TAF The Atmospheric Fund

A Clearer View on Ontario's Emissions

Electricity emissions factors and guidelines

2019 EDITION

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About The Atmospheric Fund

The Atmospheric Fund (TAF) is a regional climate agency that invests in low-carbon solutions in the Greater Toronto and Hamilton Area and helps scale them up for broad implementation. TAF is supported by dedicated endowment funds provided by the City of Toronto (1991) and the Province of Ontario (2016).

THE ATMOSPHERIC FUND

75 Elizabeth Street
Toronto, ON M5G 1P4

taf.ca
info@taf.ca
@AtmosphericFund

Juan Sotes,
Carbon & Co-Benefits Quantification Manager
jsotes@taf.ca

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Ontario TORONTO

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Foreword

Precise quantification is the backbone of good strategy

With climate actions gaining momentum worldwide, the importance of accurate carbon emissions quantification and estimation has grown. Only with precise emissions calculations can we properly identify, prioritize, and monitor climate change mitigation strategies.

When it comes to electricity-related emissions, conventional methods can oversimplify and potentially distort the emissions impact of consumption, conservation, and the shift to renewables.

At the core of it is the electricity mix that's unique for each jurisdiction. In Ontario, more than 90 per cent of electricity is produced carbon free (from hydro, nuclear, and renewables), but the remainder comes from natural gas – especially during peak hours. While natural gas supplies a small share of electricity in Ontario, it is disproportionately likely to be the generating resource that responds to changes in demand. That's why an in-depth understanding of Ontario's electricity emissions, and the use of appropriate emissions factors, is key to properly quantifying the carbon impact of projects, programs, and policies that affect electricity consumption or generation.

In order to improve carbon quantification practices, TAF has developed a range of electricity emissions factors for different purposes. This document summarizes those factors, outlines the methodology and data sources used, and provides guidelines for which emissions factor to apply for different purposes. This 2019 document is an update of our original guidelines. It contains updated data, seasonal emissions factors, and an improved methodology, based on further research as well as valuable feedback received from readers of the previous edition.

The emissions factors and this guide will be especially helpful for Ontario's provincial and municipal policymakers, engineers, scientists, electricity industry professionals, and non-profit organizations involved in the quantification of carbon emissions.

Guidelines

Quantifying carbon emissions typically fulfils one of two purposes:

- To understand current or historical emissions, such as with a carbon[1] inventory for an organization or city
- To evaluate the carbon impacts of an actual or potential change, such as a project, policy, or infrastructure decision

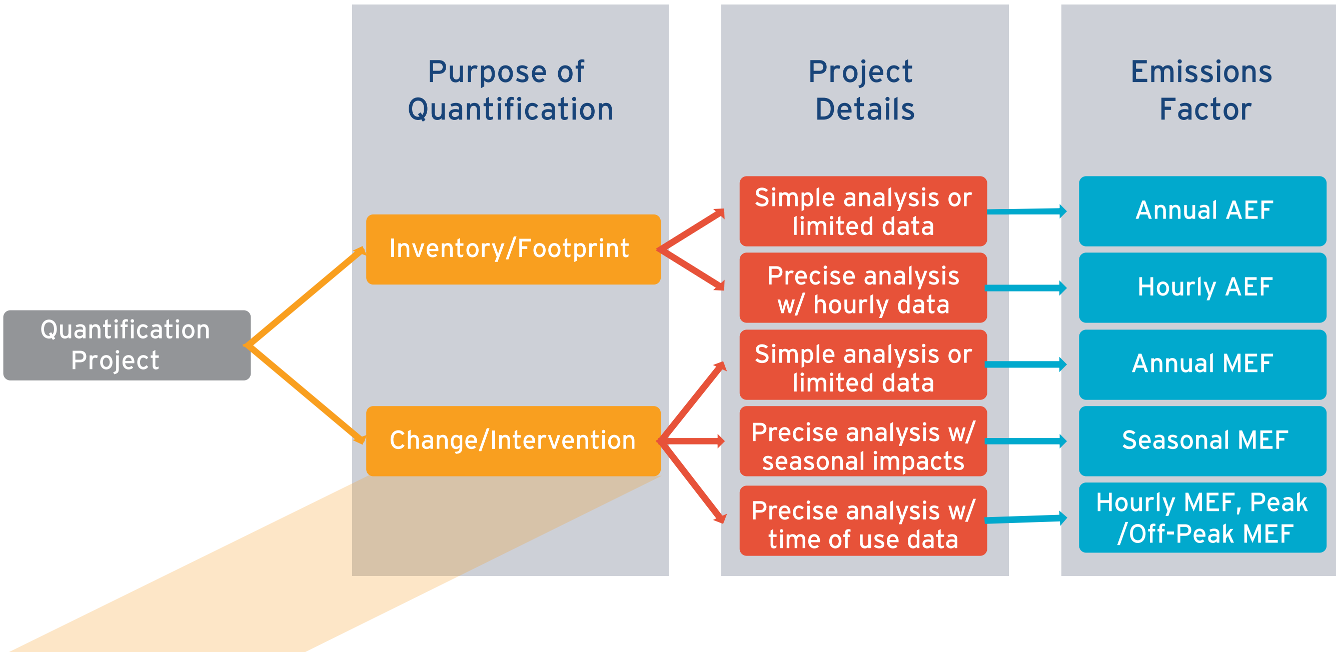
Quantifying current or historical emissions related to electricity generally involves determining the quantity of energy consumed and multiplying it by the average carbon intensity of the electricity supply. Quantifying the carbon impact of a change (real or proposed) is more complex. In addition to understanding the quantity of electricity consumed, conserved or generated as a result of the change, quantifying the carbon impact requires consideration of the marginal impact on the electricity system. In other words, it requires consideration of which generating source (hydro, nuclear, renewables, or natural gas) is expected to respond to the change in electricity demand.

Although the resource in question is the same (electricity), different electricity emissions factors should be used for different quantification purposes:

- **If the purpose is to inventory, use an Average Emissions Factor:** When quantifying current or historical emissions resulting from electricity consumption, use an Average Emissions Factor (AEF).
- **If the purpose is to quantify impact, use a Marginal Emissions Factor:** When estimating the carbon impact of a change, like from an energy efficiency or renewable energy project, use a Marginal Emissions Factor (MEF). This is because changing the demand for grid electricity results in specific facilities increasing or decreasing electricity production. The impact of the change is not evenly distributed across all generating resources.
- **In either case, when forecasting, use a Forecasted Emissions Factor:** When estimating future carbon emissions, use a Forecasted Emissions Factor, either Forecasted AEF or Forecasted MEF. The electricity system evolves over time and the Independent Electricity System Operator (IESO) provides regularly updated forecasts of future generation sources. Generally, estimating future emissions is done when looking at the impact of a change, and therefore a forecasted MEF is recommended. Based on the latest available forecasts from IESO, electricity emissions factors are expected to trend upwards over time. These expected changes in the electricity system should be accounted for when estimating long-term impacts. However, one should bear in mind that there is significant uncertainty around the forecasted factors, as policy decisions and technological developments may result in material changes to the forecasts.

[1] TAF uses the term carbon to refer to CO_2 equivalent, regardless of the specific greenhouse gases involved.

Decision Aids



Type of Intervention	Examples	Preferable emissions factor	Backup emissions factor
Electricity efficiency	Lighting retrofit	If the lights are only on overnight: Off-Peak MEF	If the lights are on all day, or it is unknown: Annual MEF
Electricity storage	A battery that can be charged off peak and then used to supply electricity during peak hours	If the specific hours are known: Hourly MEF	If the specific hours are unknown: Peak / Off-Peak MEF
Load shifting	Shifting use of appliances such as laundry machines and dishwashers to off-peak times	If the specific hours are known: Hourly MEF	If the specific hours are unknown: Peak / Off-Peak MEF
Renewable electricity generation	Installing solar photovoltaic (PV) panels	If the hourly production data is available or can be estimated: Hourly MEF	Simple analysis or hourly data unknown: Peak MEF
Increase in electricity-consuming activities	Increasing deployment of electric vehicles	If predominately charged overnight: Off-Peak MEF	Charging time unknown or random: Annual MEF

Methodology Overview

TAF has developed a series of electricity emissions factors: AEFs (annual and hourly), MEFs (annual, hourly, peak, off peak, and seasonal), and forecasted emissions factors. All data used to generate the electricity emissions factors come from publicly available data from IESO or the Government of Canada's *National Inventory Report*. The forecasted emissions factors are based on the latest IESO forecasts for electricity supply and demand. A more detailed description of the sources of information and methodology is presented in the appendix.

Limitations

All the emissions factors presented in this report exclude the impacts of:

- Emissions associated with the construction, maintenance, and eventual decommissioning of power plants or renewable energy facilities
- Location of the consumption or generation of electricity and thus the effect that transmission bottlenecks might have on emissions
- Upstream emissions from natural gas production and transmission as well as uranium mining and processing
- Emissions generated from imported electricity[2]

Major changes in province-wide electricity consumption or production will themselves affect the MEF once implemented. The methodology applied to obtain the factors presented in this report allows the accurate use of MEF values up to 100 MW of change in demand or generation. Beyond that, the MEF values will gradually start to change. Therefore, caution should be used in applying the MEFs presented in this report to large-scale, transformative interventions; a customized modelling approach would be preferable.

Emissions Factor		Methodology
Average Emissions Factor	Annual	The total emissions from electricity production in Ontario divided by the total electricity produced in any given year.
	Hourly	The total emissions from electricity production in Ontario divided by the total electricity produced in a specific hour of the day, averaged over the year.
Marginal Emissions Factor	Annual	The emissions generated by changes in generation divided by the changes in electricity production in any given year.
	Hourly	The emissions generated by changes in generation divided by the changes in electricity production in a specific hour of the day, averaged over the year.
	Peak/Off Peak	Like Annual MEF but calculated separately for peak and off-peak hours.
	Seasonal	Like Annual MEF, but calculated separately for each season of the year.
Forecasted	Annual AEF	Forecasted Annual AEFs for 2019-2035.
	Annual MEF	Forecasted Annual MEFs for 2019-2035.
	Peak/Off-Peak MEF	Forecasted Peak and Off-Peak MEFs for 2019-2035.

[2] 97% of Ontario's 2017 imports came from Quebec and Manitoba, with very low or zero emissions associated. Therefore, electricity imports are unlikely to increase the emissions factors. (see http://www.ieso.ca/en/Power-Data/Supply-Overview/Imports-and-Exports)

Emissions Factors and Their Applications

Annual Average Emissions Factor

The Annual AEF is a measure of the average amount of carbon pollution produced per kWh of electricity consumed in Ontario, and is reported annually in Canada's National Inventory Reports (NIR) as consumption intensity. Since the 2019 NIR only includes data up to 2017, TAF calculated the factor for 2018. Annual AEFs are intended for calculating emissions from current or historical electricity consumption (such as for an inventory).

2018 Value
Annual AEF
31
(g CO_2eq/kWh)

Calculated with 2018 IESO data and TAF's internal methodology.

Example

When calculating the emissions generated by a specific building over a year, the total kWh of electricity consumption will be multiplied by the AEF value. For example:

150,000 kWh x 31 g CO_2e per kWh = 4,650,000 gCO_2e = 4.65 TCO_2e.

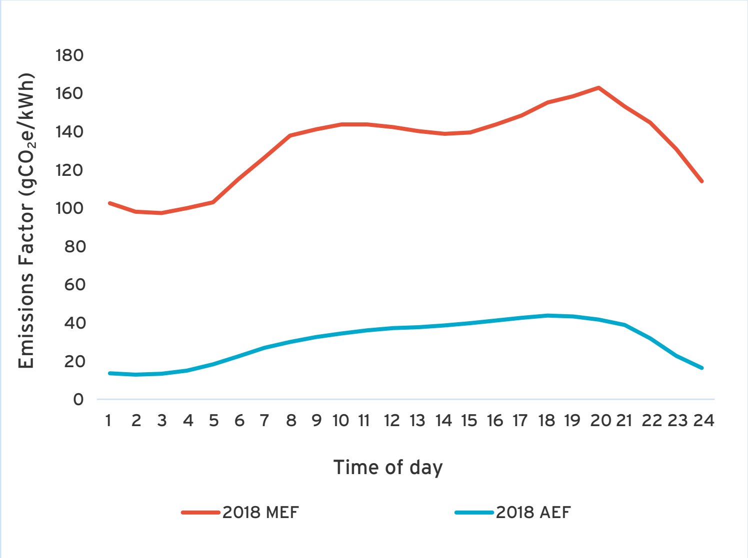
Hourly Average Emissions Factor

The Hourly AEF is similar to the Annual AEF, but reflects the average carbon intensity of electricity consumed in Ontario in any given hour. It can be used for calculating emissions from current or historical electricity consumption when a greater degree of precision is needed and where hourly data is available or can be estimated.

As the graph demonstrates, Hourly AEFs and MEFs are quite different.

Values, Hourly AEFs

Hourly AEF (gCO_2eq/kWh)					
	2018	**2017**	**2016**	**2015**	**2014**
1	14	12	27	34	29
2	13	12	26	33	29
3	13	12	26	33	29
4	15	12	27	35	31
5	18	14	29	38	33
6	23	15	32	41	36
7	27	17	35	44	39
8	30	18	37	47	42
9	32	19	40	48	43
10	34	20	41	50	44
11	36	21	42	51	46
12	37	22	44	53	47
13	38	23	44	53	47
14	39	24	46	54	48
15	40	25	47	55	48
16	41	26	49	56	49
17	43	27	50	57	50
18	44	28	51	58	50
19	43	27	51	58	50
20	42	26	51	57	49
21	39	24	49	56	47
22	32	21	44	50	43
23	23	17	36	43	37
24	16	13	30	38	31



Annual Marginal Emissions Factor

In Ontario, electricity generation is predominantly nuclear (59 per cent) and hydro power (21 per cent) (IESO, 2018), but conserving electricity is expected to disproportionately reduce natural gas-fired generation. Because of its relatively higher cost and ability to rapidly increase/decrease production, natural gas power plants are frequently used to respond to changes in demand (in other words, they are 'on the margin'). Nuclear power plants are rarely on the margin because they have very limited ability to adjust output. An emissions factor which reflects this reality is commonly referred to as MEF.

As there are no commonly accepted Ontario-specific MEFs, TAF has developed them.

2018 Value
Annual MEF
134
(g CO_2eq/kWh)

Calculated with 2018 IESO data and TAF's internal methodology.

The Annual MEF[3] is an estimate of the change in carbon emissions resulting from an actual or proposed change in electricity consumption in Ontario, whether the change in question is an increase or decrease. It is also applicable to renewable energy projects, as these reduce demand for grid-supplied electricity.

An annual MEF will be sufficient for many purposes. Estimates can be refined by applying hourly, seasonal, peak, and off-peak MEFs. In case of doubt about which MEF to use, Annual MEF is recommended. Notably, it is not possible to quantify the impact of energy storage or load shifting initiatives without the use of either hourly or peak/off-peak factors.

Example

Lighting retrofits illustrate the importance of using MEFs to estimate the impact of changes in electricity consumption. Installing more energy-efficient lights has cross effects with heating and cooling systems. Since inefficient lights produce a lot of waste heat, removing them can increase the heating system's energy use during the winter and also reduce the cooling system's energy use in the summer. Using Annual AEF, energy efficient lighting upgrades seem to result in a net increase in carbon emissions. But using the Annual MEF shows that the real impact is a net reduction, even when taking account of the cross effect on the heating system.

The review of a feasibility study provided the following results:

- A: Savings from change in lighting: 94,249 kWh/year
- B: Increase in natural gas consumption for heating: 6,116 m^3/year
- C: Reduction in electricity consumption for cooling: 2,495 kWh/year

Carbon reductions = A (electricity emissions factor) - B (natural gas emissions factor) + C (electricity emissions factor)

If we use the Annual AEF (31), the change of light bulbs would be thought to increase emissions 14.54 TCO_2e/year. But using Annual MEF (134) shows the reduction to be 1.35 TCO_2e/year.

[3] It was called Annual Average Marginal Emissions Factor (AAMEF) in the previous report, but TAF has changed the name to avoid confusions with the AEF.

Hourly Marginal Emissions Factor

Hourly MEFs are similar to the Annual MEF, but reflect the change in carbon emissions resulting from a change in electricity consumption in Ontario in any given hour.

Hourly MEFs enable additional precision and customization. Hourly factors can be applied to interventions where specific hourly changes in electricity generation or consumption are known or can be estimated – for example, switching electric appliance usage to night hours, solar PV generation, battery storage). It is worth mentioning that the differences in hourly MEF throughout the day are not as significant on the weekend, when total demand is lower.

Example

A combined heat and power (CHP) is a natural-gas powered reciprocating engine that is used to generate heat and electricity. A case study that used the CHP to generate electricity and heat domestic hot water provided the following results:

- Savings in grid electricity consumption: 562,192 kWh/year
- Net Increase in natural gas consumption: 58,147 m^3

Carbon reductions = SE-ING

- **SE:** Carbon savings in electricity consumption
- **ING:** Carbon increase in natural gas consumption

The use of Hourly MEF results in a more accurate way to estimate the difference between CHP and electricity consumption. Using the AEF, the use of CHP systems would result in an increase of 93 TCO_2e/year, but considering that the system would be activated in the late afternoon, from 6m to 9pm, and using the relevant Hourly MEFs, the increase in carbon emissions would account only for 22 TCO_2e/year. Note that in both cases, the net result remains an increase in carbon emissions.

Values, Hourly MEFs

	Hourly MEFs (gCO_2eq/kWh)				
	2018	**2017**	**2016**	**2015**	**2014**
1	102	53	90	120	92
2	98	47	80	111	82
3	97	47	74	111	81
4	100	47	76	114	80
5	103	48	83	117	88
6	115	53	96	123	100
7	126	64	107	124	115
8	138	73	121	130	131
9	141	76	126	135	137
10	144	82	129	136	143
11	144	85	126	139	144
12	142	86	126	139	147
13	140	88	127	139	148
14	139	87	129	138	145
15	139	90	126	139	148
16	144	90	131	143	151
17	148	91	137	145	160
18	155	100	144	141	161
19	158	103	149	145	165
20	163	100	151	144	167
21	153	99	143	142	156
22	145	84	133	141	143
23	131	70	121	135	124
24	114	59	106	127	105

Peak and Off-Peak Marginal Emissions Factor

Peak and Off-Peak MEFs are a measure of the carbon impacts of changes in electricity consumption during peak and off-peak times. They are simpler to apply than hourly MEFs, but still provide greater precision than an Annual MEF. Peak hours are defined as weekdays, 7am to 7pm, following IESO's definition[4]. As with Hourly MEFs, Peak and Off-Peak MEFs can be used for time shifting consumption and energy savings during peak hours. These MEFs are recommended when there is not enough information about the exact hours of the day where the shift on electricity consumption is taking place, or only an approximate calculation is needed.

Values, Peak and Off-Peak MEFs

	MEF (gCO_2eq/kWh)				
	2018	**2017**	**2016**	**2015**	**2014**
Peak MEF	148	91	134	141	157
Off-Peak MEF	123	66	108	127	113
Annual MEF (as comparison)	134	77	120	133	131

[4] The separation is the same for all years, following IESO's criteria, although for some years a high Hourly MEF can be observed also from 8-9pm, increasing the Off-Peak MEF.

Example: Load Shifting

As with the hourly MEF, when applying MEFs to energy storage or load-shifting strategies, apply them to both the consumption of electricity (for example, energy drawn from the grid to charge a battery) and the avoided consumption (for example, energy drawn from a battery instead of the grid). The quantities of electricity that would have been consumed with and without the strategies in place should be multiplied by their respective MEFs. The net difference in emissions is then the impact of the strategy.

Let's imagine a household shifts its 3 kWh consumption of their electric clothes dryer from peak to off-peak hours, and dries three laundry loads a week on average.

The avoided carbon emissions in 2018 =

3 kWh x 3 loads/week x 52 weeks/year x Peak MEF 148 gCO_2eq/kWh = 69,264 gCO_2eq

The generated carbon emissions in 2018 =

3 kWh x 3 loads/week x 52 weeks/year x Off-Peak MEF 124 gCO_2eq/kWh = 58,032 gCO_2eq

Net difference = 11,232 gCO_2eq, a 16 per cent carbon reduction over the year.

Example: Renewable Generation

One of the positive attributes of solar energy is that it is peak coincident, meaning the panels produce energy primarily during peak hours. When installing solar panels, the avoided emissions would be equal to the total energy generated by the panels. If the panels generated 15,000 kWh over the year, and assuming that this energy is not stored (avoiding peak emissions), the carbon emissions reduction in 2018 would be:

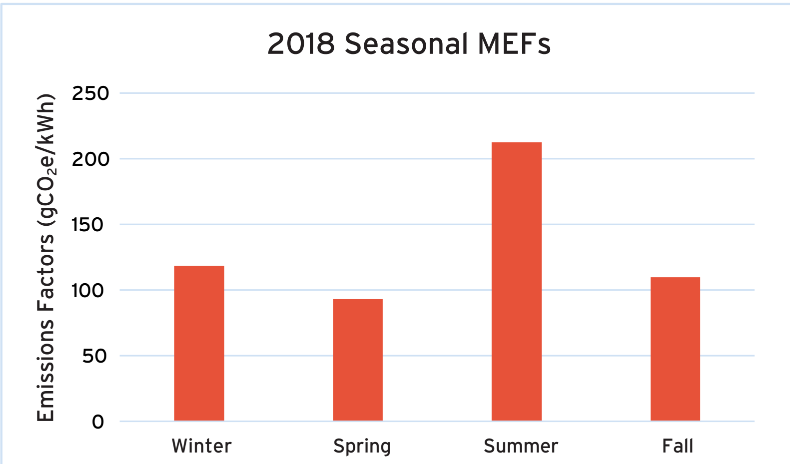
Carbon reductions = 15,000 kWh x 148 gCO_2e/kWh = 2,220,000 gCO_2e = 2.22 TCO_2e

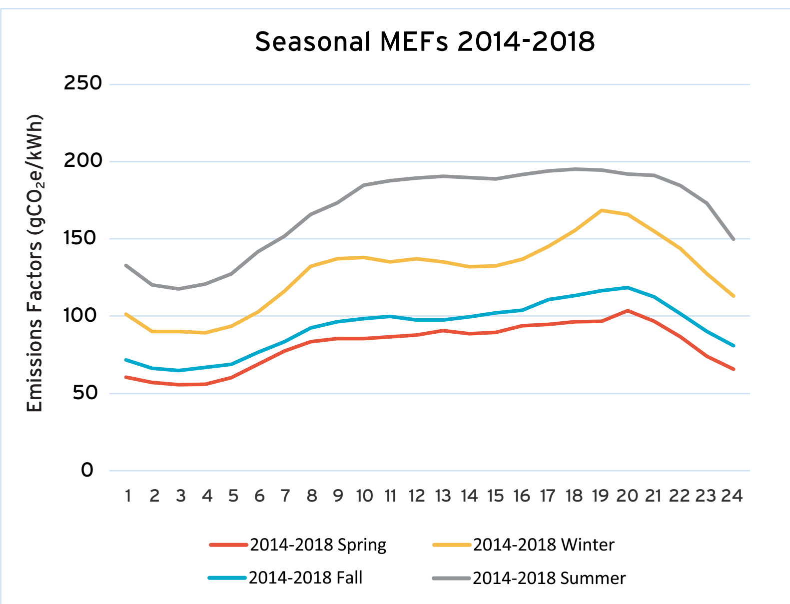
In the case of solar energy, Hourly MEFs could be used to provide a more accurate estimate of carbon reductions. However, a Peak MEF provides a reasonable approximation and is far simpler to apply.

Seasonal Marginal Emissions Factor

Electricity demand and generation both vary seasonally. Seasonal MEFs[5] provide a measure of the carbon impact of changes in electricity consumption in any given season. Seasonal MEFs can be used to calculate emissions when an intervention impacts electricity consumption in a specific time of the year. For example, a winter MEF can be used for heating interventions and a summer MEF for cooling.

Seasonal MEFs are not forecasted since summer and winter MEFs are highly dependent on extreme temperatures impossible to predict.





The MEF is lowest in spring, with relatively low demand due to mild temperatures and high availability of hydro generation enhanced by the snow thaw. Fall also has low demand, but not the same availability of hydro generation, which is why it's higher than spring. Winter has a higher MEF due to higher consumption from electric heating systems, but a similar trend as the shoulder season, with more noticeable peaks around 8am and 8pm. Summer is characterized by the highest MEF, and notable spike during the middle of the day, both associated with the higher cooling loads resulting from higher daytime temperatures in the summer.

MEF values for summer and winter are highly influenced by temperature. For example, the MEF curve in a year with extremely high temperatures in summer can be expected to show higher values than a mild winter.

[5] Winter: December 21 to March 20; Spring: March 21 to June 20; Summer: June 21 to September20; Fall: September 21 to December 20.

Example

If a building installs a more efficient chiller, the electricity savings will occur primarily over the summer, therefore a summer MEF is recommended to better estimate the real impact of the improvement. Replacing a chiller with a full load efficiency of 0.83 kW/ton for one with 0.6 kW/ton, for 500 tonnes capacity, which runs for 2,000 hours over the summer, would result in:

Reduction in electricity consumption =
(0.83 – 0.6) kW/ton x 500 Tonnes x 2,000 hours =
230,000 kWh

Carbon emissions reduction =
230,000 kWh x 213 gCO_2e/kWh = 48,990,000 gCO_2e
= **48.99 TCO_2e**

Values, Seasonal MEFs

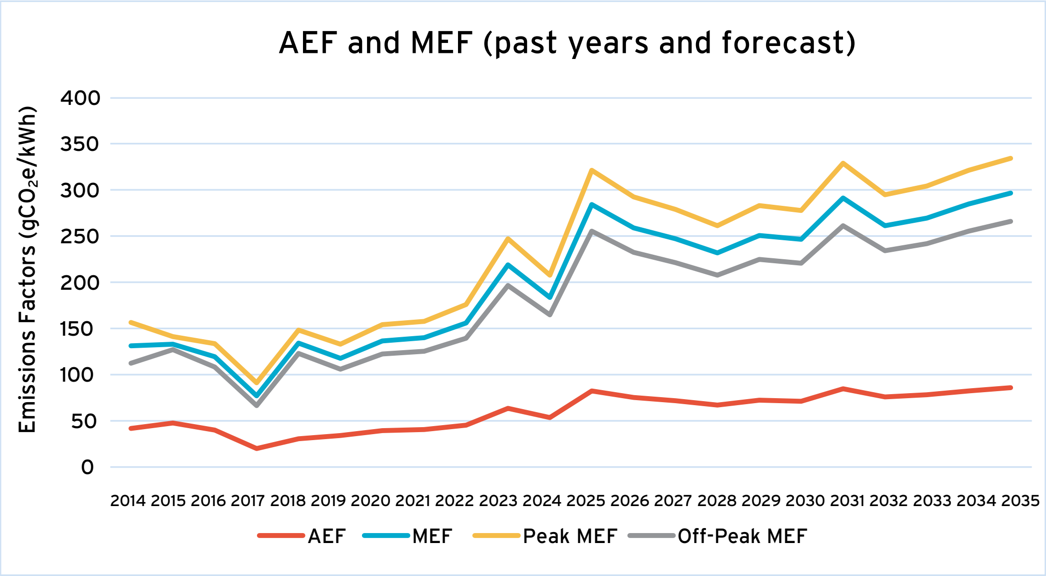
	2018 Seasonal MEFs (gCO_2eq/kWh)			
Hour	**Winter**	**Spring**	**Summer**	**Fall**
1	94	60	187	68
2	87	61	184	58
3	85	58	191	54
4	89	56	199	54
5	89	65	194	62
6	91	76	206	86
7	103	86	217	98
8	121	95	221	113
9	126	97	224	116
10	126	104	222	121
11	125	102	224	123
12	125	98	226	119
13	123	104	214	119
14	122	100	214	118
15	122	102	212	121
16	126	107	213	127
17	131	109	212	140
18	135	120	219	146
19	150	115	215	153
20	155	121	220	155
21	141	111	219	141
22	133	100	226	119
23	117	83	225	97
24	99	74	202	79
Seasonal Average	**119**	**93**	**213**	**110**

Forecasted Emissions Factors

In many cases, it is desirable to understand the impact of changes in electricity consumption well into the future (for example, over the expected life of a renewable energy project). It is common practice to use the most recent year's emissions factor and simply carry it forward. However, it is possible to forecast future emissions factors, based on published IESO data, and the use of forecasted factors is likely to be more accurate. TAF has forecasted most emissions factors to 2035. In order to forecast the MEF for future years, TAF has used the total and natural gas generation values presented in the last IESO's Technical Planning Committee (IESO, Technical Planning Committee, 2018 II).

There is an expected increase in natural gas electricity generation over the next 15 years in the province, which is the reason for the increase in both AEFs and MEFs. Emissions are forecasted to gradually increase from 3.35 MT CO_2e in 2018 to 10.90 MT CO_2e in 2035. The forecasted emissions factor will help to avoid underestimating the effects of interventions in the future, since any increase or reduction in consumption will have a progressively bigger impact over the next 15 years.

IESO's forecast changes over time, with any new policy decisions and technological developments, and there is considerable uncertainty around the forecasted factors, becoming more significant as the forecasts go further into the future. Changes may result in material variations to the forecasts, but the information used for this report is the most accurate available.



Values, Forecasted Emissions Factors

	Emissions Factors (gCO_2eq/kWh)			
Year	**AEF**	**MEF**	**Peak MEF**	**Off-Peak MEF**
2019	34	118	133	106
2020	40	136	154	122
2021	41	140	158	125
2022	45	156	176	140
2023	63	219	247	197
2024	53	184	208	165
2025	82	284	321	255
2026	75	259	293	232
2027	72	247	279	221
2028	67	232	261	208
2029	73	251	283	225
2030	71	246	278	221
2031	84	292	329	262
2032	76	261	295	234
2033	78	270	304	242
2034	82	285	321	255
2035	86	296	335	266

Appendix: Methodology

Electricity Generation

The electricity market is highly complex, and there are multiple variables that determine which resource is on the margin at any given point in time. Different approaches can be applied to determine the MEF of electricity generation such as total generation, changes in generation, and market price. Most of the time, the availability of data is the factor that determines which methodology can provide better results. IESO makes several sets of data available to the public (including a series of public reports[6] and a data directory[7]), but this data is not enough to accurately determine marginal values (confirmed by IESO).

For our purposes – using MEFs to better reflect the change in emissions associated with increasing or decreasing demand at any given moment – a good proxy to determine the marginal resource would be the type of generator that sets the market clearing price, but unfortunately the IESO does not generate a report on marginal resources.

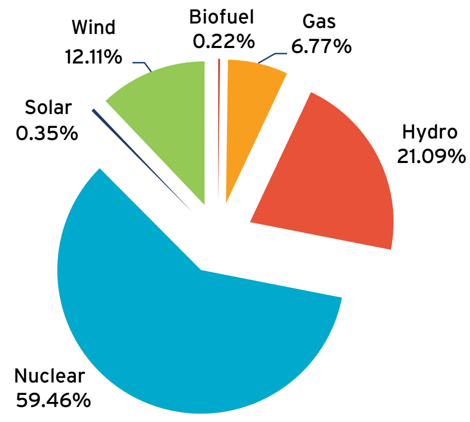
The best available source of information is the *Generator Output and Capability Report* (IESO 2018 III) which presents "the energy output and capability for generating facilities in the IESO-administered energy market with a maximum output capability of 20 MW or more. For variable generation only, forecast values are published instead of capability, as this provides a more accurate view of how much energy these units could be expected to produce."

Using this data carries certain limitations:

- "Behind the meter" generation in Ontario is not captured by IESO's generation data which only reports distribution connected and contracted generators. This document is not intended to provide information or emissions factors for this type of electricity generation.
- There are 3,337 contracts[8] with an output capability of 20 MW or less that account for 2,487 MW. Only 21 small generators run on natural gas, with a capacity of 107 MW. Those small contractors, many of which are clean energy, would most certainly lower the amount of natural gas on the margin.

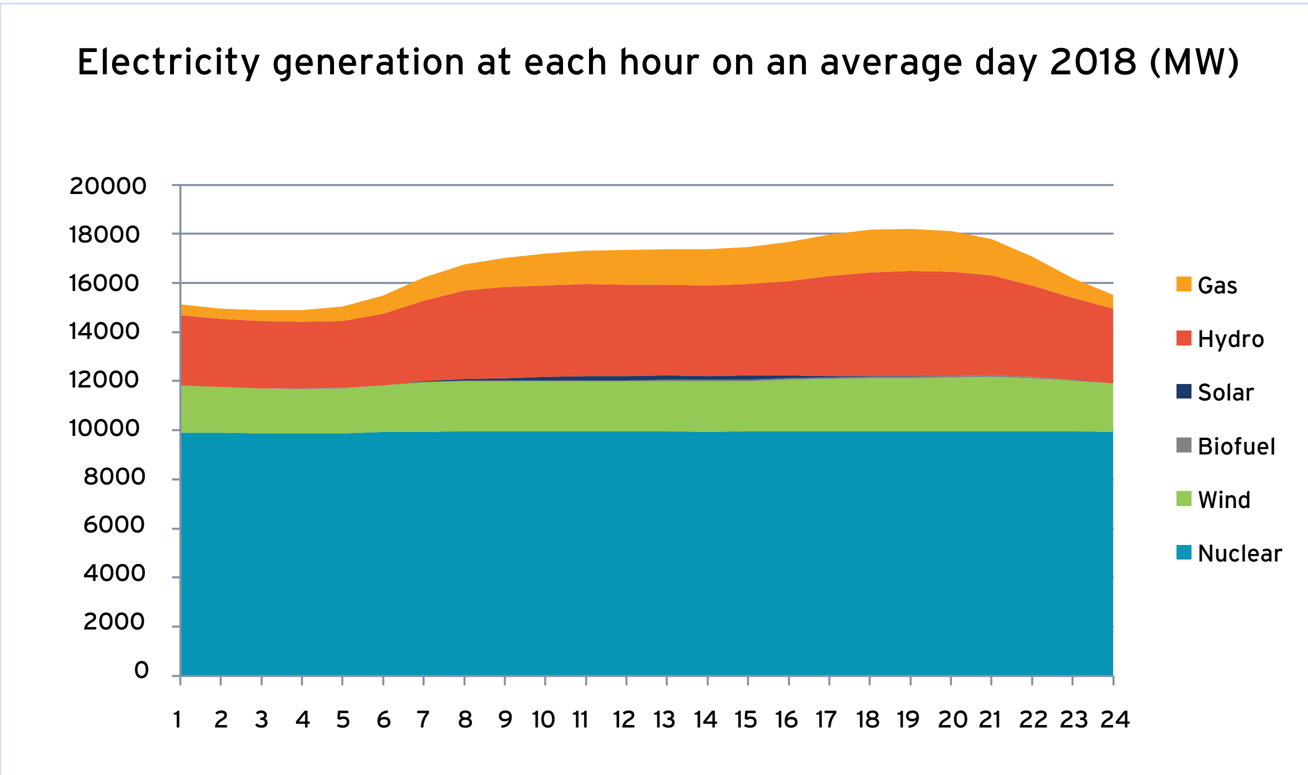
The *Generator Output and Capability Report* database provides hourly generation values. By adding the hourly generation per type of generator, it is possible to determine the total generation and hourly changes by source. For 2018, the total electricity generation in Ontario accounted for 146.36 TWh, imports for 8.43 TWh and exports for 18.59 TWh. Total demand was 137.4 TWh, a four per cent increase from 2017[9].

Ontario Electricity Generation 2018



[6] Available at http://reports.ieso.ca/public/.
[7] Available at http://www.ieso.ca/Power-Data/Data-Directory.
[8] Available data at the IESO Active Contracted Generation List.
[9] Data available at http://www.ieso.ca/en/Corporate-IESO/Media/Year-End-Data.

The electricity generation on an average day follows a similar pattern as demand, with a small peak around 9am and one more significant around 7pm. The two main sources that changes generation over the day to meet demand are hydro and natural gas, making them the most prominent resources in marginal electricity generation.

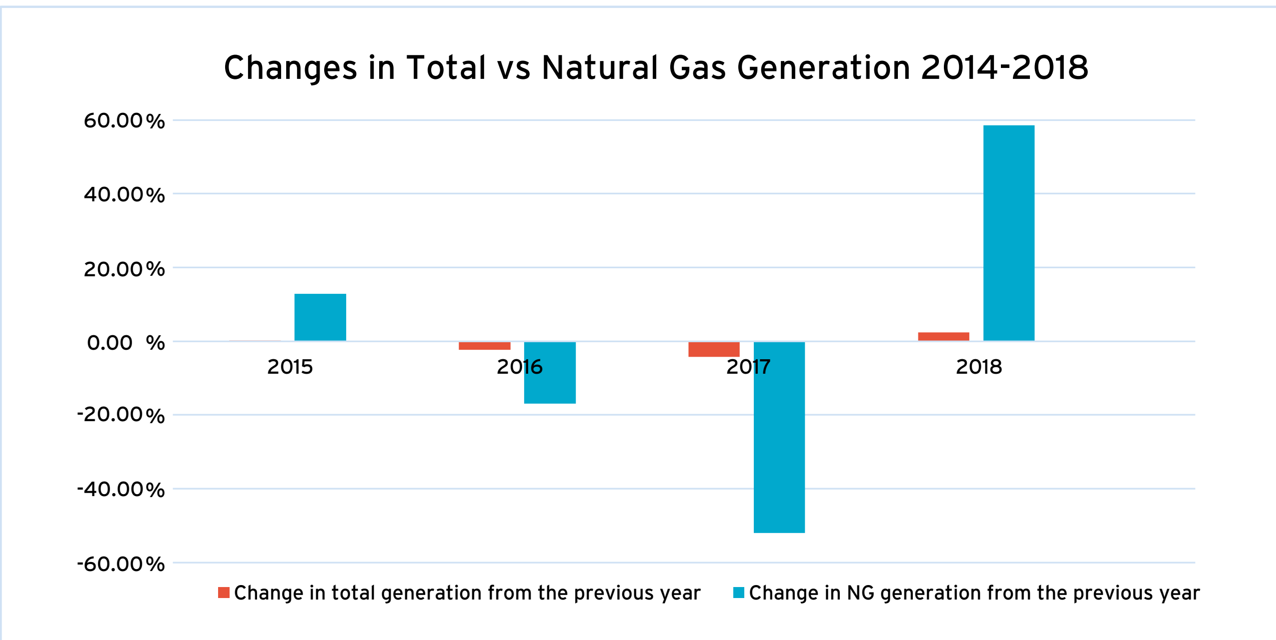


Natural Gas Generation

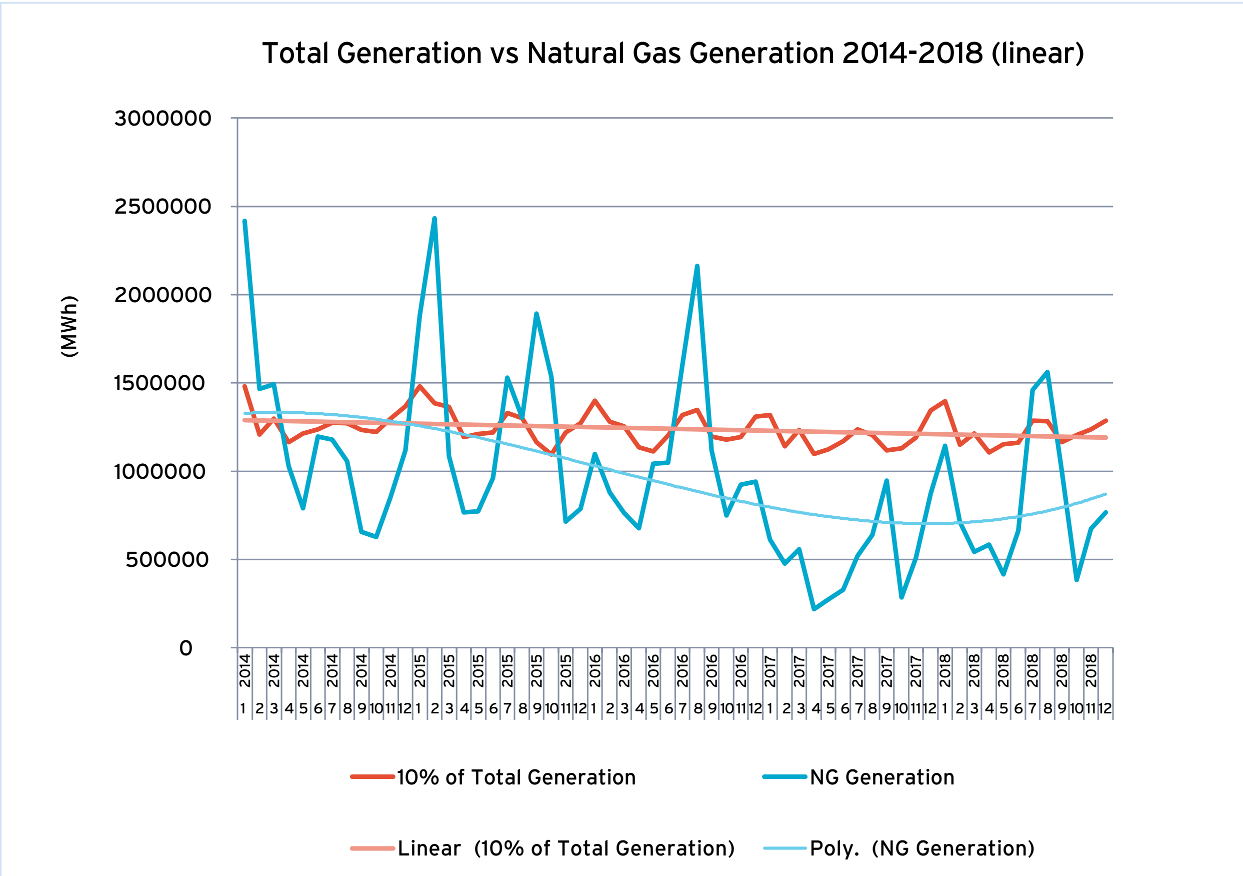
The only source of carbon emissions in Ontario's electricity generation is natural gas (biofuel consumption is negligible). Therefore in order to determine the MEF, the goal is to determine the proportion of natural gas on the margin.

Electricity generated with natural gas is an expensive resource, and it's used to provide flexibility to the system and increase supply in periods of high demand, but these are not the only variables that influence natural gas generation. For example, an important part of natural gas generation is the combined cycle plants, which require long periods of time to start and then need to run for at least four hours, excluding this generation from short-term changes in demand; natural gas generators also run at night to carry out capacity and other tests. There are also generators running under contracts signed before the market implementation, which generate electricity regardless of demand.

One constant that can be observed is that small changes in total generation result in a much larger change in natural gas generation.



Looking at generation as a linear variation, it's possible to appreciate that demand has been stable over the last years, with a progressive decline in natural gas generation. This trend was accentuated in 2017, probably given the mild temperatures in both winter and summer. IESO expects natural gas generation to increase in the next 15 years.



Changes in Methodology

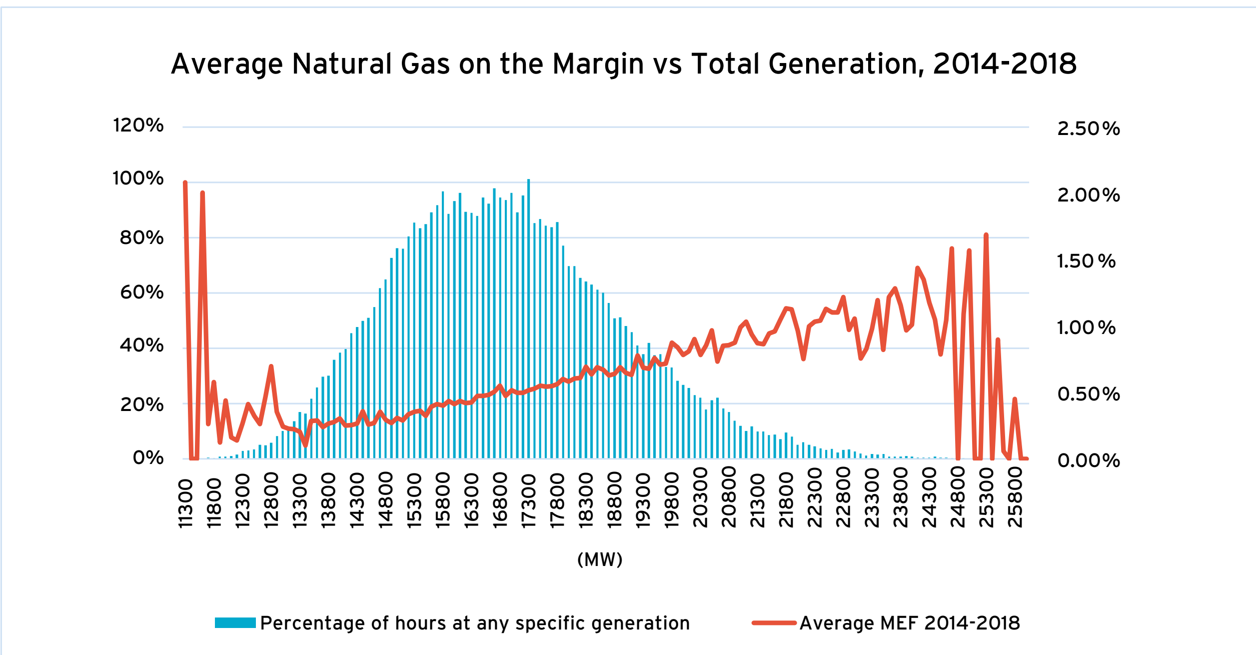
Given that the publicly available information is not enough to determine the MEF, several assumptions must be made in order to process the data.

In TAF's last publication, we applied the following constraints to obtain our MEF values:

- It had to be a minimum one per cent change in generation compared to the previous hour.
- To be consider as marginal generator, a source had to account for at least 20 per cent of the change in generation

Those constraints were put in question as part of the feedback received from our last report. After performing a sensitivity analysis, TAF staff decided to remove them, since their impact in the results is negligible.

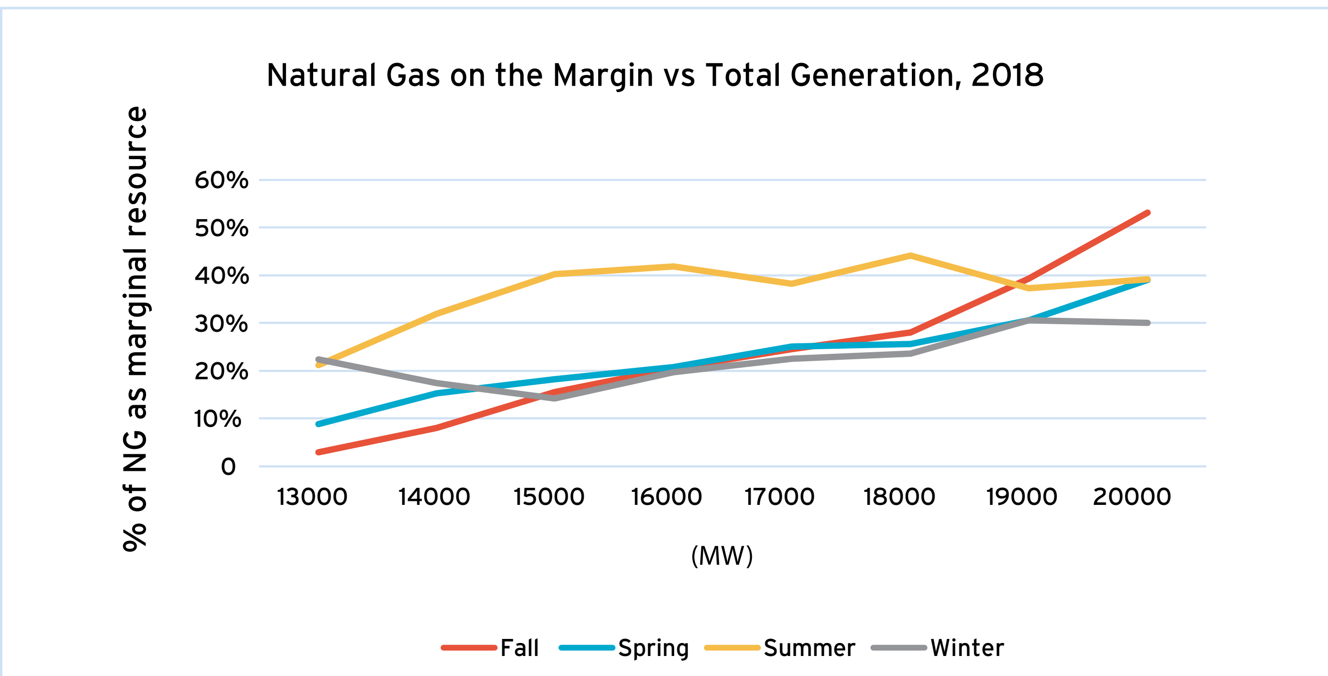
After undertaking additional research, TAF considers that the best indicator to determine the amount of natural gas as marginal resource is total electricity demand. As total demand increases, the proportion of natural gas on the margin also increases. That can be observed in the figure below.



It is also possible to appreciate that the amount of natural gas on the margin presents highly oscillating values at very low (under 13,000 MW) or very high (over 21,000 MW) demand. This can be explained given that the sample size for these extreme values is not large enough to cancel the effect of the variability of the system (like wind and hydro generation, and system constraints). It would be reasonable to expect a very low value (but not zero) when demand is very low, and a very high value when demand is very high (probably close to 80-100 per cent of marginal generation). As a result of the lack of enough good quality data, this methodology probably overestimates natural gas on the margin at low demand and underestimates it at high demand values, but those errors are minimized when the average MEF is calculated for each hour, given that very high or low demand values are less frequent.

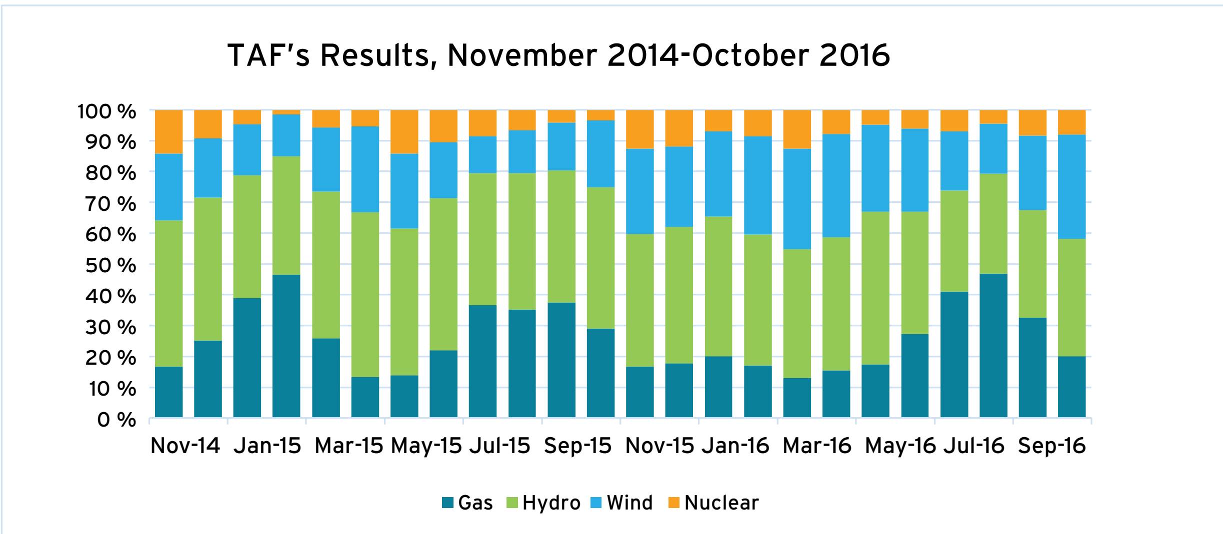
The other main factors that affect the amount of natural gas on the margin (closely related to the previous one) are extreme temperatures, which increases general and peak demands, and the availability of other resources – solar and hydro being the ones with the most significant seasonal variations. The increase of natural gas as a marginal resource displays a different correlation with the increase in generation for each season of the year. The main variables are the availability of hydro or solar energy and the expected peak demand. Given the characteristics of some natural gas facilities (long periods needed to start and the need to function for several hours), when peak demand is expected to be high, those facilities start before the system reaches peak demand. As can be appreciated in the figure below, the proportion of natural gas as marginal resource in periods of intermediate demand is larger in the summer, given the shortage of hydro generation and the expected high peak demand.

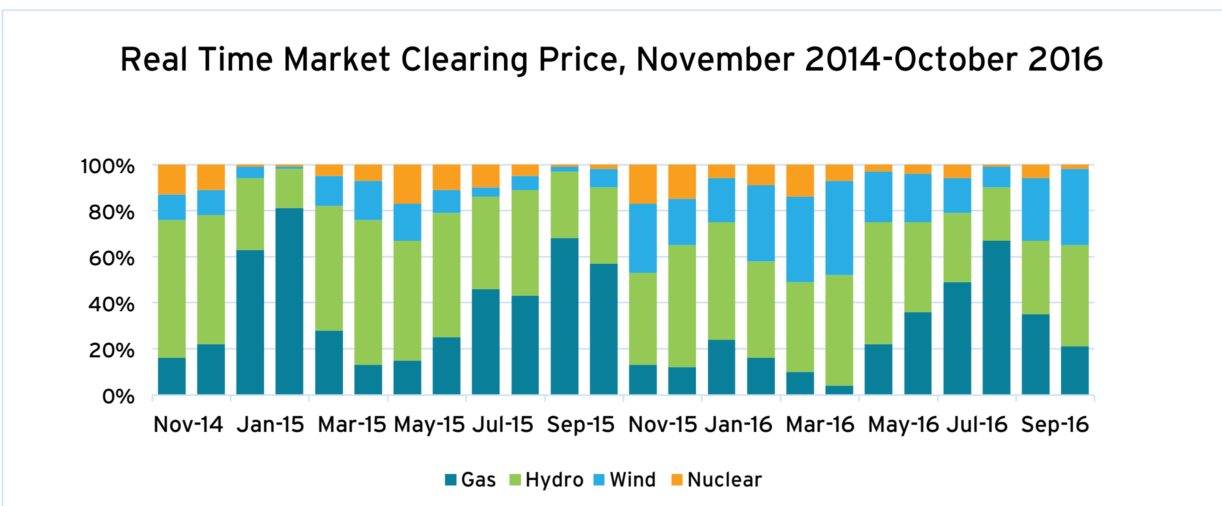
To estimate the MEF addressing this variable, the proportion of natural gas as marginal resource was calculated as a function of total generation, for each season, and was finally applied to every hour.



Results Evaluation

IESO provides information related to the type of generator that sets the market clearing price. The Market Surveillance Panel of the Ontario Energy Board uses this information. It has several reports with data regarding the proportion each generator sets of the market clearing price. The most recent report contains information covering the period from November 2014 to October 2016, which was used to determine the accuracy of the current methodology.





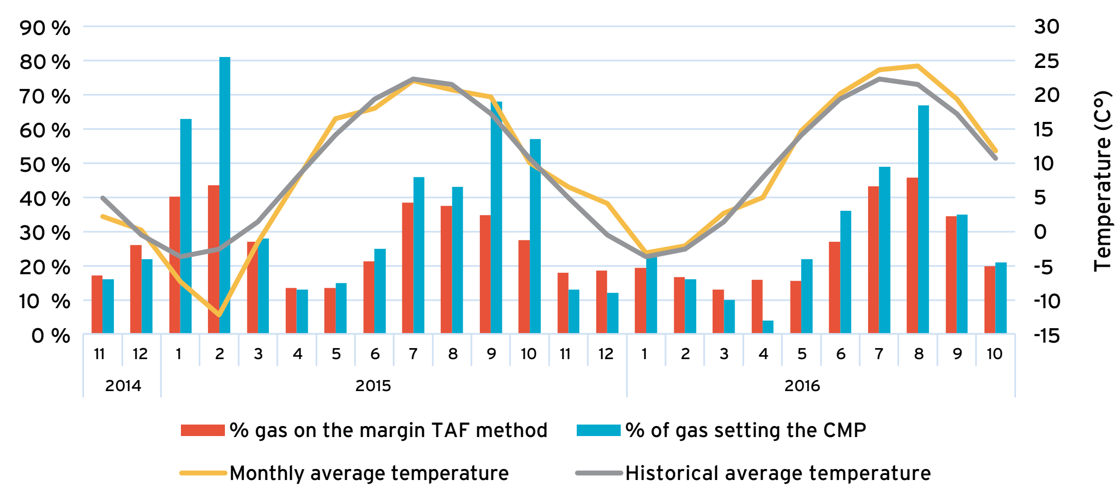
The current methodology doesn't capture the high variability in wind and hydro generation and underestimates the amount of gas on the margin when wind generation is particularly low.

The chart below shows the comparison between TAF's percentage of gas on the margin and the CMP for each month from November 2014 to October 2016, as well as the specific temperature for each month and the historical average temperature. The larger differences take place in January and February 2015, with the lowest observed temperatures, and August 2016, with the highest observed temperature. Those three months coincide also with low wind electricity generation.

There are also large differences in September and October 2015, which can't be explained by extreme temperatures. Wind generation is very low in both months, but it's unclear if the difference is also magnified by other factors.

This comparison shows that TAF's methodology captures the trends in natural gas marginal generation. Lack of data means it underestimates the MEF for exceptionally high demand levels and extreme temperatures We look forward to refining the methodology over time.

Market Clearing Price vs TAF Marginal Resource, November 2014-October 2016



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