A clearer view on Ontario's emissions:

Practice guidelines for electricity emissions factors

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The Atmospheric Fund

TAF

About The Atmospheric Fund (TAF)

www.taf.ca

Founded in 1991 by the City of Toronto, TAF's mission is to invest in urban low-carbon solutions to reduce carbon emissions and air pollution. To date, TAF has invested more than $50 million, helping Toronto save more than $60 million in energy costs, and contributed to a city-wide reduction of carbon emissions of 24 per cent below 1990 levels.

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Introduction

As climate action gains momentum worldwide, it's more important than ever to accurately quantify carbon emissions and the potential for emissions reductions. Only with precise emissions calculations can we properly identify and prioritize 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, around 90 per cent of electricity is produced carbon-free (hydro, nuclear, renewables), but the remainder comes from natural gas – especially during peak hours. That's why an in-depth understanding of Ontario's electricity emissions factors is key to properly quantify the emissions impact of actions such as behavioural changes and energy efficiency projects/interventions.

The Atmospheric Fund (TAF) has applied research to the current Ontario electricity system in order to develop emissions factors which better represent the potential impacts of reducing or shifting the consumption of grid electricity. The methodology is applied on an annual and hourly basis in order to further enable flexibility and precision in calculating impacts in comparison to using average emissions factors. This approach will help all stakeholders to better assess and quantify emissions reductions measures on Ontario's path to a low-carbon future.

Purpose

The goal of this document is to provide guidance on the appropriate electricity emissions factors to use when quantifying carbon emissions from the consumption; conservation; shifting of consumption; and renewable generation of electricity in Ontario. The newly calculated emissions factors and this guide will especially be helpful for Ontario's provincial and municipal policymakers, engineers, scientists, electricity industry professionals, and non-profit organizations involved in the quantification of carbon emissions.

Background

Quantifying emissions typically fulfills two purposes: understanding the relative magnitudes of the emissions sources and evaluating the impacts of emissions reduction measures. Quantifying the sources of emissions generally involves determining the quantities of resources consumed and multiplying them by their relevant emissions factors. Quantifying emissions reductions requires estimating the avoided resource consumption and multiplying it by factors which reflect the avoided emissions.

Although the resource in question is the same (electricity), TAF recommends using different electricity emissions factors for different quantification purposes.

1	When quantifying a baseline level of emissions resulting from electricity consumption (e.g. for a building, company, or whole city), an **Average Emissions Factor** *(AEF)* is recommended. AEFs are derived by dividing the total emissions from electricity production in Ontario by the total quantity of electricity produced, and is reported annually in Canada's National Inventory Reports as Consumption Intensity.
2	When estimating emissions reductions, a **Marginal Emissions Factor** *(MEF)* is recommended. This is because conserving grid electricity (whether via efficiency or displacing with renewables) is expected to conserve a different proportion of fuel than the general electricity mix is comprised of.

In the case of Ontario's electricity grid, generation is predominantly nuclear (61 per cent) and hydro power (23 per cent) (IESO, 2017), 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'). An emissions factor which reflects this reality is commonly referred to as a Marginal Emissions Factor – or MEF for short.

For more sophisticated analyses, emissions reduction estimates can be further refined by applying hourly or time-of-use weighted MEFs. As there is no commonly accepted source for Ontario specific MEFs, TAF has developed its own factors which are presented in this guideline.

Methodology

What does 'marginal' mean? An electricity source is said to be 'on the margin' if it would have been conserved had the demand been lowered.

Estimating a marginal emissions factor requires more effort than the commonly used average emissions factor but can also lead to a better estimate of the avoided emissions. TAF explored four different methodologies and ultimately chose one published in the International Journal of Energy Research (Farhat & Ugursal, 2010). TAF's selected approach uses a set of criteria to estimate how much each fuel contributes to the change in hourly generation and uses that as a measure of how often that fuel is 'on the margin'. The results were hourly *marginal* emissions factors which are compared to hourly average emissions factors (also calculated by TAF from IESO data) in Figure 1 and can also be found in Appendix A.

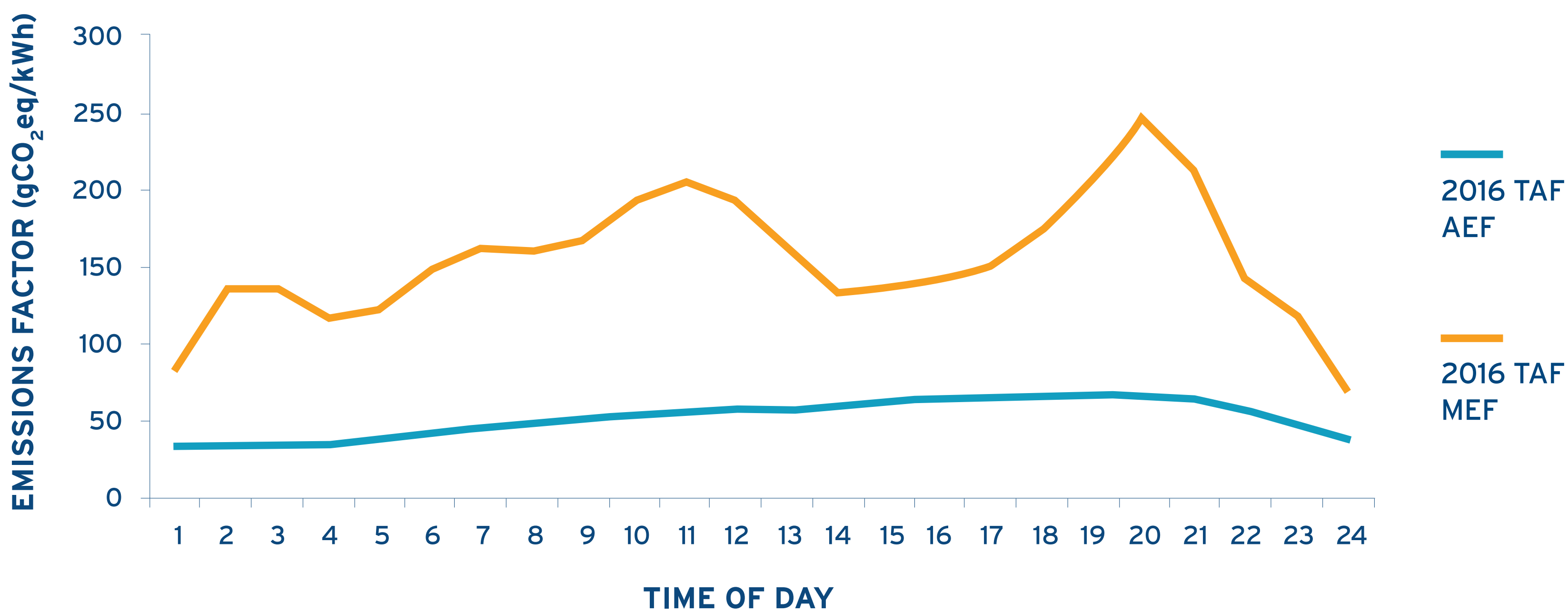


Figure 1: Hourly Average and Hourly Marginal Emissions Factors

Year-Round Marginal Emissions Factor: The MEF in the table is an annual marginal operating electricity emissions factor that can be easily applied to electricity conservation estimates in general. TAF has also developed appliance-specific, hourly, and projected annual emissions factors– see the appendices for details.

While the hourly MEFs are highly variable, TAF found that when applied to numerous common load profiles (which can be found in Appendix B and C) the average MEF on an annual basis was around 159 grams of carbon dioxide equivalent per kilowatt-hour (gCO_2eq/kWh). This value can be simply applied to grid electricity conservation projects to better estimate their emissions reduction impact. Table 1 summarizes the two primary emissions factors, their use cases, and their sources.

Type	Use Case	Emissions Factor (gCO_2eq/kWh)	Year	Source
Average	Calculating emissions from electricity consumption for a baseline or inventory.	43	2015	Canada's 2017 National Inventory Report
Marginal	Calculating emissions reductions from electricity conservation, shifting or renewable generation	159	2016	2016 IESO data and TAF's methodology

Table 1: Types of Emissions Factors

Applications and Limitations

Some types and examples of interventions where a marginal electricity emissions factor could be applied are shown in Table 2.

Type of Intervention	Example
Electricity efficiency	Replacing incandescent or fluorescent light bulbs with LED light bulbs
Electricity storage	A battery or an electric vehicle which can be charged overnight and then used to supply electricity during peak demand
Load shifting	Shifting use of appliances such as vacuums, washing machines, and dishwashers to off-peak times
Renewable electricity generation	Installing solar photovoltaic (PV) panels
Electricity conservation	Moderating set points on electric air conditioners & heating systems (when electric)

Table 2: Interventions Applicable to MEFs

The MEF that TAF developed does not reflect the:
- Avoidance of construction of new power plants and their associated emissions;
- Location of the consumption or generation of electricity and thus the effects of transmission bottlenecks might have on emissions;
- Upstream emissions from natural gas production and transmission as well as uranium mining and processing.

Hourly Marginal Emissions Factors

The hourly MEFs generated enable additional precision and customization when calculating the emissions impacts of electricity interventions and can be found in Appendix A. Hourly factors can be applied to interventions where specific hourly changes in electricity generation/consumption are known or can be estimated (e.g. switching electric appliance usage to off-peak hours, solar PV generation, battery storage).

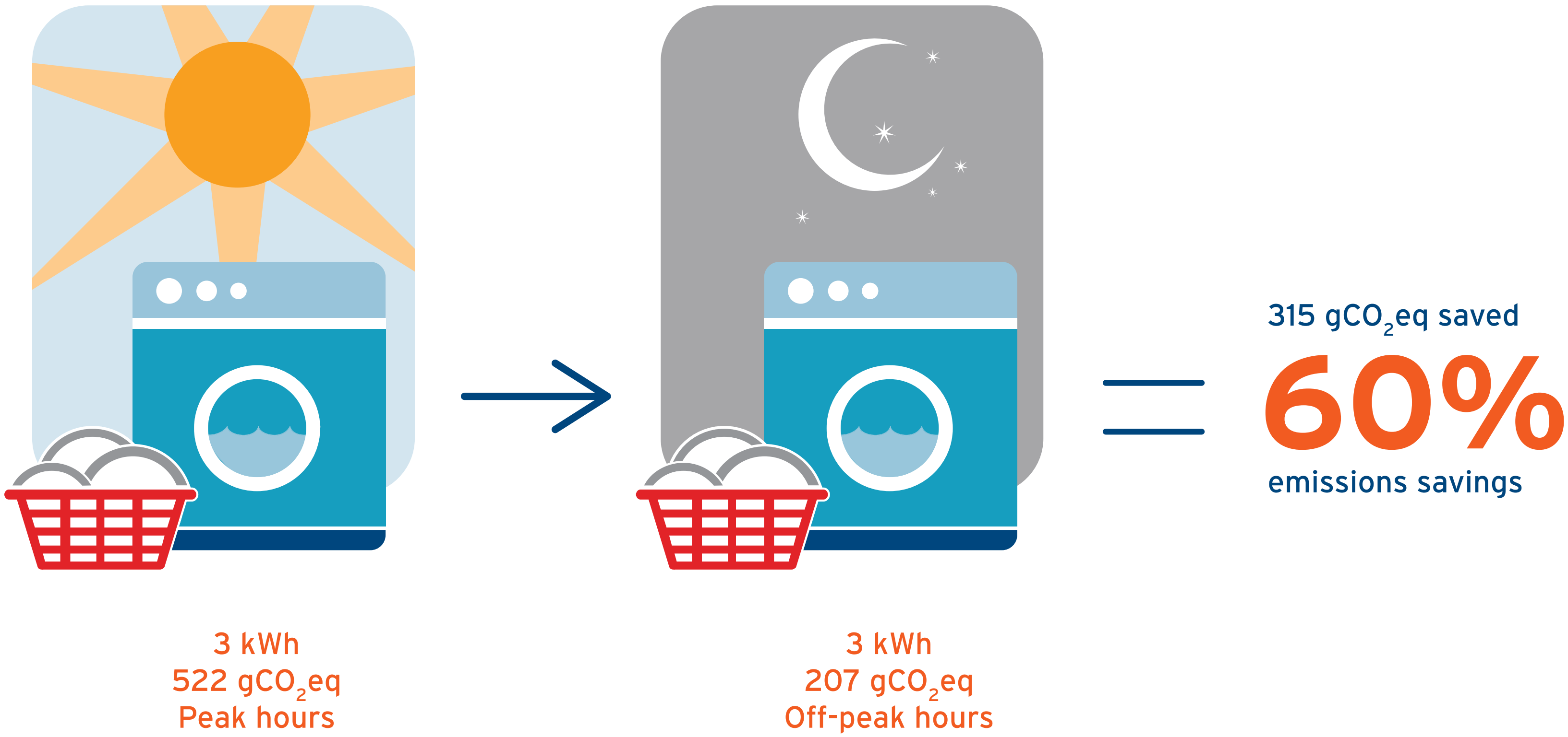
In Appendix B and C, TAF has provided time-weighted end-use MEFs for various common loads in order to provide a quick and simple approach to estimating emissions reductions for specific measures without having to obtain or estimate the hourly load profiles. These end-use MEFs can be applied to the quantities of electricity conserved by the respective sectors and equipment listed.

Energy Storage & Load Shifting

When applying marginal emissions factors to energy storage or load shifting strategies, hourly MEFs should be applied to both the consumption (e.g. energy drawn from the grid to charge a battery) and avoided consumption (e.g. energy drawn from a battery instead of the grid) of electricity. The quantities of electricity that would have been consumed with and without the strategies in place should be multiplied by their respective hourly marginal emissions factors. The net difference in emissions is then the impact of the strategy.

Example:

For example, if a household decides to shift the 3 kWh load of their clothes dryer from 6 pm to 12 am then the avoided emissions would equal 522 gCO_2eq (3 kWh * 174 gCO_2eq/kWh) and the generated emissions would equal 207 gCO_2eq (3 kWh * 69gCO_2eq/kWh) resulting in a net difference of 315 gCO_2eq – or 60 per cent less carbon emissions. This would similarly apply to the use of energy storage but care should be taken to consider the inefficiencies in storing electricity.



Decision Tree

A simple decision tree can assist in determining which specific emissions factors should be used based on the type of quantification being undertaken:

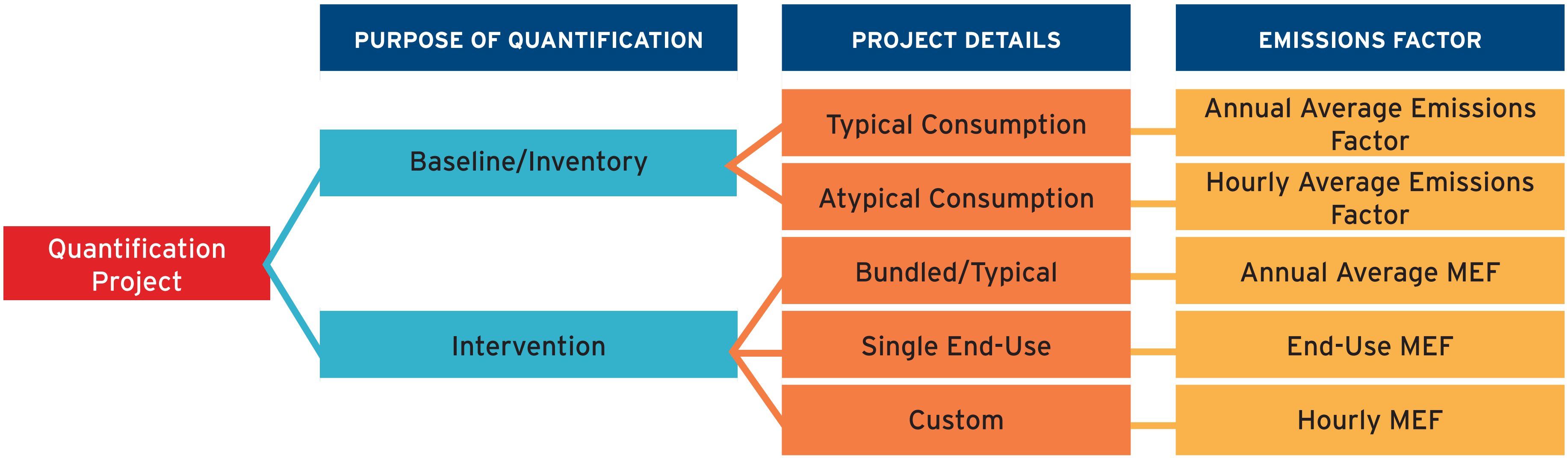


Figure 2: Emissions Factor Decision Tree

Projected Factors

In order to project the marginal electricity emissions factor for future years, TAF assumed Ontario's Long-Term Energy Plan's conservation target of 30 TWh by 2032 (Ontario Ministry of Energy, 2017) would instead be met by natural gas generation. This is essentially a worst-case scenario from an emissions perspective since it is difficult to predict what fuel sources will be used to meet future electricity demand. The result is annual average MEF of 371 gCO_2eq/kWh in 2032. Average emissions factors and annual average MEFs for years between 2016 and 2032 are linearly interpolated and can be found in Appendix D.

Conclusion

Accurately calculating carbon emissions is critical to identifying and prioritizing climate change mitigation strategies.

Due to the complexities of Ontario's electricity system, no single emissions factor is appropriate for all purposes.

In general, TAF recommends the use of an **average emissions factor** when estimating baseline emissions associated with electricity consumption, and the use of a **marginal emissions factor** when estimating emissions reductions from interventions to reduce emissions.

For more detailed analyses, the use of **hourly or time-of-use weighted marginal factors** is recommended. The use of marginal factors better reflects the complexities of electricity generation and consumption. This is especially important in electricity systems, such as Ontario's, where peak demand electricity tends to be supplied by a source with more emissions than baseload electricity sources.

APPENDICES
Emissions Factors Using 2016 Data

Appendix A - Hourly Marginal and Average Emissions Factors

2016 Electricity Emissions Factors (gCO_2eq/kWh)

Hour	Marginal	Average
1	81.6	33.7
2	135.1	32.5
3	133.7	32.8
4	115.3	34.4
5	121.2	37.3
6	147.9	41.1
7	161.1	44.8
8	159.9	47.9
9	166.3	51.0
10	192.1	53.3
11	203.8	55.0
12	192.5	56.5
13	161.1	57.1
14	132.5	59.7
15	136.0	61.4
16	141.6	63.1
17	150.6	64.6
18	174.3	66.2
19	207.3	66.1
20	247.1	65.2
21	211.2	63.3
22	138.5	57.0
23	118.6	46.1
24	68.7	37.7

Appendix B – Commercial End-Use Marginal Emissions Factors

2016 TAF MEF (gCO_2eq/kWh)

	Food Retail	Hospital	Large Hotel	Large Non-food Retail	Large Office	Nursing Home	Other Commercial Buildings	Other Hotel Motel	Other Non-food Retail	Other Office	Restaurant	Schools	University & Colleges	Warehouse Wholesale
Space Heating	157.9	150.3	149.0	157.9	156.9	156.6	153.7	149.9	157.9	157.9	157.9	157.9	157.9	152.2
Computer Equipment	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8
Cooking	163.0	170.8	167.7	170.4	163.1	170.8	163.9	167.6	165.8	163.1	168.6	163.5	161.3	164.5
Cooling Chillers	168.4	168.4	168.4	168.4	163.7	168.4	168.4	168.4	168.4	163.7	168.4	168.4	168.4	168.4
Domestic Hot Water	166.8	159.7	161.5	166.4	154.3	165.0	163.9	161.5	162.6	154.3	167.9	161.8	165.7	161.0
Elevators	157.5	155.4	159.0	158.7	159.0	159.0	158.7	159.0	159.9	157.6	160.9	160.2	159.1	161.2
Forced Air Central Heating	157.9	150.3	149.0	157.9	157.9	156.6	153.7	149.9	157.9	157.9	157.9	157.9	157.9	152.2
HVAC Fans Pumps	162.4	162.4	162.4	162.4	160.8	162.4	162.4	162.4	162.4	160.8	162.4	162.4	162.4	162.4
Lighting Exterior	138.0	138.0	138.0	138.0	138.0	138.0	138.5	138.0	138.0	138.0	138.0	138.0	138.0	138.0
Lighting Interior General	163.9	155.9	159.1	163.3	161.4	159.7	158.8	159.1	162.7	161.4	163.2	160.4	158.7	161.3
Miscellaneous Equipment	155.8	155.4	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8
Non Ducted Central Heating	162.7	150.3	149.0	162.7	157.9	156.6	153.7	149.9	162.7	157.9	162.7	157.9	157.9	152.2
Other Plug Loads	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8	155.8
Refrigeration	154.1	155.8	155.2	154.8	153.8	155.2	155.5	155.2	154.5	153.8	154.7	153.8	153.8	154.1

Appendix C – Residential End-Use Marginal Emissions Factors

Residential Equipment	2016 TAF MEF (gCO_2eq/kWh)
AC General	160.7
Clothes Dryers	168.1
Clothes Washers	167.1
Computers	159.9
Cooking	169.2
Dehumidifiers	159.9
Dishwashers	170.9
Domestic Hot Water	163.8
Elevators	168.1
Forced Air Central Heating	157.0
Freezers	154.9
Lighting	161.7
Lighting Common Area	154.1
Miscellaneous	154.1
Non Ducted Central Heating	157.0
Other Consumer Electronics	154.1
Refrigerators	155.4
Set Top Boxes	159.6
Space Heating Room	157.0
Swimming Pool Spa Heaters Pumps	166.8
Televisions	159.9
Ventilation And Circulation	159.7
Solar PV	170.4

Appendix D – Projected Marginal and Average Emissions Factors

Emissions Factors (gCO_2eq/kWh)

Year	Marginal	Average (IESO, 2016)
2016	158.8	32.1
2017	172.1	26.6
2018	185.3	24.5
2019	198.6	21.8
2020	211.9	23.9
2021	225.2	25.4
2022	238.5	26.1
2023	251.7	29.7
2024	265.0	24.0
2025	278.3	33.2
2026	291.6	26.9
2027	304.9	27.6
2028	318.1	26.0
2029	331.4	27.4
2030	344.7	26.6
2031	358.0	31.4
2032	371.3	27.8

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