employed two methods of measuring TFP growth rates. The first method, referred to as the 'average growth' method, calculates the year-on-year changes in the TFP Index and then takes the average of the resulting growth rates over the course of the study period.[19]   As further outlined in Figure 5, a mathematical equivalent can be calculated by (i) taking the natural logarithm of the ratio of the last TFP index value divided by the first TFP index value, and (ii) then dividing the resulting value by the number of annual year-on-year observations between the start and end year.[20]

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[17] It should be noted that these four index formulations generally produce very similar results.

[18] Indexes are chained by comparing data for each year to the data from the year immediately preceding it (with the exception of the base year). This method provides a more accurate portrayal of year over year growth.

[19] Economic Insights. *Total Factor Productivity Index Specification Issues*. December 7, 2009.

[20] The number of annual changes can be calculated as the number of years for which data is collected as part of the TFP study period minus one. In our example, a study period of 2002-2012 has 11 years of data and (11 – 1 = 10) annual changes over that period.

Figure 5. Calculating average TFP growth for a study period of 2002-2012

$$\text{Average industry TFP growth} = \ln\left(\frac{2012 \text{ industy TFP index}}{2002 \text{ industry TFP index}}\right)/10$$

A second method of obtaining a numerical estimate of the TFP growth rate is referred to as the 'trend regression' method; it is a regression-based method that estimates the linear trend of the TFP index values over the study period timeframe. As outlined in Figure 6, this method is calculated by carrying out a linear regression of the natural logarithm of the TFP index values against the number of years of the study period (starting from 0) and a constant term. The estimated slope of this regression is the average TFP growth rate.[21]

Figure 6. Trend regression of TFP growth for a study period of 2002-2012

$$\textbf{Regress: } \ln(\text{industry TFP index}) = \beta * T + \alpha$$

Where:
β = trend growth rate for the industry TFP index over the study period
T = time in years $(0, \dots, 10)$
α = constant term

'Average growth' is the more common method of measuring study-period TFP growth rate, and has been used in previous studies presented before the OEB.[22] The preference of this method can be attributed to the fact that it calculates the actual growth rate of the TFP index values over the course of the study period. However, in certain instances the 'average growth' method can be misleading, most notably when a series exhibits volatility at its endpoints. Because the 'average growth' method tracks the exact growth from start to end, if the endpoints of a series are outliers with respect to the trend then the average method may not give a very good estimate of the underlying TFP trend.

In instances where a series is volatile at its endpoints, it can be argued that the 'trend regression' method may give a better estimate of the underlying TFP growth trend, in that it reduces the weight attached to the first and last years of the study period. The trend regression method has been used to calculate trend growth rates in New Zealand and Australia.[23] However, because the 'trend regression' method is only a linear estimate of the TFP growth rate, in the case where

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[21] Ibid.

[22] For example: PEG. *Productivity and Benchmarking Research in Support of Incentive Rate Setting in Ontario: Final Report to the Ontario Energy Board.* November 2013.

[23] For an example of a TFP study using the trend regression method see: Economic Insights. *Electricity Distribution Industry Productivity Analysis: 1996–2008.* September 1, 2009.

endpoints are outliers it may not track the actual endpoint to endpoint growth rate as well as the 'average growth' method.

Each method has its own set of strengths and weaknesses. For this reason, LEI has presented the results for both methods in Section 6, which we believe is a useful indication of the robustness of the analysis.[24]

3.3   Appropriate length of TFP study

The main purpose of conducting a TFP study of this nature is to establish industry trends, which are innately long term. Logically, the best method of establishing a trend is by looking at multiple years of data and performance. Multiple years of data limits bias that can be caused by numerical outliers or one-off events that affect performance in any single year. Therefore, a productivity trend should cover a period that extends through a sufficiently long timeframe, to limit exposure to year-on-year productivity changes as well as one-off circumstances with respect to factors like weather, consumption, lumpy capital spending, and fluctuations in labour.

This is especially true for hydroelectric generation businesses, which go through business cycles related to the long lifetime of the assets, and where productivity is also heavily dependent on shorter term, exogenous factors such as hydrology, which can lead to high year-on-year variability in output. The use of a long term data series helps smooth out anomalies associated with one off circumstances, and compensates for year-on-year variability that is observed in data. However, if the range of data is too long, the estimated trends may be biased and not representative of current dynamics. The time period should ideally incorporate more recent data that captures the latest trends in the industry, while eliminating earlier time periods with differing productivity growth drivers.

LEI reviewed eighteen previous TFP studies and found that it was common to use data spanning ten years or more for productivity studies.[25] Given data availability (see Section 5 for further details), best practices for TFP analysis, and also the context of the hydroelectric business, LEI believes that the eleven year timeframe of 2002-2012 is appropriate for this study.[26] For OPG, 2002 is also the year the Ontario competitive electricity market opened, a

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[24] Note that the presentation of both methods only refers to the final TFP growth estimate value. In all other instances, such as when estimating quantity sub-index growth rates, only the average TFP growth rate is presented. This is because both methods follow the exact same process, until the final step of calculating the TFP growth rate over the study period timeframe.

[25] Data spanned between 10 and 39 years depending on the study. For more information on this portion of the review see Appendix B Section 9.1.3.3.

[26] LEI notes that the Pacific Economics Group ("PEG") report on productivity and benchmarking in Ontario, presented to the OEB in November 2013, also reviewed data over the 2002-2012 period.

significant event impacting OPG's business environment. US electricity markets also went through reforms and restructuring phases in the late 1990s and early 2000s. The eleven year study period balances the high variability of year-on-year trends but is also not so long term as to capture "stale" industry trends that would not repeat themselves in the future.

4 TFP inputs and outputs

Selecting the appropriate inputs and outputs is a key part of a TFP study. Intuitively, selected inputs and outputs would be those that most accurately represent actual productivity, while also having data that is available and quantifiable. Although there are many dimensions to the hydroelectric industry, and theoretically there are many viable input and output possibilities, not all are measurable. To better understand the appropriate choice of inputs and outputs, LEI reviewed 18 previous academic and regulatory TFP studies. More information of this review can be found in Appendix B Section 9.1.3, but the general consensus was that inputs to a TFP study should include capital and O&M, while outputs should reflect key products or services.

For the purpose of this TFP study, LEI determined it would be best to use a single output of generation measured in MWh, and two inputs: physical capital measured in MW and O&M measured in dollars. Sections 4.1 and 4.2 below provide more insight into why LEI chose a single output two input model.

Figure 7 below illustrates the TFP model with a single output and two inputs. Note that index methods employ indices that are constructed from ratios of output and input quantities. Where there are multiple outputs or inputs, weights are used to create composite indices (for example, outputs can be weighted by revenue shares and inputs can be weighted by cost shares). In the case of LEI's selected TFP model presented in Figure 7, input weights are represented by α for the O&M share and (1- α) for the capital share. This process is described further in Section 4.2.2.

Figure 7. Calculating the TFP index

$$\textbf{TFP Index} = \frac{\textbf{Output Quantity}}{\textbf{Input Quantities}} = \frac{\textbf{Net Generation}}{\boldsymbol{\alpha} * \textbf{O\&M} + (\mathbf{1} - \boldsymbol{\alpha}) * \textbf{Capital}}$$

4.1 TFP study outputs

Hydroelectric assets provide a multi-dimensional service, with multiple products such as generation, ancillary services, reliability, firm capability, system support, water management for flood control, and recreational use.

After considering 18 productivity studies on generation, conducted both for academic and regulatory purposes, LEI found that generation was the most common metric chosen for measuring output. [27] Generation is an appropriate output because it is the essential output being produced by every power generator. Furthermore, generation data is readily available, and is generally measured consistently across power plants and firms. Based on this, LEI concluded

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[27] See Appendix B Section 9.1.3.1 for more detail.

that annual generation measured in MWh was an essential output measure for a TFP study of this nature.

LEI recognizes that the generation output metric is dependent on hydrology and system operations. However, the longer term nature (eleven years) of the TFP study compensates for the year-on-year variability in annual generation, and therefore LEI believes variability in annual hydrology should not be an obstacle to this TFP study. Using OPG as an example, the average of water flows during the study period (2002-2012) is within 1% of the twenty year average (1994-2013) as shown in Figure 8;[28] therefore, it is reasonable to conclude the eleven year study period in general is appropriate and compensates for varying water conditions over the years.[29]

Figure 8. Historical OPG water flow
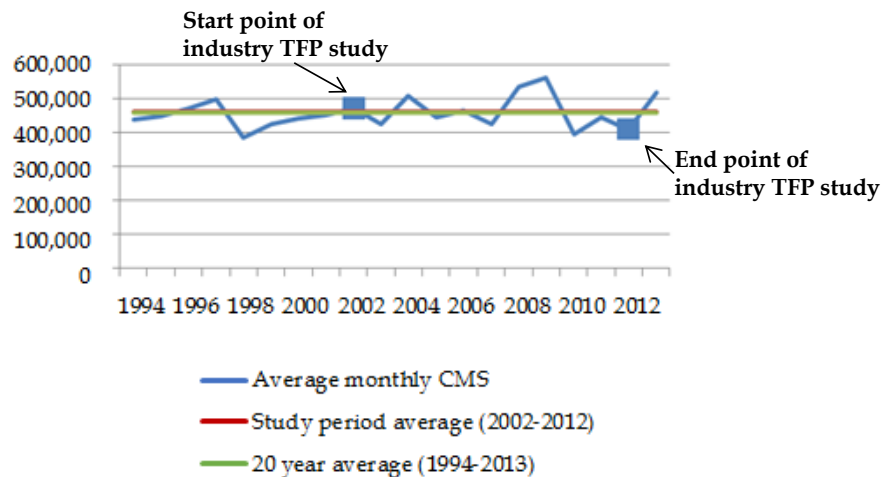
Source: Based on information provided directly to LEI by OPG

In addition to generation, LEI considered other outputs including measurements of other services that can be provided by hydroelectric plants in the output index. For example, LEI noted that in one particular study, outputs of a hydroelectric industry TFP study included availability (in MWh), energy produced in the driest month, and summer peaking capacity. Availability can be considered an output, as hydroelectric operators (including OPG) spend

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[28] Based on information provided directly to LEI by OPG.

[29] LEI understands that in individual cases this statement may not be true. Notable is the case of Western Area Power Administration (described in Section 5.2.3), which shows that historical average and study-period average water flows may not match up. LEI performed an outlier check against individual peers included in the industry TFP study based on their final average TFP growth rates; results from this check can be seen in Section 6.3.

effort to achieve certain levels of availability (i.e., minimize forced outage rates) for reliability purposes. However, availability data is often not available publically, and the method of measuring availability may vary from individual peer to peer. More generally, availability would already be implied in the annual MWh figure already being used as the primary output. For these reasons, availability was not used as a separate output in the industry TFP study. However, LEI did conduct a sensitivity analysis for a small subgroup of peers where a two output model was evaluated; the results are similar to a single output model and have been included in the Appendix A in Section 8 of this report.

Additional generation measures, such as energy produced in the driest month, or winter and summer peaking capacity, could in theory also be used as outputs. However, data for these outputs is less readily available for all industry peers. As well, compensation for OPG's regulated assets is not geared off such specific production statistics. Other services, such as sales of ancillary services, or water management for flood control and recreational use, are difficult to represent in a TFP study because they lack consistent and easily measurable data; therefore, they should be considered qualitatively only.

To conclude, LEI decided it would be best to use only a single output model consisting of generation measured in MWh. Firstly, this is because this was common practice in reviewed generation TFP studies, and secondly, it is a numerical data point which is both available and consistently measured across firms.

4.2   TFP study inputs

Based on a number of factors discussed below, LEI concluded that a two input model consisting of capital measured in MW of installed hydroelectric generation capacity, and Total O&M costs measured in dollar values, would best capture inputs that are most relevant to hydroelectric operations.

A review of the inputs used in 18 previous productivity studies can be seen in Appendix B in Section 9.1.3.2. The most common input observed for generation related productivity studies was capacity as a physical measure of capital. Capital can also be measured using replacement cost, but this is much less common – in fact, nearly every generation related TFP study used capacity as a measure of capital.[30] Therefore, LEI concluded that capital measured in MW capacity should be used as an input.

The TFP case study review also showed that the second most common input is number of employees, which captures the labour involved in power production. Due to data constraints, LEI could not rely on number of employees or otherwise isolate the labour costs from total

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[30] Further discussion on physical as compared to monetary measures of capital can be found in Appendix C Section 10.

O&M costs. However labour costs are already reflected in O&M costs indirectly through the input price indices (which is discussed further in Section 4.2.1).

Fuel consumed and maintenance costs were also often utilized, however, given that this TFP study is for hydroelectric generation rather than thermal or fossil-fuel fired generation, fuel costs are not a relevant input.

4.2.1   O&M input quantities

Input prices are used to derive appropriate quantities of certain inputs for the calculation of TFP. To calculate quantities of O&M costs, the labour, non-labour, and total O&M costs are deflated using their respective price indices.

More specifically, total O&M costs were deflated (i.e., converted into quantity) using a total O&M price index which is comprised of a labour price index and non-labour price index, combined together using a labour to non-labour share, as discussed below and in the following Section 4.2.2.

Figure 9. Canadian O&M price indices, 2002-2012

Year	Labour Price Index	Non-Labour Price Index	O&M Price Index
2002	1.00	1.00	1.00
2003	1.02	1.02	1.02
2004	1.05	1.04	1.05
2005	1.09	1.06	1.08
2006	1.11	1.08	1.10
2007	1.15	1.11	1.14
2008	1.18	1.14	1.16
2009	1.19	1.15	1.18
2010	1.24	1.16	1.21
2011	1.26	1.19	1.23
2012	1.27	1.21	1.25

Source: Based on StatsCan data. Weights of Labour and Non-Labour PI as described in Figure 11

For Canadian data, labour O&M price index was based on industrial aggregate average weekly earnings ("AWE") (reported by *Statistics Canada*; in current dollars, for Canadian utilities, including overtime, seasonally adjusted, for all employees), and the non-labour O&M price index was based on the gross domestic product price index estimate of final domestic demand ("GDP-IPI FDD") (reported by *Statistics Canada*; implicit price indexes, gross domestic product, final domestic demand, for Canada). For US data, labour O&M price index was based on data gathered from US Bureau of Labor Statistics ("BLS"), and non-labour O&M price index was

based on the GDP-PI data gathered from the US Bureau of Economic Analysis ("BEA").[31] Canadian O&M price indices over the TFP study timeframe are presented in Figure 9, while US O&M price indices over the TFP study timeframe are presented in Figure 10.

Figure 10. US O&M price indices, 2002-2012

Year	Labour Price Index	Non-Labour Price Index	O&M Price Index
2002	1.00	1.00	1.00
2003	1.03	1.02	1.02
2004	1.06	1.05	1.05
2005	1.09	1.08	1.09
2006	1.12	1.11	1.12
2007	1.16	1.14	1.15
2008	1.19	1.17	1.18
2009	1.23	1.18	1.21
2010	1.26	1.19	1.23
2011	1.29	1.21	1.26
2012	1.33	1.23	1.29

Source: Based on data from the US BLS and BEA. Weights of Labour and Non-Labour PI as described in Figure 11

Labour and non-labour O&M price indices for Canada and the US are combined into Canadian and US total O&M price indices using a fixed labour share of total O&M of 62% (Figure 11), as suggested by confidential EUCG database,[32] that includes hydroelectric generation specific data for 18 companies over 2004-2012 timeframe.

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[31] See Section 5.4 for detailed discussion of how US and Canadian data was treated in order for them to be comparable.

[32] The EUCG dataset containing hydro-specific generation data for 18 companies over 2004-2012 was shared with LEI by EUCG for the purposes of this study. LEI was not able to use this data in the TFP study because eleven-year datasets could not be constructed for any of the peers, and 11 of the 18 peers had data within the 2004-2012 timeframe missing.

London Economics International LLC
390 Bay Street, Suite 1702
Toronto, ON, M5H 2Y2
www.londoneconomics.com

Figure 11. Labour and Non-labour O&M shares implied by EUCG data

Year	Labour Share based on O&M	Non-Labour Share based on O&M
2004	60%	40%
2005	63%	37%
2006	61%	39%
2007	61%	39%
2008	60%	40%
2009	62%	38%
2010	65%	35%
2011	63%	37%
2012	65%	35%
Average (2004-2012)	**62%**	**38%**

Source: Confidential EUCG database, provided to LEI directly by OPG

The total O&M price indices for US and Canada are blended into a North American O&M price index by applying a weight of 22% for the Canadian share of the industry (i.e., OPG) based on Canadian peer's share in total O&M for the industry; therefore, the weight of US total O&M price index in the North American total O&M price index is 78%. Figure 12 presents the total O&M price index for North America as a whole, while Figure 13 shows the growth trend in these indices in graphical form.[33]

Figure 12. North American combined O&M price indices, 2002-2012

Year	US O&M Price Index	Canadian O&M Price Index	North American O&M Price Index
2002	1.00	1.00	1.00
2003	1.02	1.02	1.02
2004	1.05	1.05	1.05
2005	1.09	1.08	1.08
2006	1.12	1.10	1.11
2007	1.15	1.14	1.15
2008	1.18	1.16	1.18
2009	1.21	1.18	1.20
2010	1.23	1.21	1.23
2011	1.26	1.23	1.26
2012	1.29	1.25	1.28

[33] North American index was created in order to create an industry peer set including both US and Canadian peers.

Figure 13. O&M price index growth rates (%) for US, Canada, and North America
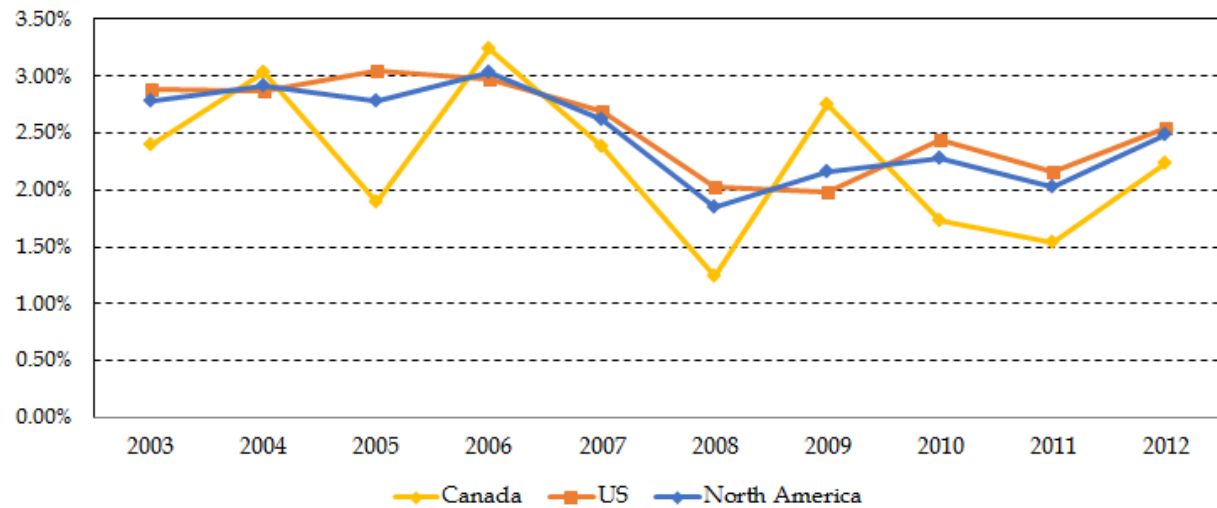
Source: Based on data from Statistics Canada, US BLS and BEA

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[34] Weights based on O&M share of Canadian and US peers as calculated by LEI, using data gathered from FERC Form 1, individual firm annual reports, and information provided directly by firms. Based on internal analysis, Canadian O&M share was calculated to be 22%, and US O&M share was 78%.

4.2.2   Input share weights

Given LEI has determined multiple inputs to the TFP study, capital and O&M costs, weights or cost shares must be used to combine the sub-indices into a composite input quantity index. Capital input shares can be difficult to assess, but LEI believes that the endogenous approach is both appropriate and relatively easy to implement, as discussed in the text box below.

The capital share is determined as the share of the estimated cost of capital to total costs (capital plus total O&M). Based on combined industry business operations data, capital share for the 2002-2012 period averaged 81% for the industry as a whole. These industry-level capital shares, which can be seen in Figure 14, were calculated by LEI using firm-specific data.[35]

<div style="border:2px solid #4472a8; background:#4472a8; color:white; padding:1em;">

<u>Capital input share</u>

Capital cost input shares may be estimated using two methods, an endogenous or an exogenous approach. The endogenous approach is the residual of revenue less operating costs (assumes prices are proportional to marginal costs and revenues are equal to costs); it is appropriate for competitive conditions or if a firm has been regulated for an extended period under a cost of service methodology such that revenues cover costs.

The exogenous approach is calculated by forming a user cost measure based on an estimated depreciation rate, a rate of return on capital, a deduction for the estimated rate of capital gains or addition for capital losses (i.e., annual change in the asset price index), and applied to a starting point asset value (capital stock). It recognizes that there has to be a "return of" capital over the asset's lifetime (i.e., the firm has to recoup its original investment) and a "return on" capital to compensate for holding the asset over its lifetime reflecting the opportunity cost of using the funds in an alternative investment. The exogenous approach must also consider that capital gains resulting from an increase in the price of the asset reduce the cost of holding (and using) the asset over the year. The exogenous approach also requires making a judgment on the firm's true opportunity cost of capital, and usually assumes geometric depreciation of capital.

LEI used the endogenous approach (revenue=costs) to determine capital input shares, as it is easier to implement and is expected to provide a reasonable approximation of capital inputs in the business.

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[35] See Section 5 for information on the data gathering process for the industry.

Figure 14. Annual implied Capital to Total O&M shares for hydroelectric generation industry[36]

Year	Capital Share	O&M Share
2002	85%	15%
2003	88%	12%
2004	86%	14%
2005	89%	11%
2006	86%	14%
2007	82%	18%
2008	85%	15%
2009	78%	22%
2010	76%	24%
2011	75%	25%
2012	66%	34%
Average	**81%**	**19%**

Source: Based on LEI internal analysis, using data sources described in Section 5.2

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[36] In general, changes in capital share were largely driven by year-over-year revenue fluctuations. Specifically, revenue from 2011 to 2012 declined by a rate of -34%, causing capital share for the industry as a whole to drop from 75% in 2011 to 66% in 2012. Lower market revenues are a function of volumes of sales (which may be affected by hydrological conditions) as well as wholesale market price conditions, which can be attributed to external drivers in the regional power markets, such as (but not limited) to gas prices, demand conditions, and aggregate supply.

5 Data for TFP study

Ideally, a hydroelectric industry TFP study would include a large set of peers that are similar in terms of location, capacity, and asset allocation. For the purpose of this study, the peers should include medium to large hydroelectric generators. LEI focused its data research on the United States and Canada due primarily to data availability. As outlined below, LEI considered a total of 28 hydroelectric peers across North America, including 22 in the US and 6 in Canada (including OPG). However, issues with data availability meant that 11 of these peers could not be included in the final industry peer group. Of particular note is that with the exception of OPG, no other Canadian firm could be included in the study. In the US, all major utilities are required to submit comprehensive financial and operating reports to the Federal Energy Regulatory Commission ("FERC") under FERC Form 1 ("FF1"), which is then made publicly available.[37] In contrast, no such data bank exists in Canada, and therefore the financial data required for the TFP study from Canadian peers could not be attained either through public resources or directly from the individual utilities. Still, LEI believes that a set of 16 US peers and OPG is sufficient for developing a robust TFP trend.[38]

5.1 Peer selection

5.1.1 Peer selection criteria

When selecting peers in order to construct an industry group, LEI used a multi-dimensional criteria set, which focused on comparability across peer hydroelectric operations, while keeping in mind issues related to data availability. As a general rule, LEI looked for firms that have a hydroelectric fleet with a total capacity of between 500-1,000 MW (medium size) or more than 1,000 MW (large size). Additionally, a peer needed to have more than one plant, and ideally the average age of a peer's hydro fleet would be around the average age for OPG's prescribed

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[37] FERC Form 1 is a regulatory requirement for Major electric utilities, designed to collect financial and operational information on utilities subject to FERC jurisdiction. Major utilities are defined as: having "one million megawatt hours or more; 100 megawatt hours of annual sales for resale; 500 megawatt hours of annual power exchange delivered; or 500 megawatt hours of annual wheeling for others (deliveries plus losses)." FERC Form 1 filings can be found here: <http://www.ferc.gov/docs-filing/forms/form-1/data.asp>

[38] LEI notes that there is OEB precedent to rely on US data when necessary. See for example Pacific Economic Group report: "Price Cap Index Design for Ontario's Natural Gas Utilities" (March 2007), which was undertaken under OEB directive. This study used US TFP results to establish TFP growth targets for two Canadian gas utilities (Enbridge Gas Distribution Inc. and Union Gas Limited). Report filed under OEB case number EB-2006-0209, available online at: <http://www.ontarioenergyboard.ca/documents/cases/EB-2006-0209/TFP_study_20070330.pdf>

hydro fleet. Practical considerations relating to the availability of reliable data over the entire timeframe of the study also played an important part in peer selection.[39]

In addition to meeting the above criteria, peers needed to have data available on the hydroelectric portion of their operations, in order to ensure consistency of data. Inputs and outputs, and therefore productivity, would be completely different for thermal generation, for example. For peers which exclusively operated hydro facilities, this was straightforward. However, a number of peers were excluded from the study because there was no division in reported O&M data between the hydro and non-hydro components of their operations. Peers needed to have annual data on O&M (measured in dollars) and net generation (measured in MWh), for the 2002 through to 2012 timeframe. Revenue data was also collected when available, but was estimated when necessary (see Section 5.3 for more detail). The data and peer selection stage of the study provided LEI with plant-level hydro-specific data on annual generation (MWh), capacity (MW), and O&M (dollars), as well as revenues for developing the capital input share.

As discussed in Section 3.3, an eleven year timeframe was chosen for the study because it is long enough to smooth out anomalies associated with one off circumstances, but not too long that it relies too heavily on "stale" data or periods when data is not available. The start year of 2002 was chosen because it was the first year that full datasets could be constructed across the peer group.[40] As well, the opening of the Ontario competitive market occurred in 2002 which impacted the business environment for OPG; similarly, market restructurings were occurring across parts of the US in the late 1990s and early 2000s. The end year, 2012, was chosen because this represented the latest available information while LEI was gathering data for this study in the first quarter of 2014. Considering issues related to data availability and length requirements of a TFP study, LEI determined a study period timeframe of 2002 to 2012 was optimal.

5.1.2 Final peer group

Consistent with above criteria, LEI considered a total of 28 industry peers in North America, including 22 in the United States and 6 in Canada. These consisted of OPG, 14 private US companies that filed FERC Form 1, 2 US municipal utilities, 2 US federal power authorities, 4 US federal power administrations, and five various other Canadian companies.

However, primarily due to lack of certain necessary data, eleven peers could not be included (see more detailed discussions in Sections 5.2.3 and 5.2.4 below). The final peer group selected,

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[39] Note that LEI did not consider the ownership structure of the firm, the regulatory regime under which the firm operated, or the type of energy market in which the firm operated (e.g. bilateral energy versus regional transmission organization ("RTO") administered energy market, energy-only versus energy & capacity).

[40] Most peers did not have full datasets available before 2002, including OPG, with revenue data only available starting mid-2002 after market opening.

as summarized in Figure 15, includes 17 firms: OPG, 14 US investor owned firms that file FERC Form 1 data, one US federal operator (Southeastern Power Administration), and one US municipal operator (Seattle City & Light).

Figure 15. List of peers included in industry

Company	Average age of hydro fleet (2014)	Sum of hydro plant capacity (MW) 2012
Pacific Gas and Electric	53	3,578
Duke Energy Carolinas, LLC	46	2,852
Virginia Electric and Power	33	2,122
Idaho Power	54	1,695
Alabama Power	66	1,583
Southern California Edison	72	1,112
Georgia Power	62	1,071
Pacificorp	69	1,016
Avista Corporation	66	914
Portland General Electric	60	808
Union Electric	69	779
Appalachian Power	56	779
South Carolina Electric & Gas	52	750
Alcoa Power Generating Inc.	87	514
Ferc Form 1		
Seattle City Light	59	1,929
Southeastern Power Administration	38	3,392
Federal and Municipal		
OPG	**64**	**6,905**

Source: Source: FF1 dataset, OPG, SEPA and Seattle annual reports, data provided directly by companies

Figure 16. List of peers by capacity and average age of hydro fleet
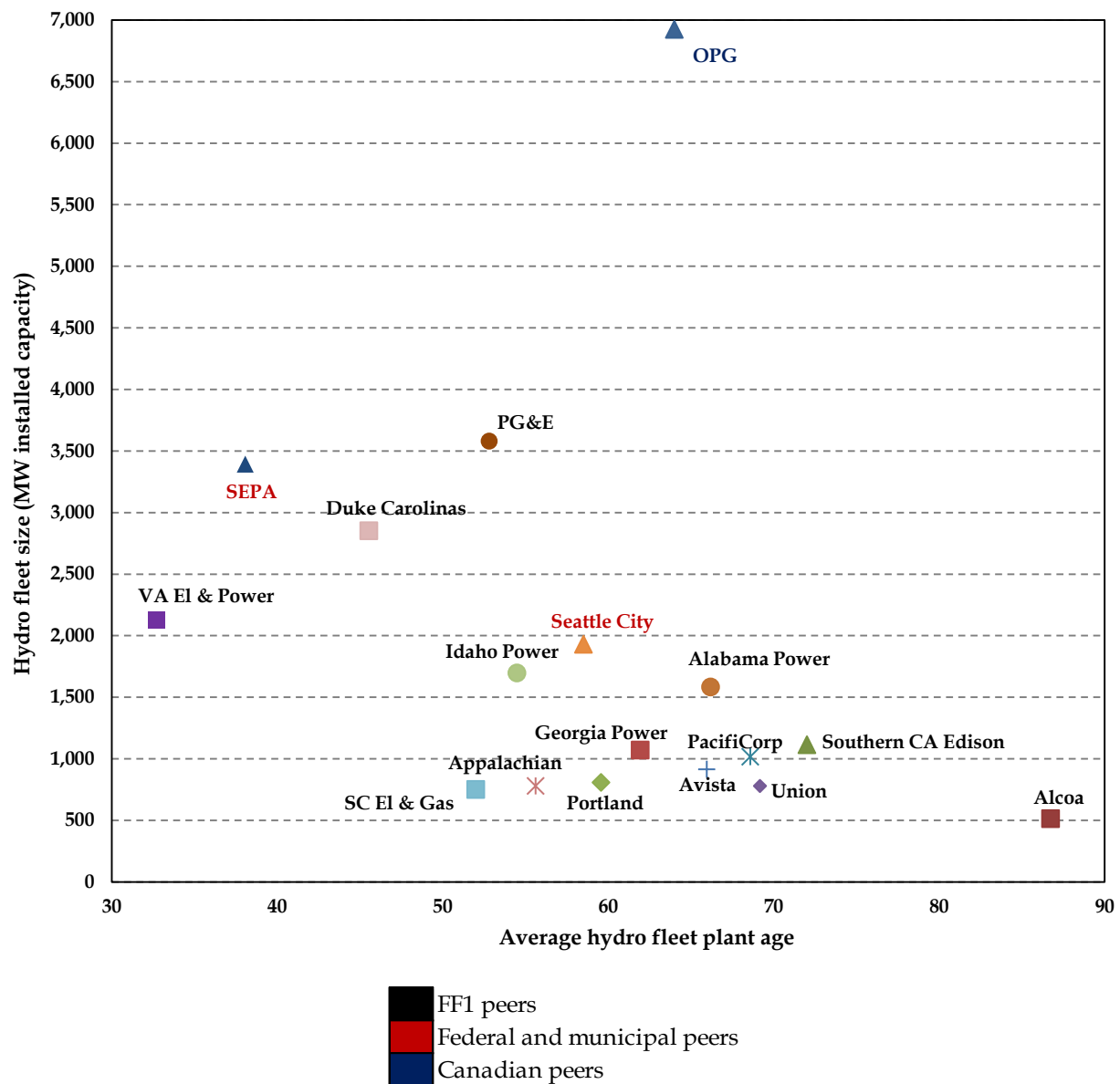
Figure 17. Breakdown of top four peers by 2012 O&M costs ($)[41] and Capacity (MW)
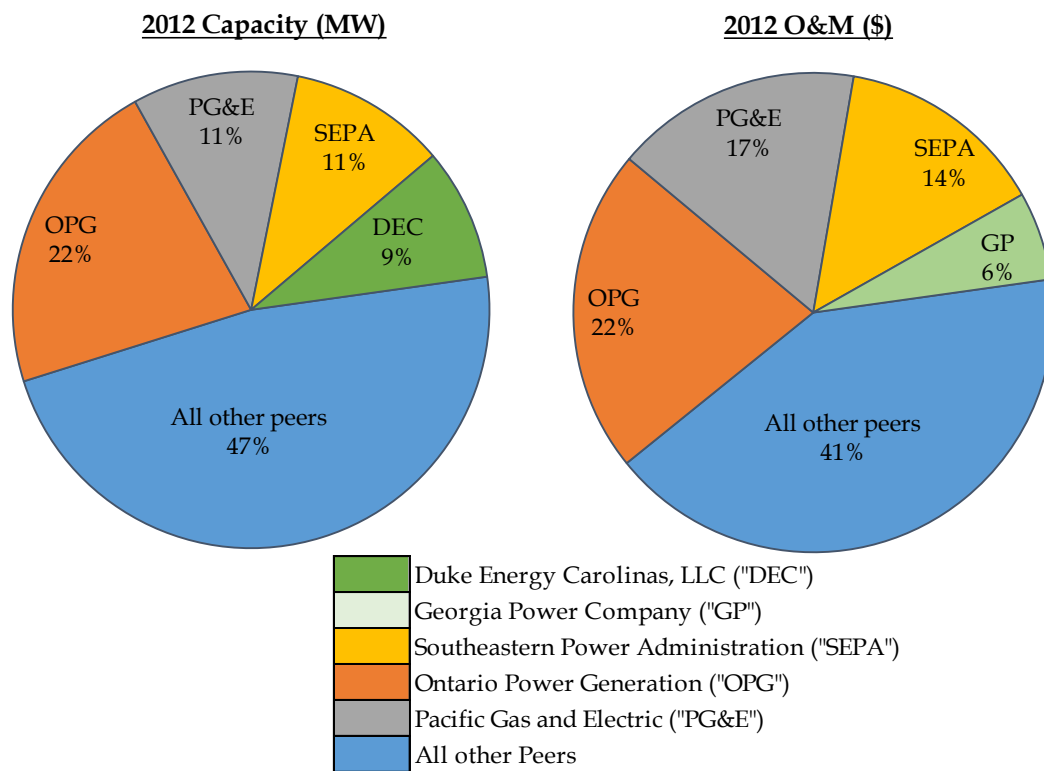
2012 Capacity (MW)

PG&E 11%
SEPA 11%
DEC 9%
OPG 22%
All other peers 47%

2012 O&M ($)

PG&E 17%
SEPA 14%
GP 6%
OPG 22%
All other peers 41%

Legend:
- Duke Energy Carolinas, LLC ("DEC")
- Georgia Power Company ("GP")
- Southeastern Power Administration ("SEPA")
- Ontario Power Generation ("OPG")
- Pacific Gas and Electric ("PG&E")
- All other Peers

Source: FF1 dataset, OPG, SEPA and Seattle annual reports, data provided directly by companies

5.2   Peer data

LEI considered multiple reputable primary sources for data including FERC Form 1, EIA, StatsCan, US BEA, US BLS, ISO price data, NERC, and company public reports and websites. Although LEI relied mainly on primary sources, data was also sourced and cross checked against third party commercial databases,[42] and the confidential EUCG database.[43]

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[41] O&M amounts for US peers were converted from US dollars to Canadian dollars using the 2012 OECD PPP for GDP, at a rate of 1.25 Canadian dollars per 1 US dollar. See Section 5.4 for further explanation of conversion process. Further, all O&M values were deflated by their respective indices in order to isolate productivity trends, as previously described in Section 4.2.1.

[42] Including Energy Velocity and SNL Financial.

[43] While various sources were used to create the dataset used in the final analysis, LEI believes these different sources are comparable because a TFP study is an analysis of trends rather than efficiency levels. Therefore, any potentially unobserved inconsistencies between datasets will not impact results in the same way as they would for a benchmarking study.

5.2.1 Data provided by OPG

OPG provided LEI with operating and financial data on each of the five hydro plant groups ("PGs") for the TFP study in January 2014. These figures include net generation, O&M (excluding water rental charges/GRC), and revenue data. Net generation and O&M figures were provided from January 2002 until December 2013.[44] For revenue, data for January until April 2002 was not available due to markets opening in May 2002 and therefore revenue amounts had to be imputed.[45]

Figure 18. Data provided by OPG

Data provided by OPG	
Operational data	**Financial data**

▪ Maximum Continuous Rating (MW, plant level)
▪ Net generation (MWh, plant group level)
▪ Plant names and plant info (initial COD, MW, plant type, whether provides ancillary services, etc)
	▪ Total OM&A ($K, plant group level)
	  – Labor OM&A (fully-loaded wages)
	  – Non-labor OM&A
	▪ Revenue ($K, plant group level)
	▪ Other costs ($K, plant group level)
	  – NS projects
	  – HTO and corporate costs

5.2.2 FERC Form 1 data

As discussed in Section 5.1 and as presented in Figure 19, LEI identified fourteen large and medium size peers (with hydroelectric portfolios of more than 500 MW) that submit FERC Form 1 annually. FF1 data is submitted by all major electric utilities and is available for large hydro plants. FERC provides guidelines on data requirements, therefore, data sourced from FF1 can be considered reliable. The use of a single data set for this peer group also gives it consistency. FF1 data was used for total O&M costs (non-capital input), nameplate capacity (capital input) and generation (output).

LEI performed adjustments on two companies to correct certain data issues or missing data points in FF1 annual filings. Duke Energy's 2002 FF1 data was missing, so O&M and generation

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[44] Certain stations were operated by OPG as merchant generating stations, but during the study period were decommissioned so new generating stations could be constructed. These stations include Ear Falls, Healey Falls, Lower Sturgeon, Sandy Falls, Wawaitin and Hound Chute. Data for these sites was removed from the study once the stations were decommissioned.

[45] Revenue figures for the missing months were estimated by multiplying generation figures for each month by the average monthly HOEP for the same month in 2003-2012 (See Section 5.3 for further discussion on revenue estimations). However, LEI notes that using different estimation methods to calculate OPG's 2002 revenue between January and April had little to no effect on the final industry TFP results.

were interpolated for that year based on 2001 & 2003 values. Alabama Power's generation data was missing for 2004, and therefore also required interpolation along the same lines.

As noted in Section 5.2, LEI used a variety of sources and where possible, cross-checked FF1 data with other data sources. However, LEI believes that given the reputation of the publisher, using FF1 data is both reliable and robust.

Figure 19. List of FF1 peers including 2012 capacity, O&M (US $), and net generation data			
Ferc Form 1 peers	Capacity (MW)	O&M ('000 $)	Net Generation (MWh)
Pacific Gas and Electric	3,578	117,025	7,874,464
Duke Energy Carolinas, LLC	2,852	32,219	3,989,993
Virginia Electric and Power	2,122	8,551	4,495,195
Idaho Power	1,695	26,329	7,882,921
Alabama Power	1,583	30,413	2,667,009
Southern California Edison	1,112	32,693	2,625,534
Georgia Power	1,071	41,988	1,410,378
Pacificorp	1,016	30,661	4,080,847
Avista Corporation	914	12,820	4,088,289
Portland General Electric	808	20,991	3,462,116
Union Electric	779	11,546	1,317,309
Appalachian Power	779	23,502	970,063
South Carolina Electric & Gas	750	5,699	752,595
Alcoa Power Generating Inc.	514	12,338	1,466,400

5.2.2.1   Consistency between FF1 and OPG data

LEI attempted to maximize data consistency by using the same data source (FERC Form 1) as much as possible. However, there were still some instances where the method of reporting for primary data differed between industry peers. Most notably was the use of operations, maintenance and administration ("OM&A") for OPG versus O&M for all other peers. Data provided by OPG was OM&A, but FERC Form 1 data does not report administration costs at the hydroelectric business level.

Although administration costs were included by OPG, they were found by OPG to be relatively flat historically, and were not a sizeable component of the total OM&A, so their inclusion would not measurably impact TFP results. TFP analysis measures change in productivity over time, so if administration costs are trending consistently with O&M costs over time, then OM&A trends can be used as a reasonable proxy for O&M trends. OPG subsequently reviewed administration costs in OPG's cost of service regulatory filings to the OEB and observed that the trend in administration costs was "flat" and that administration costs were not a significant component

of OM&A. [46] As such, OPG and LEI concluded that the inclusion of administration costs in the OM&A data for OPG (and not in the O&M data for peers) would not materially bias the industry TFP study.

In addition, O&M data was confirmed to be consistent between FF1 and OPG. Figure 20 below shows the list of FF1 O&M line items compared to OPG. Note that data provided by OPG does not include water rental and GRC fees, therefore the "water for power" line item was removed from FF1 O&M costs for consistency.[47]

Figure 20. FF1 O&M line items compared to items included in OPG costs

Line item	Included in OPG total O&M costs (without HTO and Corp)
Operation	
535 Operation supervision and engineering	Yes
536 Water for power	No
537 Hydraulic expenses	Yes
538 Electric expenses	Yes
539 Miscellaneous hydraulic power generation expenses	Yes
540 Rents	Yes
Maintenance	
541 Maintenance supervision and engineering	Yes
542 Maintenance of structures	Yes
543 Maintenance of reservoirs, dams and waterways	Yes
544 Maintenance of electric plant	Yes
545 Maintenance of miscellaneous hydraulic plant	Yes

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[46] Based on OPG's COS filings with the OEB from 2010-2013, on plant group level.

[47] The 'water for power' line item can be removed because it is a pass-through item and therefore does not affect productivity.

5.2.3 Federal and municipal peer data

Once research into the five Canadian and fourteen FF1 peers had been completed, LEI expanded the search to federal and municipal operators, in order to include as many peers as possible in the industry TFP analysis. Five federal and three municipally owned companies were evaluated for consideration in the industry TFP study. While these operators control sizeable hydroelectric assets, they are not required to file FF1 data, and therefore the data inputs for the TFP study needed to be researched on an individual company basis. The primary data source for this peer set consisted of annual reports and other financial filings published by the companies themselves. Supplementary information was also obtained through direct communication with the companies.

The five federal companies considered for the study were Southeastern Power Administration ("SEPA"), Southwestern Power Administration ("SWPA"), Western Power Administration ("WAPA"), Bonneville Power Administration ("BPA"), and Tennessee Valley Authority ("TVA"). Of these five, only SEPA was included in the final study due to data issues with the other federal companies. For municipal companies, the three that were considered include New York Power Administration ("NYPA"), [48] Los Angeles Department of Water and Power ("LADWP"), and Seattle City Light ("Seattle"). Of these three, only Seattle was included as part of the final peer set due to data issues with the other municipal companies.

For this TFP study, LEI required data associated only with hydroelectric assets. Published data for TVA and BPA was only available at the company level and did not distinguish between hydro and non-hydro components.[49] TVA and BPA were not included in the final peer group because they report O&M on a company level, and, for TVA, a sizeable portion of its generation facilities were not hydroelectric. TVA's hydro component consisted of only around 14.6% of their total generation assets in 2012, as measured in capacity. For BPA, hydro consisted of 82.8% of its 2014 capacity. [50] LEI contacted BPA and TVA for hydro-specific O&M figures, but both firms could not provide breakdowns by specific generation asset types.

SWPA generation facilities were entirely hydro, but O&M from 2003-2005 was either not available or not complete.[51] According to SWPA, the issue arose because the US Army Corps of

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[48] Although NYPA is a state power authority, it is labeled in this report as municipal for ease of grouping; referring to NYPA as municipal does not affect results or interpretation of results.

[49] Based on analysis of primary documents including TVA and BPA's annual reports, and direct contact with the companies requesting hydro-specific data. TVA's annual reports can be found here: <http://www.snl.com/IRWebLinkX/FinancialDocs.aspx?iid=4063363>, BPA's annual reports can be found here: < http://www.bpa.gov/Finance/FinancialInformation/AnnualReports/Pages/default.aspx>.

[50] Ibid.

[51] SWPA annual reports can be found here: <http://www.swpa.gov/annualreport.aspx>

Engineers (which runs SWPA's hydro facilities) experienced issues related to accounting for fixed assets.[52] This issue led to the removal of consolidated annual reports for those years from the public record. Because of this three year data gap, SWPA could not be included in the final peer group.

Figure 21. WAPA annual generation (MWh) over 2002-2012 period[53]
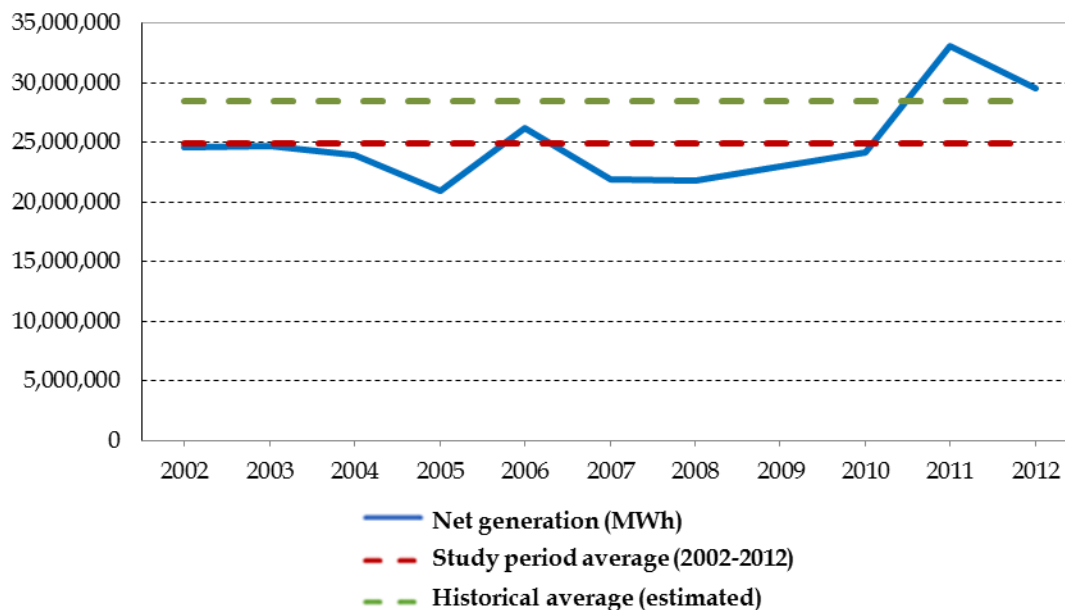
Source: WAPA annual reports

For WAPA, a complete set of hydro-specific data was obtained through annual reports as well as direct communications with the company.[54] Net Generation, revenue and O&M were adjusted to take into account one coal plant owned by WAPA. O&M was further adjusted to

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[52] Based on direct conversations with SWPA officials.

[53] Net Generation for the period prior to 2002 was not available for WAPA. However, statements in WAPA's annual reports (see for example 2008, 2011 and 2012 annual reports available online at: <http://ww2.wapa.gov/sites/western/newsroom/pubs/Pages/default.aspx>) refer to a long period of drought from 1999 to 2010, that reduced WAPA's annual net generation to numbers well below historical average. For example, the 2012 annual report states that 2012 net generation is close to historical average after more than a decade of below average generation due to drought. Based on statements like these, LEI estimated WAPA's historical generation. LEI notes that WAPA's annual generation fluctuations also skewed industry TFP results.

[54] 2002-2012 annual reports for WAPA are not available online. WAPA provided LEI directly with hard copies of their annual reports and statistical appendices for 2002-2012.

remove annual transmission related costs, which were not available in the annual reports but were directly provided by WAPA. However, an abnormal hydrology cycle over the course of the study period (2002-2012) was observed - WAPA's annual average hydroelectric generation was below historical average levels for many of the years in the study period and then significantly higher in last few years. Annual generation over the 2002-2012 study period can be seen in Figure 21.[55] The abnormal generation fluctuations and the size of WAPA's hydroelectric facilities were large enough to potentially skew the final TFP results. For this reason, LEI decided that WAPA should not be included in the final study.

SEPA is the only federal company that was included in the final peer group. Data for net generation, revenue, and O&M were all available in SEPA's own annual reports.[56] Unlike the other federal companies, SEPA does not own its own transmission facilities, and therefore O&M figures listed in its annual reports did not need to be corrected. Revenue figures had to be adjusted to take into account sales of "Purchased Power", which is essentially power sold by SEPA but generated by other operators.[57] This information, provided directly to LEI by SEPA, was subtracted from total revenue to calculate revenue related to the sale of SEPA's hydro power.

Municipal companies, LADWP and NYPA, were not included because their generating facilities were not entirely hydro, and neither provided hydro specific O&M figures. For LADWP, hydro was around 25% of total capacity in 2012. For NYPA, 2012 capacity was about 73% hydro, and data only extended back to 2007.[58] Given that hydro-specific O&M data could not be gathered, these companies could not be included in the TFP study.

Seattle is the only municipal power company that was included in the peer group. Data for net generation and O&M was compiled from information found within Seattle's own annual reports.[59] Seattle's generation facilities are entirely hydroelectric, and therefore generation and O&M data was already in the form necessary for the TFP study. Revenue figures for Seattle had to be estimated, as outlined in Section 5.3.

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[55] Based on information obtained from WAPA's 2002-2012 annual report.

[56] SEPA annual reports from 2007-2012 can be accessed here: <http://energy.gov/sepa/listings/annual-reports>
Hard copy annual reports from 2002-2006 were provided to LEI directly by SEPA.

[57] Based on direct conversations with SEPA, information contained in annual reports, and information on company website.

[58] These amounts were obtained from LADWP and NYPA annual reports. LADWP annual reports can be found here: <https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-financesandreports/a-fr-financialinformation?_adf.ctrl-state=1aardt9i2g_4&_afrLoop=419000985723718> and NYPA annual reports can be found here: <http://www.nypa.gov/financial/>

[59] Seattle annual reports can be found here: <http://www.seattle.gov/light/pubs/annualrpts.asp>

5.2.4   Canadian peers

In addition to the twenty two US peers above, LEI also considered five Canadian peers: Hydro Quebec, BC Hydro, Newfoundland & Labrador Hydro, Manitoba Hydro, and NB Power. To collect the necessary data, LEI reviewed Canadian databases such as StatsCan and NERC, company annual reports, regulatory filings where available, and other publicly available information for all five companies. While LEI was able to collect most of the operational data, all five companies lacked sufficient publicly-available data related to the appropriate hydro-specific O&M expenses. LEI made repeated information requests to all five companies regarding the appropriate hydro specific O&M costs, but was unable to obtain the information. Therefore, due to lack of necessary data for the TFP study, Canadian peers were ultimately excluded from the final peer list.

5.3   Revenue data estimation

As is discussed in Section 4.2.2, revenues (less O&M costs) are used to estimate capital input shares, which are in turn used to determine appropriate weights (α and $(1-\alpha)$) assigned to the two inputs (Capital and O&M). For all peers with the exception of SEPA, LEI had to perform revenue estimations in some form, because revenue data exclusively from the operation of hydroelectric operations was not obtainable directly from the primary source data.

Revenues for all the FF1 peers were estimated using reported production data and reported wholesale energy prices, because revenues are not directly reported in FF1. Monthly production data came from the EIA-923 dataset, and LEI used historical monthly ISO zone prices for peers operating within ISO market, or monthly bilateral prices for those in non-ISO markets, based on nearest power price hub traded on ICE.[60] This same process was carried out to estimate Seattle's revenue for the same reason.

For OPG, revenue data from January 2002 to April 2002 was not available because markets were not yet open; therefore, LEI had to estimate revenues by multiplying net generation for the missing months by the average of 2003-2012 HOEP prices for corresponding months. All other revenue data from April 2002 onwards was provided directly by OPG.[61]

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[60] For peers in SERC, posted bilateral prices were utilized. Certain hubs in the Pacific Northwest are not consistently traded, so LEI extrapolated to nearby hubs which were more liquid. Dominion joined PJM in 2005, so ISO prices are not available before then; LEI extrapolated based on VACAR zone price.

[61] Revenue provided by OPG solely represents energy market sales of hydroelectric generation, based on actual settlement with the IESO. It does not reflect any variance accounts, regulatory rate true ups, or any other payments such as Surplus Baseload Generation or Hydroelectric Incentive Mechanism.

5.4   Comparing US and Canadian data

As was discussed at the beginning of Section 5, LEI believes that using a peer group of OPG and 16 peers is reasonable. However, one notable difference with respect to data comparability relates to currency differences, as revenue and O&M figures from US peers are measured in US dollars, while for Canadian peers those figures are in Canadian dollars. When estimating individual TFP results, the difference in currencies does not affect results, as a simple scaling up or down of O&M and revenue would result in the exact same outcome. However, in the case of calculating industry TFP trends, Canadian and US figures are compared, and using non-adjusted figures can lead to biases (albeit small) in the TFP results. To adjust for this, LEI inflated all US peer revenue and O&M data by the Purchasing Power Parity ("PPP")[62] for Gross Domestic Product ("GDP") between the US and Canada, as estimated by the OECD.[63] LEI used the 2012 (end year) amount of 1.25 Canadian dollars per 1 US dollar; however, sanity checks using 2002 (start year) and average of 2002-2012 PPP values produced the same industry TFP results.

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[62] PPP reflects the rate of currency conversion between two countries in relation to the reflective purchasing power of a unit of currency in each country. PPP is much more useful than exchange rates when comparing values between countries, because it is not as volatile.

[63] LEI chose to inflate US data instead of deflating OPG data because this is a Canadian study. The inflation of US revenue and O&M data did not affect individual TFP results for OPG and 16 US peers, as it only causes a linear shift in data. The effects of the US data inflation can only be seen when comparing US peers with OPG, with the only effect being that US peers make up a larger part of the industry than they would have if data was not adjusted.

6 TFP Results

This section presents TFP results for the industry consisting of 17 peers using a Single Output – Two Input Model as outlined in Section 4, based on plant and company level data collected from 2002 to 2012. We report the TFP trend based on two different growth calculations as outlined in Section 3.2.2. The final result for the industry TFP study ranged from a growth rate of -1.02% (under the 'average growth' method) to -1.00% (using the 'trend regression' method). Section 6.1 lays out the TFP model used, Section 6.2.1 presents the results from the industry TFP study using the 'average growth' method, Section 6.2.2 presents the industry TFP results using the 'trend regression' method, and Section 6.3 presents some observations regarding outliers.

6.1 TFP model

Based on LEI's research and available data (see Section 5 for more detail), LEI used a Single Output – Two Input Model. In this model, the output was generation measured in MWh, and the two inputs were physical capital measured in MW and O&M measured in constant prices. The TFP formula is shown in Figure 22, where:

- the Single Output is measured as Net Generation (MWh) (see discussion in Section 4.1);
- the Two Inputs are Capital measured as Capacity (MW) and Non-capital costs measured as total O&M inputs in constant prices (see discussion in Section 4.2);
- the Capital share is 81% and the O&M share is 19% (see discussion in Section 4.2.2);
- the Labour share of O&M is 62% and the Non-labour share of O&M is 38% (see discussion in Section 4.2.1
- the Labour price index and non-labour price indexes are O&M-weighted blends for North American hydroelectric peer industry using Canadian and US labour and non-labour price indexes (see discussed in Section 4.2).

Figure 22. Final TFP index

$$TFP\ Index\ = \frac{Output\ Quantity}{Input\ Quantities} = \frac{Net\ Generation}{19\% * \frac{O\&M\ Cost}{(38\%) * (Non-labour\ PI) + (62\%) * (Labour\ PI)} + 81\% * MW}$$

In any one year, the TFP Index value is measured as the ratio of total Outputs to total Inputs, using the Chained Fisher Ideal index method discussed in Section 3.2.1. A TFP study's key finding is the industry's long-term TFP growth rate; as discussed in Section 3.2.2, this can be measured either by the year-on-year changes in the annual TFP index values over the study timeframe (the 'average growth' method), or based on the slope of the linear regression of the TFP index values (the 'trend regression' method).

6.2 Industry TFP results

6.2.1 Industry TFP results using the average growth method

The results for the industry TFP study over the 2002-2012 period using the average growth method suggest a TFP growth rate of -1.02%, as summarized in Figure 23.

Figure 23. Key TFP study results using the average growth method

Average index growth rates (2002-2012)		
Input Index	Output Index	TFP Index
0.51%	-0.51%	-1.02%

As outlined in Figure 26, average growth rate for capital inputs measured in MW was 0.21% over the 2002-2012 period, with little year over year fluctuations. This result is to be expected for a mature hydroelectric industry as construction of new generation facilities is infrequent. O&M input growth was higher than capital input at an average rate of 2.34% over the study period, and year over year fluctuations were greater. LEI calculated capital's share of input for this peer set to be on average 81%, and O&M share of input to be 19% (see Section 4.2.2 for more background information on input shares); annual input weights are listed in Figure 24. With more weight assigned to capital, the total input index growth rate is estimated to be 0.51% using the average growth method, and year over year fluctuations are small, as seen in Figure 26.

Figure 24. Annual input weights

	Input Weights	
Year	Capital (MW)	O&M ($)
2002	85%	15%
2003	88%	12%
2004	86%	14%
2005	89%	11%
2006	86%	14%
2007	82%	18%
2008	85%	15%
2009	78%	22%
2010	76%	24%
2011	75%	25%
2012	66%	34%
AVERAGE	**81%**	**19%**

For output, net generation growth rate was on average -0.51% for the industry.[64] Note year over year fluctuations were much more visible compared to the average, which is to be expected due to varying hydrology cycles during the 2002-2012 period, as well as other factors such as changes in demand and surplus baseload generation conditions. Since net generation is the only output, it equals the output index growth rate as measured using the average growth method.[65]

The average input index growth rate of 0.51% and average output index growth rate of -0.51% resulted in an average negative TFP growth rate of -1.02% for the industry over the study period.

Figure 25. Quantity sub-index values for inputs and output

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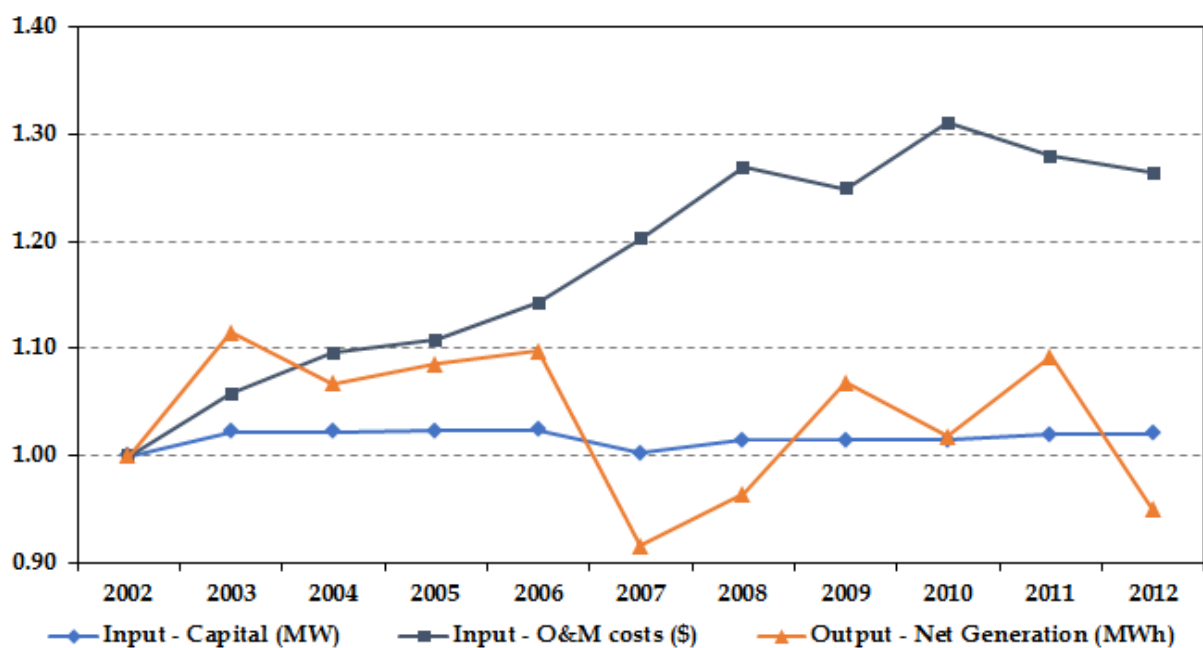
[64] A negative generation growth rate does not imply the same capital is producing less over time, but rather is related to the hydrology cycles at the start and end years of the study.

[65] The degree of variability in the output index (see Figure 27) presents a case for calculating growth rates using a trend regression method rather than the average growth method (which is based on trends measured from one endpoint to another endpoint) in order to smooth out the volatility and sensitivity of results to the choice of endpoints. Please see Section 6.2.2 for the results using the trend regression method.

Figure 26. Quantity sub-index growth rates for inputs and output

	Quantity Sub-Index Growth Rates		
Year	Input (K) weight 81%	Input (O&M) weight 19%	Output (MWh) weight 100%
2002-2003	2.21%	5.67%	10.89%
2003-2004	0.01%	3.48%	-4.33%
2004-2005	0.06%	1.08%	1.64%
2005-2006	0.07%	3.15%	1.17%
2006-2007	-2.13%	5.10%	-18.18%
2007-2008	1.20%	5.40%	5.23%
2008-2009	0.01%	-1.64%	10.22%
2009-2010	0.01%	4.82%	-4.79%
2010-2011	0.49%	-2.41%	7.01%
2011-2012	0.14%	-1.24%	-13.98%
AVERAGE	**0.21%**	**2.34%**	**-0.51%**

Figure 27. Input, output and TFP index growth rates using the average growth method

	Index Growth Rates		
Year	Input Index Growth	Output Index Growth	TFP Index Growth
2002-2003	2.68%	10.89%	8.21%
2003-2004	0.46%	-4.33%	-4.80%
2004-2005	0.19%	1.64%	1.45%
2005-2006	0.47%	1.17%	0.70%
2006-2007	-0.98%	-18.18%	-17.20%
2007-2008	1.89%	5.23%	3.34%
2008-2009	-0.30%	10.22%	10.51%
2009-2010	1.12%	-4.79%	-5.92%
2010-2011	-0.22%	7.01%	7.23%
2011-2012	-0.27%	-13.98%	-13.72%
AVERAGE	**0.51%**	**-0.51%**	**-1.02%**

LEI believes that negative TFP trends can be "expected" for mature hydroelectric businesses, because of the fixed production capability, fixed capital stock and rising costs of maintenance through the life cycle of a hydroelectric resource. As discussed earlier in Section 3.1, common drivers of productivity include technological innovation and improved economies of scale. However, for a mature hydroelectric business, great leaps forward in technology are extremely rare and economies of scale are generally fixed as soon as the asset is built and put into operation (although occasionally, refurbishments and other capital programs can increase energy production due to advances in new equipment). In general, it should be expected that output levels would be stable over time;[66] capital inputs are constant (once a hydroelectric plant is put into service); and OM&A would likely be increasing over time (in order to maintain asset operational capability as the asset ages).

6.2.2   Industry TFP results using the trend regression method

The trend regression method estimates the linear trend in the observed TFP index values over time. The slope of the linear regression on the TFP index is the estimate of average TFP growth rate. This method can be useful in establishing average trends in instances where a series exhibits volatility at its endpoints. For the purposes of this study, the year-over-year changes in the output index, visible in Figure 28 below, appears to be the main driver for annual changes in the TFP index value. Such a degree of movement in the output index presents a case for calculating growth using the 'trend regression' method.

Figure 28. Fisher input, fisher output, and TFP index values

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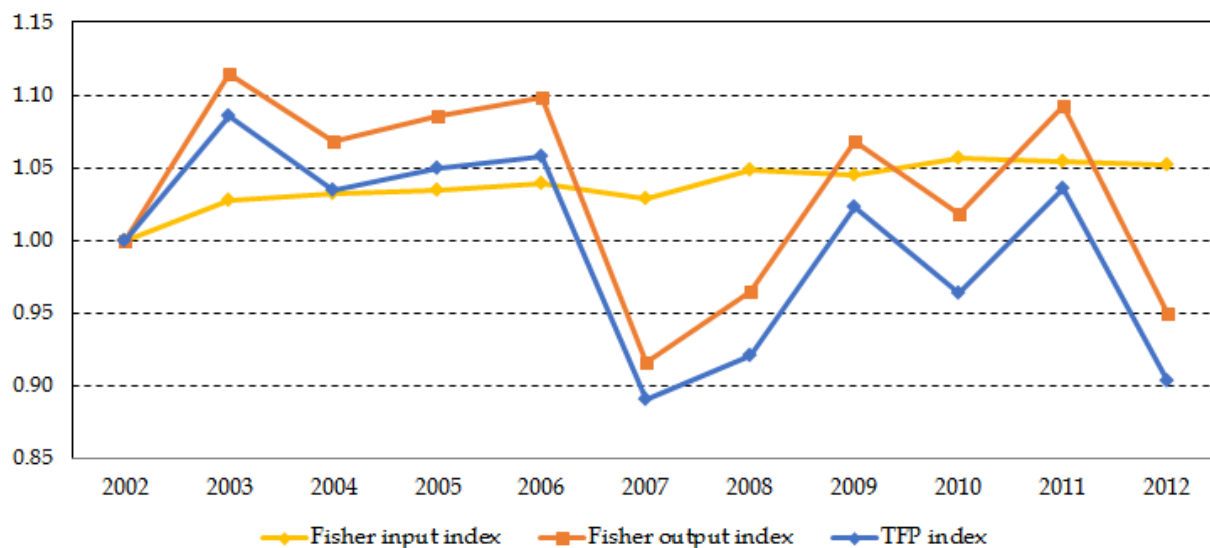
[66] Assuming constant water flow levels over the course of the study and given generator design is fixed once the asset is brought into service, unless there are refurbishments that increase output.

As discussed in Section 3.2.2, the 'trend regression' method estimates TFP growth rate for a study period by first taking the natural logarithm of TFP index values (index values are visible in Figure 28), then carrying out a linear regression of the natural logarithm of the TFP index values against the number of years of the study period (from 0 to 10) and a constant term. Figure 29 illustrates the final formula for calculating the TFP growth rate using this method, while Figure 30 provides a visual representation of the results from this process; the slope of the line is the estimate of TFP growth rate from 2002-2012 using the 'trend regression' method.

Figure 29. Equation of line under 'trend regression' method

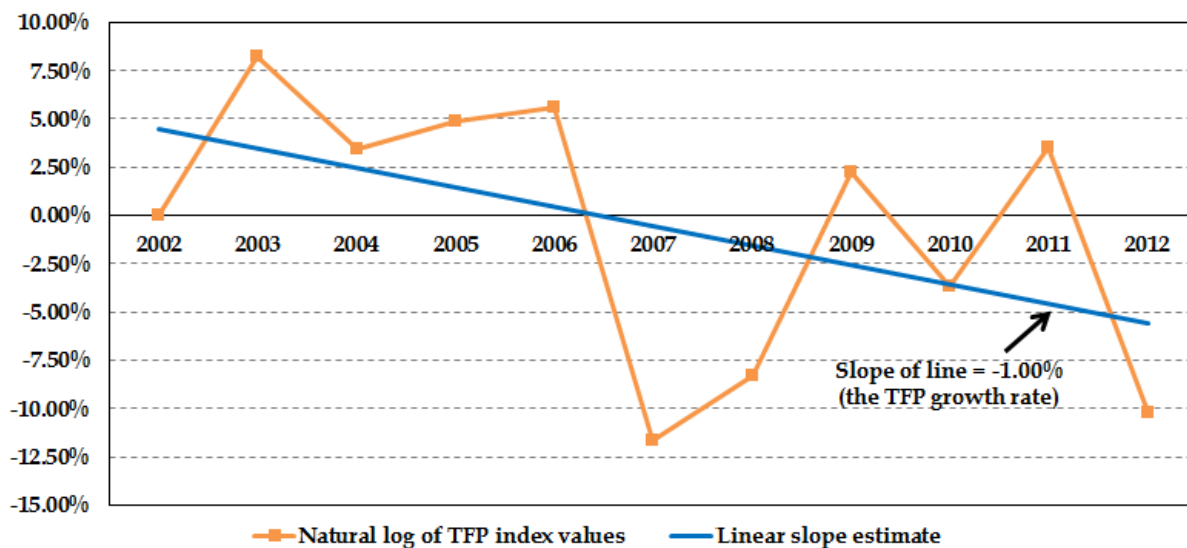$$\ln(\text{industry TFP index}) = -1.00\% * T + 4.46\%$$

Where:
$\ln(\text{industry TFP index})$ = natural logarithm of TFP index values from $2002 - 2012$
-1.00% = trend growth rate for the industry TFP index over the study period
T = time in years $(0, \dots, 10)$
4.46% = constant term

Figure 30. Natural log of TFP index values and linear slope estimate

This same method of analysis can be carried out on the input and output index values to calculate their respective growth rates under the 'trend regression method'. As summarized in Figure 31, using the trend regression method, the input index growth rate of 0.42% and the output index growth rate of -0.58% combined into a study-period estimated annual TFP growth rate of -1.00%. Recall, using the average growth method, the input index growth rate of 0.51% and output index growth rate of -0.51% combined into a study-period estimated annual TFP growth rate of -1.02%. Therefore, both methods produce almost identical TFP growth rate estimates over the 2002-2012 period.

Figure 31. Key TFP study results using the trend regression method

Trend estimate of index growth rates (2002-2012)		
Input Index	Output Index	TFP Index
0.42%	-0.58%	-1.00%

6.3   Discussion of outlier peers

In a multi-firm analysis of this nature, numerical differences when comparing individual peer TFP growth rates should generally not be given too much significance. The index method is not a statistical technique – the key conclusions should be driven by observed trends and overall trajectories or ranges rather than precise numerical results. Still, in order to identify any potential outlier peers, LEI performed a sanity check by considering whether individual peer results lie within one standard deviation from the mean.

Based on this method of calculation, the upper bound using the 'average growth' method was found to be 1.74% and the lower bound -2.99%. Most of the 17 peers, including OPG and ten US peers, fall within the "normal" range of average TFP growth rates. However, a total of 6 peers fall outside the "normal" range; three of these peers are outliers on the positive side, and three are on the negative side. The general cause of outlier status for the six peers was sharp year-over-year changes in net generation for some years during the study period, generally caused by varying water conditions.

Using the 'trend regression' method of calculating TFP growth, the upper bound was found to be 1.28% and the lower bound -3.63%. A total of seven peers fall outside these standard deviation bounds, three on the positive side and four on the negative side; the remaining 10 peers (including OPG) fell within the "normal" TFP range.

LEI notes that although there is some variation in the company-specific results, the industry-level TFP trends are relatively stable and can be concluded to be reliable. The use of two different growth measure calculation methods improves the overall robustness of the industry TFP study – especially as the two methods result in almost identical industry TFP results. Most positive and negative outliers were relatively small peers that had a minimal impact on final results. LEI has reviewed outliers, and while it is important to explain the impact outliers could have on the study, these firms should not be excluded. This belief is supported by TFP results after eliminating the outlier peers from their respective growth measure groups, which change only slightly from -1.00% to -1.18% using the 'trend regression' method, and remain unchanged at -1.02% using the 'average growth' method.

7 Concluding remarks

On March 28, 2013, the OEB issued a report (EB-2012-0340) outlining its policy directives and next steps for implementing IR for OPG's prescribed assets. In their report, the OEB anticipated that OPG's regulated hydroelectric business will move to an IR regime, and directed OPG to file a work plan and status report for an independent productivity study in the next application to set payment amounts. To fulfill this directive, OPG retained LEI in late 2013 to assist in performing the productivity study on OPG's prescribed hydroelectric assets. This report was written to share findings of LEI's research and TFP study on the North American hydroelectric generation industry.

LEI estimates that, for an industry peer group consisting of OPG and 16 US hydroelectric generators, using data from 2002-2012, the industry TFP growth over the study period timeframe in the range of -1% per annum (more precisely, it is -1.02% using the average growth method and -1.00% using the trend regression method). LEI notes that negative TFP results can be expected for a TFP study on a mature hydroelectric industry. Additionally, LEI cautions against viewing TFP results in the same way as one would a benchmarking study, as well as against comparing individual TFP results to that of the industry. Going forward, LEI believes that this TFP study can be used to inform the productivity growth rate assumptions under the I-X regime.

8   Appendix A: Two-Output model

As discussed in Section 4.1, as a sensitivity test, LEI also constructed a two-input/two-output model for a subset of the industry. The two-input/two-output model built on the two-input/one-output model, with the addition of the Availability Factor ("AF") as a second output. Availability Factor is defined by NERC as "The fraction of a given operating period in which a generating unit is available without any outages." Because AF data is reported as a percentage, it needs to be converted into a level measure in order to be used as an output. This conversion was done by multiplying the AF percent by the number of hours in a year (8,760), giving a figure that represents annual hourly availability of a generating unit.

Note that NERC AF data was not available for all plants and peers used in the two-input/one-output model. In summary, only 10 out of the 16 peers were included in the two-output/two-input model because there was insufficient data for the remaining 6 firms. The constraint on AF data also led to reduced values of O&M, Generation and Revenue for some of the peers (where AF statistics were not available for some plants).

A major consideration in performing a two-output model is that it required that weights be assigned to each output. Revenue shares were not readily available as most plants are not separately compensated for generation and availability. Therefore, LEI tested different weights for MWh and AF, ranging from every 25% interval from 0% to 100%.

In summary, the two-input/two-output model with 50% weight assigned to Net Generation (MWh) and 50% to AF results in an industry TFP growth rate of -1.34% using the average growth method and -1.11% using the trend regression method. Additional results for this two-input/two-output model are shown in Figure 32. It should be noted that the results for the 100% MWh scenario using this dataset are more negative than the single output model TFP results because the six peers that were dropped generally had higher (more positive) TFP growth rates.

LEI decided against using AF in the final TFP model because adding AF as a second output reduced the size of the peer group from 16 to 10, and because "availability" as an output would already be captured in generation data due to the interrelationship between production and overall annual availability.

Figure 32. Two-input/two-output model (with smaller peer group due to availability of data)

Model Specifications	Industry TFP growth (2002-2012)	
	Using average growth method	Using trend regression method
Total O&M and Capital vs MWh	-1.63%	-1.29%
Total O&M and Capital vs 75% MWh and 25% AF	-1.48%	-1.20%
Total O&M and Capital vs 50% MWh and 50% AF	-1.34%	-1.11%
Total O&M and Capital vs 25% MWh and 75% AF	-1.19%	-1.02%
Total O&M and Capital vs AF	-1.05%	-0.94%

# 9 Appendix B: Lessons learned and challenges through review of economic literature on productivity studies

As part of the research phase of this study, LEI reviewed a number of previous studies that analyzed productivity of generation, distribution, transmission sectors, or electricity sector as a whole. For each study, data used, method employed, TFP composition (inputs and outputs), and study conclusions were summarized. This section presents the key findings of the review.

9.1.1 Methods for measuring productivity

The following section is an introduction to the various methods in performing a TFP study, specifically methods seen in the review: stochastic frontier analysis ("SFA"), Data Envelopment Analysis ("DEA"), and TFP indexes. They can be broadly categorized into deterministic methodologies, which "calculate" TFP, and econometric methodologies (which are also known as parametric methods), which "estimate" TFP.

TFP study methods can also be categorized into frontier and non-frontier. Frontier methods assume that production units do not fully use existing technology. These methods are able to break productivity growth down into technical change and efficiency change; technology changes can push the frontier upwards, while efficiency changes are productivity improvement, given the same technology. On the other hand, non-frontier methods assume that production is always efficient, and equates potential level of production at each moment in time. These methods do not separately estimate technical change and efficiency change.

Figure 33. Categories of methods used in productivity studies
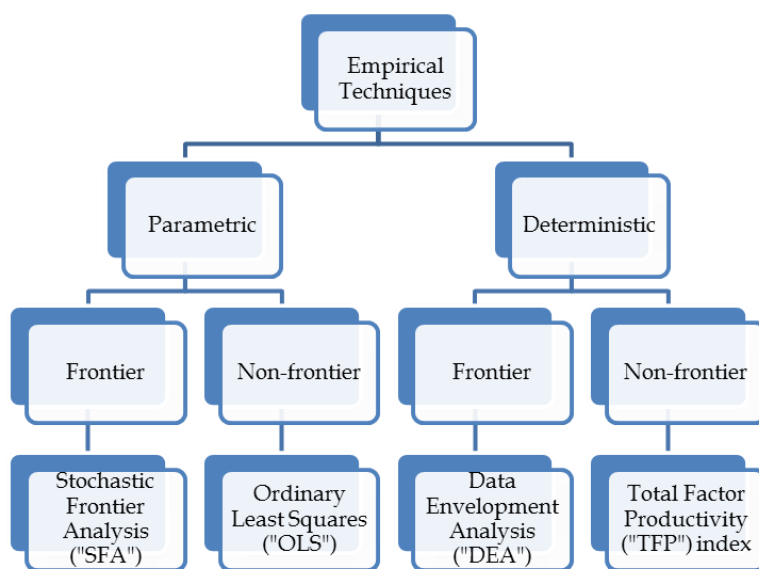
First introduced by Charnes et al in 1978, DEA is a linear programming technique which identifies best practice within a sample by fitting a frontier over the top of the data points; relative efficiencies are measured from less efficient firms with respect to the frontier. As seen in

the review, it is a method which is more popular in academic studies of generating units, given the amount of detail it can provide, which is discussed further below. It is often used with a Malmquist index, which measures productivity change between two points in time.

Figure 34. Common Indexing Techniques

Laspeyres Index:

- *Named for French economist Etienne Laspeyres*
- *Indexation method in which all input and output values are weighted at base year prices to ensure consistent price comparisons*
- *Becomes an increasingly inappropriate methodology as the time interval and/or price variability increases*

Paasche Index:

- *Named for German economist Hermann Paasche*
- *Indexation method similar to the Laspeyres method except that all input and outputs are value at their end of period prices to ensure price consistency*
- *Also becomes increasingly inappropriate as the time interval increases and/or the price variability increases*

Fisher Index:

- *Named for American Economist Irving Fisher*
- *Attempts to minimize the inaccuracies inherent in the Paasche and Laspeyres methods of price indexation by weighting all input and output prices by the geometric mean of base year and end of period prices*
- *The geometric mean involves the square root of the product of base year and end of period prices*
- *In a TFP period scenario, a Fisher Indexation TFP calculation can also be calculated as the geometric mean of the TFP calculations resulting from Paasche and Laspeyres indexation techniques*

Törnqvist index:

- *Attributed to Finnish economist Leo Törnqvist and is commonly used in TFP studies*
- *Approximates the Fisher indexation method whereby indexes are formed by each component's weighted geometric mean, relative to a base year, in which weights are equal to the components average cost share*
- *Typically analyzed in logarithmic format*

Malmquist Index:

- *Initially introduced in: "Multilateral Comparisons of Output, Input and Productivity Using Superlative Index Numbers", by Douglas W. Caves, Laurits R. Christensen and W. Erwin Diewert in 1982 but named for Swedish economist Sten Malmquist*
- *Parametric method that uses techniques similar to DEA to construct an efficient frontier which changes annually, thus measuring productivity relative to the previous year*
- *Classifies efficiency into technical change and efficiency change aspects*
- *One advantage is that it does not require price or cost information so is often in used when there are data limitation*

One of the most important benefits is that the DEA is able to decompose cost efficiency into component parts, breaking down allocative and technical efficiencies. Technical efficiencies can be in turn decomposed into scale and pure technical efficiencies. This allows researchers to identify the best role models and make recommendations on improving efficiency. As well, it is

not required to specify the functional form of the production relationship, and depending on the which version of DEA is used, it is often not necessary to specify prices or weights for inputs and outputs. Specifying weights is often one of the more challenging aspects of measuring productivity.[67] Finally, this method can easily deal with multiple inputs and outputs.

In terms of weaknesses, DEA is particularly sensitive to error in measurement error for frontier firms, since DEA uses these firms to derive efficiency. DEA also requires a large dataset, where a rough rule of thumb is that the number of observations needs to be at least three times the sum of the number of outputs and inputs to get worthwhile results. Finally, DEA has not typically been used to determine X-factors in regulatory proceedings, which can be related to them being difficult to explain, being regarded as a 'black box', and poor experiences with DEA by the regulators in the early years.

TFP index methods measure the ratio of all outputs to inputs, where input and output indexes are constructed using both quantities and prices of outputs and inputs. Traditionally, it can be used to compare rates of change of productivity but not absolute levels, though more recent developments have overcome this shortcoming. Benefits are that it is a relatively simple and robust technique, and thus it is often used for regulatory proceedings. As well, index number methods can incorporate many inputs and outputs with few observations. However, it requires values for all outputs and inputs. As well, it is not able to break down efficiencies into its component parts, such as scale efficiency or technical efficiency.

SFA is an econometric method which recognizes that some of the difference between a firm's actual costs and the line of best fit are due to random events rather than inefficiency. Like DEA, SFA is also able to break down efficiencies into its component parts, such as scale efficiency or technical efficiency. Finally, it is able to separate the error term in the stochastic production function into two elements - genuine inefficiency and random fluctuations.

In terms of disadvantages, SFA is an econometric method, which is generally more complex, difficult to communicate, and require significant data. They are therefore not typically used as frequently by experts performing productivity studies for ratemaking or other regulatory purposes. Rather, they are more often used in academic studies.[68] Furthermore, they require specification of production or cost function, and although they recognize randomness in the line of best fit, if there are in fact no measurement errors in the sample, some inefficiency would be regarded as noise.

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[67] The cost efficiency version of DEA requires specification of output and input weights in the DEA data set.

[68] OECD. *Measuring Productivity: Measurement of aggregate and industry-level productivity growth.* 2001.

9.1.2 Selecting the index TFP method

In order to choose the optimal TFP method, LEI reviewed eighteen TFP studies on electricity generation companies and distribution utilities, and has summarized the lessons learned in this section. Four different methodologies for measuring productivity were used in the studies reviewed which cover the most common methodologies. In order to summarize the studies reviewed, LEI aggregated information from all 13 generator academic studies, 1 government consultation and 4 regulatory productivity studies. [69] Many methods were reviewed for measuring productivity, but TFP index methods are most popular for regulatory purposes; although DEA is widely used for academic generation studies, its advantages are not useful in regulatory proceedings.

It is clear that DEA and TFP index methods are the most common in the utility industry. It is also clear that academic studies favour DEA. Multiple academic studies highlighted DEA's ability to break down inefficiencies and offer more detailed analysis, which allowed researchers to identify role models and make recommendations on improving efficiency. This is also an advantage for using SFA. However, these advantages are not particularly relevant for regulatory purposes, and the breakdown of efficiency into technical and allocative is not important for setting an X-factor. From this perspective, no method has a clear advantage in terms of results, which may explain why the DEA method was not seen in our selected regulatory studies.

It is important to note as well that both DEA and SFA are generally complex and difficult to communicate conceptually. The issue of complexity is particularly true in the case of econometric (and semiparametric) methods such as SFA and SPSC. These more complex methods are more often used in academic studies for their various benefits discussed above. However, because they can be difficult to explain in layman terms and are considered a 'black box', DEA, SFA and SPSC methods are not often used in government consultations and regulatory studies. Index methods on the other hand are easier to communicate because people can more easily understand the concept of taking weighted averages of output and input quantities, which is an advantage for regulators. This is one of the explanations for the popularity of index methods in regulatory work.

Data wise, it is also important to note that DEA is very observation intensive. For sensible results using DEA, with a reasonable number of outputs and inputs, one needs many observations, which may prove to be an issue within OPG's peer group. Index number methods, on the other hand, can incorporate many outputs and inputs with only a few observations. Finally, index number methods are also somewhat less sensitive to outlier observations and data errors, or at least the effects are more immediately obvious with index number methods.

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[69] Note that some studies used multiple methods.

To summarize, the indexing method is less complex, easier to communicate, and requires significantly less data than the other measuring techniques. While DEA and TFP methods are both commonly used for the electricity industry, DEA is less practical from a regulatory perspective, given its primary advantage is limited in value for setting an X-factor, it requires more data, and it is difficult to communicate. The indexing method, due to its transparency and relative simplicity, is most often the method of choice for productivity studies performed for regulatory purposes. Furthermore, in Ontario, the OEB has used the index methods for distributors. For these reasons, LEI believes the Index method is the optimal choice for measuring TFP in this study.

9.1.3 Selecting a TFP method: Review of previous studies

In order to choose the optimal TFP method, LEI reviewed eighteen TFP studies on electricity generation companies and distribution utilities, and has summarized key lessons learned in this section (for more detail see Section 9.1.2). TFP index methods were most popular for regulatory purposes, while DEA was widely used for academic generation studies but less so for regulatory proceedings.
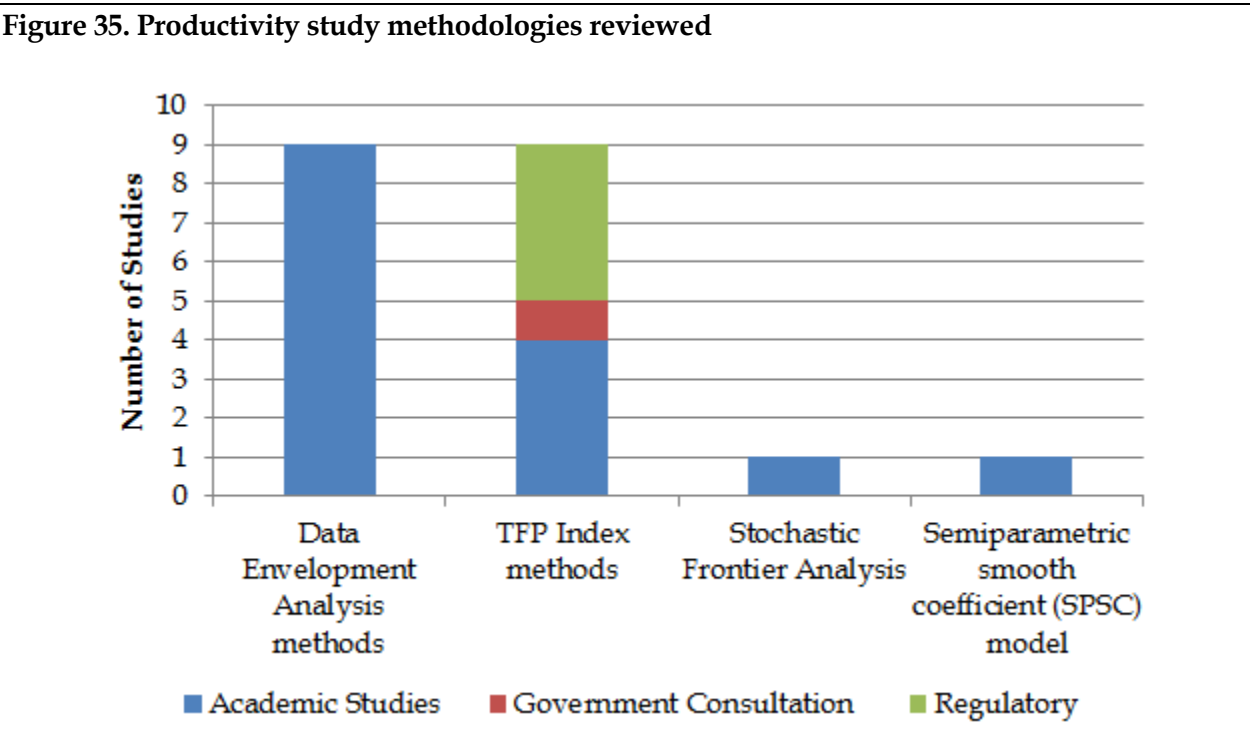
Figure 35. Productivity study methodologies reviewed

While DEA and TFP methods are both commonly used for the electricity industry, DEA is less practical from a regulatory perspective, given its primary advantage is limited in value for setting an X-factor, it requires more data, and it is difficult to communicate. The indexing method, due to its transparency and relative simplicity, is most often the method of choice for productivity studies performed for regulatory purposes. Furthermore, in Ontario, the OEB has

used the index methods for incentive regulation of distributors. For these reasons, LEI believes the Index method is the optimal choice for measuring TFP in this study.

9.1.3.1 Outputs used in TFP studies

As part of the review of 18 other productivity studies, LEI also looked at what outputs were commonly used. Despite the differences between the studies as far as methods and subject matter, there were many similarities in what was used as outputs. LEI has aggregated the parameters used by the studies related to generation, leaving out any transmission and distribution companies, as they have completely different parameters. This is summarized in Figure 36 and Figure 37 below. The most common output is energy generation in MWh, as that is what is being produced by every power plant. LEI also notes that generation data is readily available and can be consistently measured across a peer group. In two fossil fuel studies, pollutants were captured as a negative output; however, this will not be applicable to hydroelectric plants.

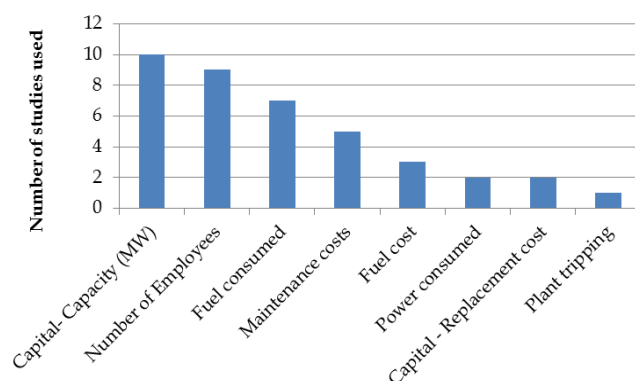**Figure 36. Outputs used in generation productivity studies**
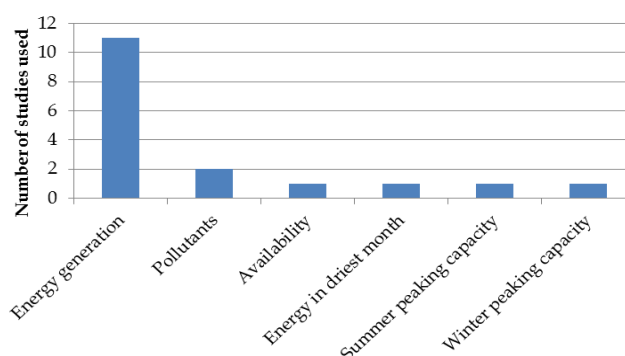
Figure 37. Example of outputs used in generation productivity studies

Outputs	Examples
Power Produced	• Generation (MWh) • Output in specific periods (e.g., to support resource adequacy)
Ancillary Services	• Reactive support/voltage control • Automatic Generation Control • Black start • Reliability must-run
Reliability	• Availability • Forced outage rates
Other Services	• Sale of ancillary services • Water management • Added flexibility to system

9.1.3.2   Inputs used in TFP studies

A review of the inputs used in eighteen previous productivity studies can be seen in Figure 38 and Figure 39 below. The most common input observed for generation related productivity studies was capacity (as a measure of capital). Specifically, capacity in MW is very commonly used as a proxy measure. Capital can also be measured using replacement cost, but is much less common – in fact, nearly every study used capacity as a measure of capital. Further discussion on physical as compared to monetary measures of capital can be found in Appendix C Section 10.

Figure 38. Inputs used in generation productivity studies

Figure 39. Example of inputs used in generation productivity studies

| Inputs	Examples
Capital	• Physical measure: Plant Capacity (MW) • Monetary measure: Depreciated or replacement value of capital stock
Operations and Maintenance	• Operations and Maintenance (O&M) without labour costs • Operations and Maintenance (O&M) with labour costs
Labour Employed	• Number of Employees • Wages ($)
Other Costs	• Power consumed • Environment and regulatory

The second most common input is number of employees, which captures the labour involved in power production. LEI decided against using number of employees in favour of O&M costs due to data limitations (employee figures were not readily available for all US peers). Labour costs were captured already in O&M costs and also in the input price indices. Another important

input is fuel, whether it is captured by fuel consumed (often in joules), power consumed (in MWh) or in terms of annual fuel costs. However, this method is more important when looking at thermal generation plants, and is not relevant the context of a hydroelectric TFP study.[70]

9.1.3.3   Length of TFP studies

LEI reviewed eighteen TFP studies sourced from academia as well as TFP studies performed for regulatory filings to aid in the determination of an appropriate period of study; Figure 40 shows the range in study period timeframe.

It is clear from the studies reviewed that a set of data which spans ten years or more is common for productivity studies. Although some academic studies have very short study periods, this can often be attributed to the purpose of the study, which is to make conclusions about the productivity method, rather than making a conclusion about productivity trends (which must be backed by a sufficiently large dataset). This can be observed in the fact that regulatory studies all used a study period of over 10 years.[71].

Figure 40. Length of reviewed productivity studies

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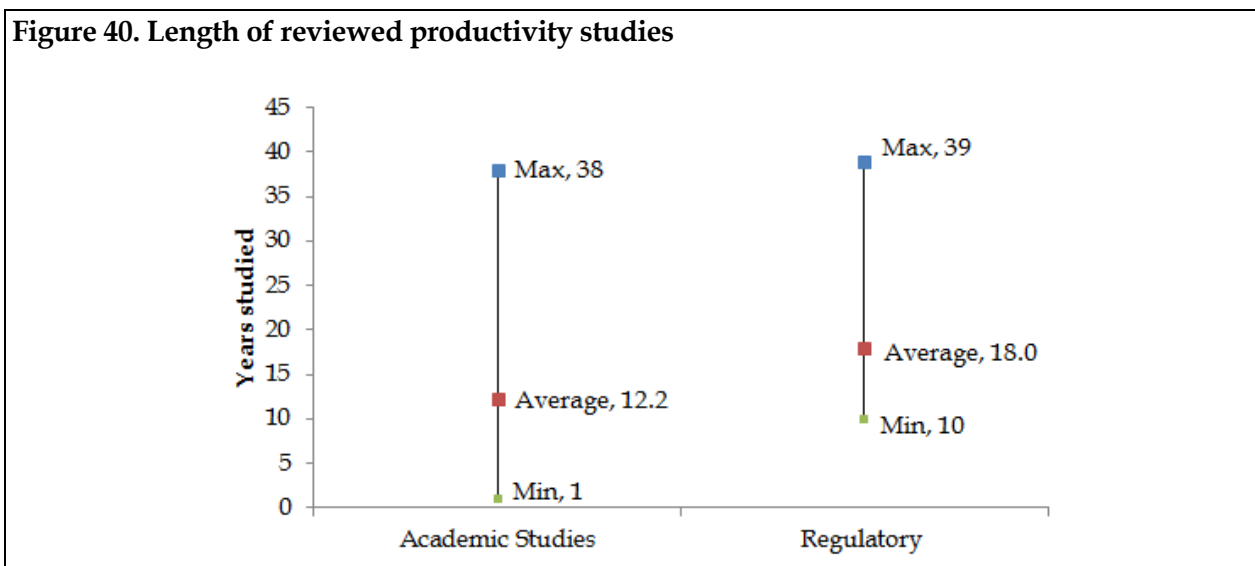
[70] 'Water for power' or water rental rates are more of flow-through items in the regulatory arrangement of hydroelectric operators and therefore do not affect productivity.

[71] LEI notes that the Pacific Economics Group ("PEG") report on productivity trends for Ontario electricity distributors, presented to the OEB in November 2013, also estimated TFP trends over the 2002-2012 period

10 Appendix C: Capital input quantities, physical or monetary approach

Selecting the appropriate inputs and outputs is a key part of a TFP study. As discussed in Section 4, for the hydroelectric business, one of the important inputs to production is capital. There are two possible methods for estimating capital input quantities: a physical method and a monetary method. The monetary method uses depreciated asset values in constant price dollar terms while the physical method uses physical indicators such as MW of capacity.

The perceived advantage of the monetary method is that it can include capital equipment of all kinds. Some practitioners also argue that the monetary method, with respect to some asset types, produces an estimate that reflects the quality of capital better. However, depreciated asset value methods do suffer from certain analytical subjectivity. For example, in order to approximate the capital input quantity under the monetary approach, one needs to employ a depreciation assumption – typically studies use either a declining balance or straight line depreciation assumption. Electricity generation assets tend to have long lives and produce a relatively constant flow of services over their useful lives (provided they are properly maintained). As a result, assumptions of declining balance or straight line depreciation are unlikely to properly reflect the true physical depreciation profile of these assets, which are more likely to exhibit a 'one horse shay' depreciation profile, as illustrated in Figure 41 below.

Figure 41. Efficiency profiles for alternative depreciation profiles
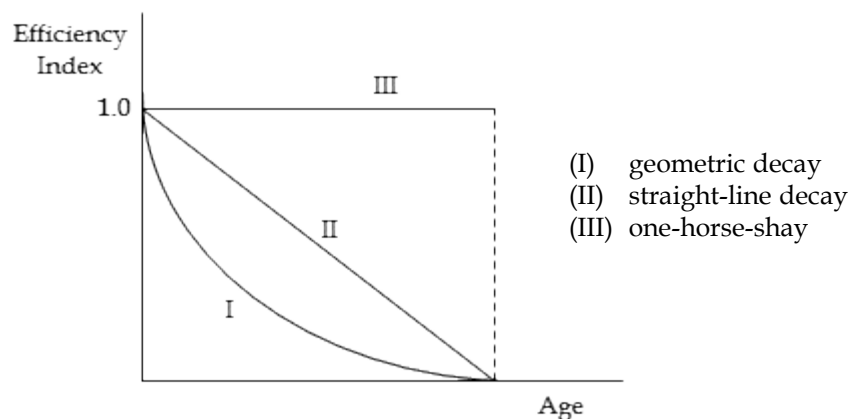
Source: Hulten and Wykoff, "The measures of economic depreciation." 1996

Furthermore, the monetary approach requires data going back many years, which would be difficult to gather for many industries, but is especially difficult in the generation sector of the electric power industry given the changes in corporate structures and ownership as a result of deregulation and restructuring. The data necessary includes: benchmark capital stock, capital additions since the base year, approved rate of return since the base year, and rate of depreciation. Generally, because measurement of capital depends on a benchmark of capital stock, many more years of data are required beyond the official start year of the TFP analysis in order to allow for an accurate capital measure under the monetary approach. Based on industry practice, a significant number of years of data is typically required (above and beyond the TFP

study timeframe) in order to estimate the capital input quantities. For example, in the electricity distribution sector, PEG used a capital benchmark year of 1989.[72]

In contrast, the physical method is straightforward if the capital input of the business can be adequately measured using physical proxies. For the generation-related TFP studies, it is common to use the installed capacity (in terms of MWs) to represent the capital input of the business. This is a readily available metric and comparably measured across companies and over time. Therefore, using the physical method of measuring capital (i.e. plant capacity in MW) was selected as the appropriate method for the purposes of this study.

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[72] PEG. *Productivity and Benchmarking Research in Support of Incentive Rate Setting in Ontario: Final Report to the Ontario Energy Board.* Issued November 2013. http://www.ontarioenergyboard.ca/oeb/_Documents/EB-2010-0379/EB-2010-0379_Final_PEG_Report_20131111.pdf