IMPACT ON THE ENVIRONMENT

QUESTION 11

How much have the coal phase-out, renewable electricity, and conservation reduced greenhouse gas emissions?

From its highest emissions in 2000 until 2015, Ontario reduced electricity system greenhouse gas emissions by 85%.

This reduction took Ontario from 30% above Canada's average electricity greenhouse gas (GHG) intensity per kilowatt hour (kWh) in 2000, to over 80% below it in 2015. Annual GHG emissions in Ontario's electricity system were reduced by about 36 Mt CO_2eq, the vast majority of Ontario and Canada's economy-wide emissions reductions in these years.[1]

Around the world, decarbonizing the electricity supply is recognized as the essential first step in transitioning to a low-carbon economy. In this respect, Ontario is a North American leader.

Contents

Q11

The details…

The decarbonisation of Ontario's electricity supply

Based on the most current official data (2015), greenhouse gas (GHG) emissions from Ontario's electricity system have fallen by 80% since Ontario's commitment to phase out coal (see Figures 11.1 and 11.2), and 85% since 2000 – the dirtiest year for Ontario's electricity grid.[2]

GHG emissions from the electricity system made up only 4% of the province's total emissions in 2015, compared to 16% in 2005.[3] In 2017 natural gas, the only remaining fossil fuel in Ontario's electricity system, made up less than 5% of Ontario's electricity consumption, compared to about 15% in 2011 and 11% in 2015.[4] Once the official emissions numbers for 2016 and 2017 are finalized, further reductions should be recorded due to the decline in natural gas-fired electricity generation.[5] As a result, the sector is forecast to contribute only about 2% of Ontario's GHG emissions in 2017.[6]

This downward trend in emissions can be attributed to:

- retiring all of Ontario's coal-fired power plants (the first plant closed in 2005, the last in 2014)[7]
- replacing coal-fired electricity generation with nuclear, renewables and natural gas
- reduced demand for electricity (due to conservation programs and codes and standards, shifts in the economy, weather and price)[8]

Greenhouse gas emissions from Ontario's electricity system have fallen by 85%.

- reducing Ontario's reliance on natural gas for baseload (around-the clock) production in 2016 and 2017 (discussed further below),[9] and
- the declining gap between the highest and lowest hours of electricity demand in 2016 and 2017 (i.e., more stable demand), resulting in less need to ramp up production at natural gas-fired generation facilities to meet peak demand.[10]

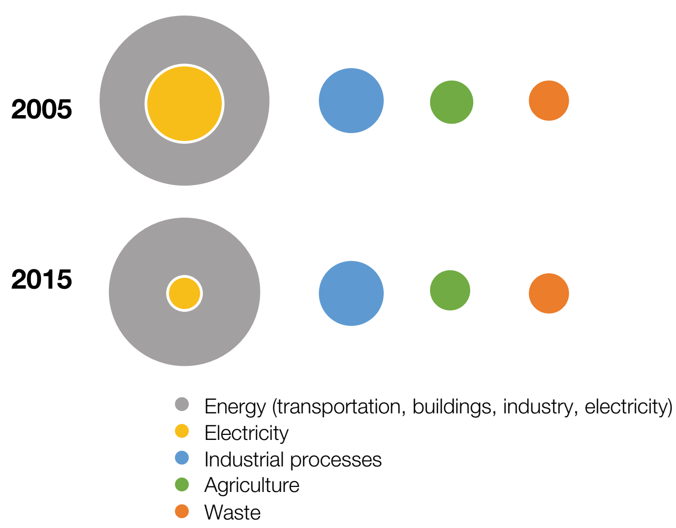

Figure 11.1. Ontario's greenhouse gas emissions by sector (2005-2015).

Note: Emissions data does not include lifecycle emissions. "Industrial processes" include emissions that are not related to energy.

Source: Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2017) at Table A11-12.

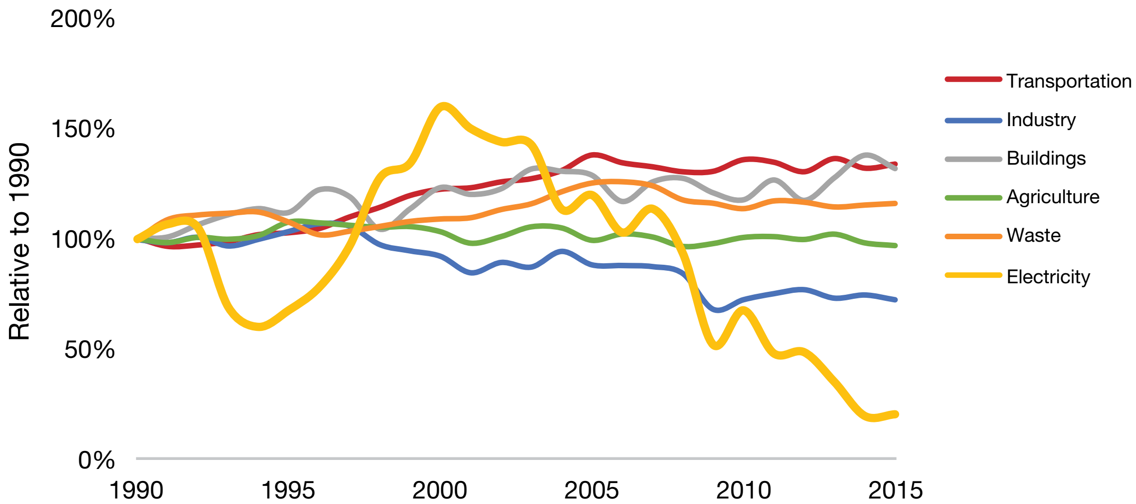

Figure 11.2. Ontario historical GHG emissions by economic sector relative to 1990 levels.

Source: Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2017) Table A11-12, at 58.

The decarbonisation of Ontario's electricity grid can also be measured by its emissions intensity – the amount of GHGs emitted per unit of electricity produced. Using this metric, the emissions intensity of Ontario's electricity has dropped by a factor of seven from 2000 to 2015, as shown in Figure 11.3.

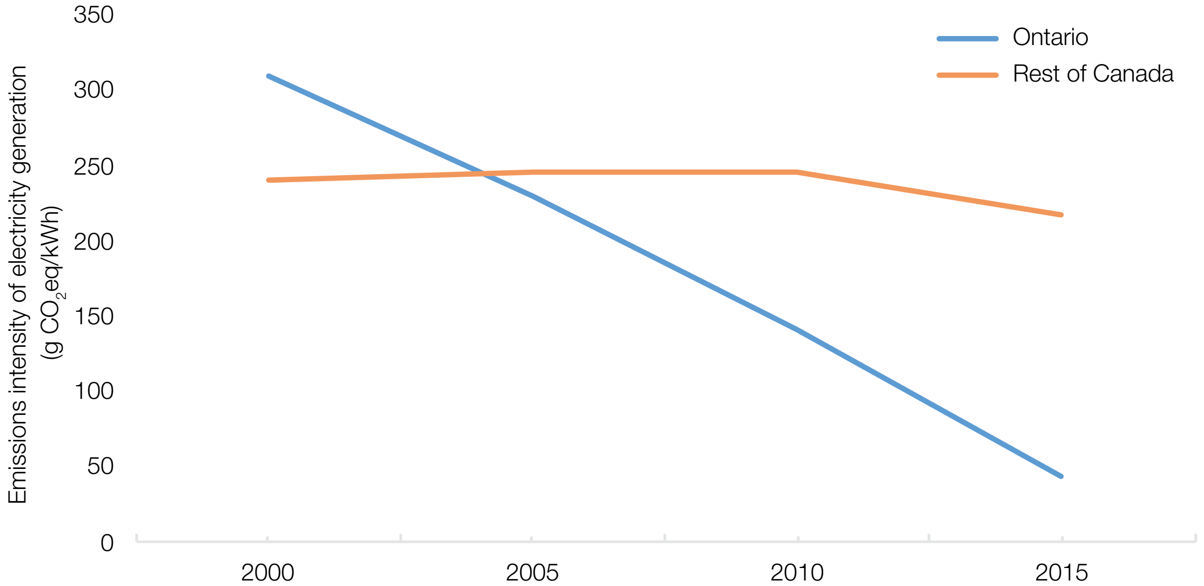

Figure 11.3. Average annual carbon dioxide equivalent[11] intensity of electricity generation (g CO_2eq/kWh) in Ontario and the rest of Canada (2000, 2005, 2010 and 2015).

Note: The "Rest of Canada" estimates are calculated by the ECO based on a weighted (by electricity generation) average of provincial GHG emissions.

Source: Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2017) Tables A13-1 through A13-14.

Coal phase-out: not GHG emissions-free

Ontario's coal plants were taken offline for public health as well as climate change reasons (see Q12). But, despite the Ontario government's commitment to prioritize energy conservation and renewable electricity, the electricity supplied by coal-fired generation was not entirely replaced by these sources alone. As Q4 describes, nuclear and natural gas-fired generation made up a larger share of Ontario's electricity supply mix in 2015 than they did a decade earlier (see Table 11.1 and Figures 11.4 and 11.5).

Nuclear and natural gas-fired generation made up a larger share of Ontario's electricity supply mix in 2015 than they did a decade earlier.

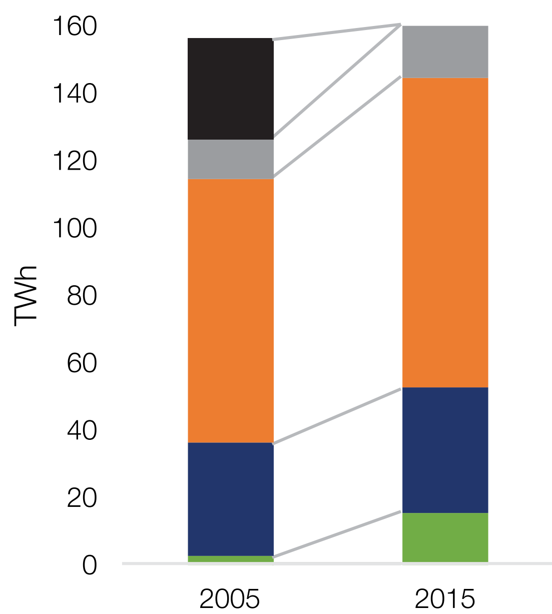

Figure 11.4. Ontario's electricity generation, by resource (2005 vs. 2015).

Source: Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (31 January 2018).

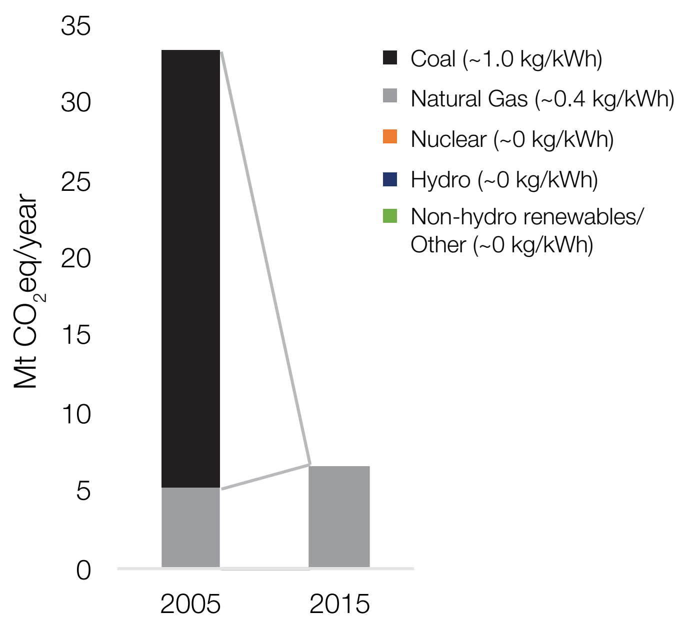

Figure 11.5. Ontario's electricity sector greenhouse gas emissions, by generating resource (2005 vs. 2015).

Note: Only operational GHG emissions are included in this graph, for lifecycle emissions see Table 11.4.

Source: Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (31 January 2018); Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2017) at 99.

Table 11.1. Changes in Ontario's electricity generation and related greenhouse gas emissions (2005 vs. 2015).

Resource	Operational GHG intensity* (g CO_2eq/kWh)	2005		2015	
		Generation (TWh)	GHGs (Mt CO_2eq)	Generation (TWh)	GHGs (Mt CO_2eq)
Coal	965	29.3	28.2	0	0
Natural gas	425	11.9	5.1	15.5	6.6
Low-emitting Resources (nuclear, hydro, wind, solar, bioenergy, other)	0**	114.8	0	144.7	0
	Total	**156 TWh**	**33.3 Mt**	**160.2 TWh**	**6.6 MT**

Note: (*) Based on an average GHG intensity of the most recent three years of plant operations in Ontario (2012-2014 for coal, and 2013-2015 for natural gas), as reported in Canada's National Inventory Report to the United Nations.

(**) These resources do not emit greenhouse gases during their operational life (with the exception of bioenergy, whose emissions are considered to be carbon-neutral), but have emissions at other stages of their life-cycle, as discussed in the textbox "Life-cycle GHG emissions from Ontario's electricity".

Source: Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (31 January 2018); Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2017) at 99.

From 2005 to 2015, Ontario's natural gas-fired electricity generation capacity was doubled (although the actual amount of electricity produced from natural gas has risen much less), in part to replace coal generation when responding to short term peaks and valleys of electricity demand. This has also helped balance fluctuations in wind and solar electricity production.

Although natural gas is a fossil fuel, it emits less GHG emissions than coal while it is being burned for fuel. This is particularly true in Ontario, where natural gas electricity generation occurs primarily at combined cycle facilities, which are more efficient (in terms of energy use and GHG emissions) than simple cycle natural gas plants (see Figure 11.6).[12]

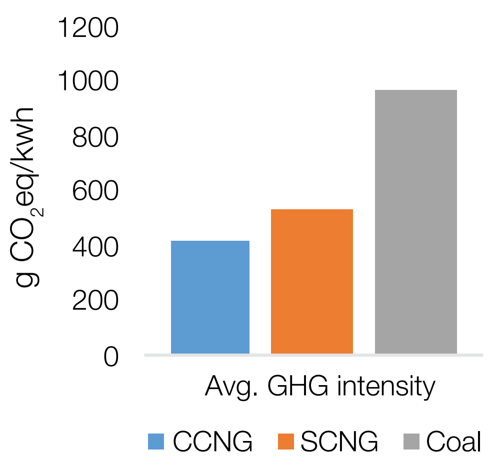

Figure 11.6. Average operational GHG emissions intensity of natural gas (combined cycle natural gas, CCNG, and simple cycle natural gas, SCNG) as well as coal plants.

Sources: Average GHG intensity of coal is the average of the final three years of plant operations in Ontario (2012-2014) (Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2017) at 99); for natural gas plants, the averages are from: EDC Associates Ltd., Trends in GHG Emissions in the Alberta Electricity Market (Independent Power Producers Society of Alberta, 2 May 2013) at 8.[13]

However, the entire life-cycle of natural gas-fired electricity may produce only slightly lower GHG emissions than coal if upstream leakage levels are high (see textbox "Life-cycle GHG emissions from Ontario's electricity"). Ideally, the electricity grid will come to rely less and less on natural gas for peaking power, and more on alternative non-emitting sources, such as storage and demand response.[14]

Natural gas-fired electricity may produce only slightly lower GHG emissions than coal if upstream leakage levels are high.

Life-cycle GHG emissions from Ontario's electricity

The federal government's reporting of GHG emissions from the electricity sector only captures the direct operation of electricity generation facilities.[15] The report leaves out the potentially significant GHGs associated with other stages of a facility's life-cycle, such as the upstream emissions from fossil fuel extraction, or the downstream emissions for waste disposal.[16]

Taking the full life-cycle into account, all methods of generating electricity produce some amount of GHG emissions. For solar, wind, nuclear and hydro, the life-cycle emissions are negligible, but for natural gas-fired generation, the added emissions are substantial (see Table 11.2). Possible ranges of life-cycle emissions for natural gas-fired generation are described in more detail in Table 11.3.

Table 11.2. Life-cycle emissions of Ontario's electricity-generating energy sources using a 100-year global warming potential.[17]

Source of electricity	Emissions (g CO_2eq/kWh)		
	Operation	**Life-cycle** (excl. operation)	**Life-cycle**
Coal	965	102	1,067
Hydro	0	16	16
Nuclear	0	35	35
Solar PV	0	41	41
Wind	0	11	11
Natural Gas	425	≈130	≈550

Note: The emissions for all electrical sources use a 100-year global warming potential, which underestimates the impact of natural gas. For assumptions related to operational GHG intensity, see Table 11.1, for natural gas life-cycle emissions, see Figure 11.7.

Source: See endnote.[18]

The natural gas figures displayed in Table 11.2 do not reflect the considerable uncertainty of emissions from this electricity source. Possible ranges of life-cycle emissions for natural gas are illustrated in Figure 11.7. Methane is the main component of natural gas and a particularly potent GHG. Thus, seemingly small leaks from natural gas wells, pipelines and other infrastructure can have major impacts on the GHG emissions of natural gas-fired generation, as discussed in Chapter 6 of the ECO's 2017 Greenhouse Gas Progress Report. Leakage rates are also uncertain (many are not measured), and variable (from one well or pipeline to another).

The global warming potential (GWP) describes a GHG's warming impact on the planet compared to the same amount of carbon dioxide, averaged over a certain period of years (often 100 years). Methane has a GWP of 34 (i.e., it is 34 times more potent that the same amount of carbon dioxide) when methane's impact is averaged over 100 years. (This is called its 100-year GWP). As the ECO explained in Chapter 3 of the 2016 Greenhouse Gas Progress Report, methane's potency over the short term is more important, as it is only in the atmosphere for 12.6 years, resulting in a much higher 20-year GWP of 86.[19] The 100-year GWP used by Canada's national emissions inventory (based on United Nations requirements) and by the provincial cap and trade program (based on Western Climate Initiative requirements) consistently underplay the importance of methane in the next 10 to 20 years.

In Figure 11.7 we compare (1) life-cycle emission estimates using a range of upstream leakage rates based on credible datasets, and (2) 20- and 100-year global warming potentials.

Although an upstream leakage rate of about 1.2% has been used as a default assumption for the natural gas supplied in Ontario,[20] this rate is uncertain. A 2.65% leakage rate is a plausible global mean leakage rate from the natural gas supply chain.[21] At the 2.65% level, using a 20-year GWP, the life-cycle impacts from natural gas power production are almost double the level of its operational emissions. Nevertheless, these life-cycle emissions are still less than the life-cycle emissions from coal. A 5.5% upstream leakage rate is at the upper boundary of the range considered plausible.[22] An overall leakage rate of about 6% would be required for natural gas power production life-cycle emissions to exceed those of coal plants.

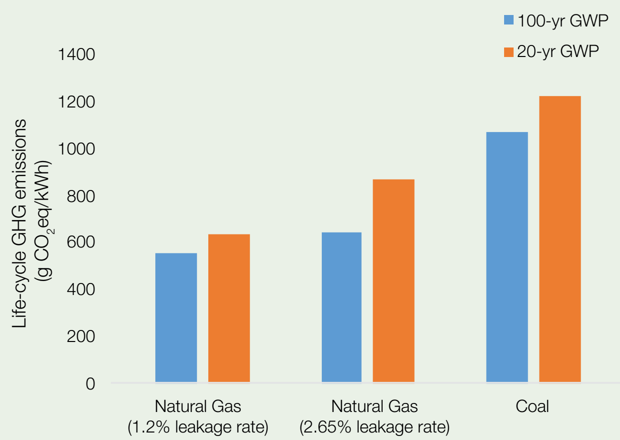

Figure 11.7. The effect of upstream natural gas leakage rates on the life-cycle emissions of natural gas-fired electricity generation plants relative to coal-fired power.

Note: Due to the substantial uncertainty associated with the leakage rates, these estimates may not be representative of Ontario conditions. The emissions estimates were generated using ECO models based on Ontario, U.S. and global data.[23] The GWP for methane applied in the Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report (i.e., 25 times CO_2 over a 100-year time horizon) has been converted to the GWP applied in the IPCC Fifth Assessment Report (i.e., 86 times CO_2 over a 20-year time horizon). See Table 11.1 for natural gas operational GHG intensity. Potential emissions from methane leakage at the natural gas power plant itself are not included.[24]

Source: See endnote.[25]

Despite an almost 100% increase in natural gas-fired electricity generation capacity on Ontario's electricity grid between 2005 and 2015, actual electricity production from natural gas (and, in turn, related operating GHG emissions) only increased by about 20%.[26] This limited demand for available natural gas-fired electricity generation capacity is because significant amounts of other new resources (nuclear, renewables and conservation) had also been added to the grid over the same time period and electricity demand was lower than expected (Q3).

From 2015 to 2017, electricity production from natural gas decreased by almost 70% (about 9.5 TWh).[27] This reduction is due primarily to an overall reduction in electricity demand (about 9 TWh), as well as:

- the expiry of some contracts for older non-utility natural gas generators that encouraged 24-hour electricity production, and the renegotiation of others with a focus instead on providing dispatchable power[28]
- flatter demand, and
- other cleaner resources (including conservation) displacing gas.[29]

From 2015 to 2017, electricity production from natural gas decreased by almost 70%.

The ECO's analysis of IESO data suggests that a major contributor to the drop in natural gas generation from 2015 to 2017 is lower reliance on gas-fired generation during hours of low electricity demand. Gas-fired generation fell by 79% during the bottom 200 hours of system demand, but only by 44% in the top 200 hours of demand.[30]

Alternative scenario: coal phase-out without conservation and renewables

What would Ontario's electricity sector GHG emissions have been in 2015 if Ontario had closed the coal plants but not invested in conservation programs and renewables?

The electricity Ontario produces from non-hydro renewable electricity sources and the reduced electricity demand that results from conservation initiatives would probably have come instead from natural gas-fired generation (the least expensive alternative at current natural gas prices).[31]

Figures 11.8 and 11.9 outline two alternative electricity generation scenarios and their related GHG impacts. Two options are shown to incorporate uncertainty about whether Ontario would continue exporting electricity (Ontario is currently a large net exporter of electricity (Q7), mostly to Michigan and New York.[32] The "2015 Alternative" scenario assumes that net exports are unchanged from their actual 2015 levels. We also include a scenario (far right bar) that assumes net exports would be zero, meaning much less natural gas-fired electricity generation would be needed overall. The real answer is likely somewhere in between.[33]

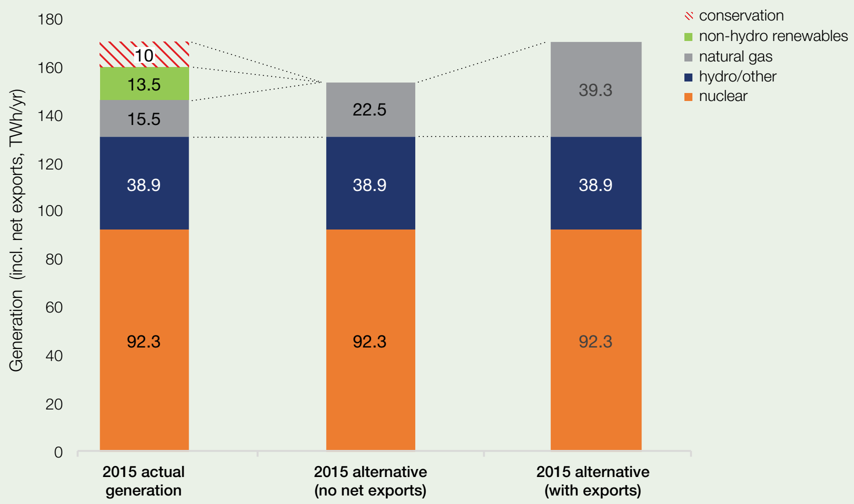

Figure 11.8. Three Ontario 2015 electricity generation scenarios: (1) the actual mix; (2) natural gas displaces all conservation/renewables established post-2005, without any net exports; and (3) natural gas displaces all conservation/renewables, but with net export levels remaining at actual 2015 levels.

Note: Assumptions for alternative scenarios:
- no conservation from provincially-funded programs or provincial codes and standards
- no non-hydro renewables
- net exports – no net exports at all (middle bar), or stay the same as in 2015 (16.8 TWh, right bar), and
- production from nuclear and hydro/other stays constant across all scenarios.

Source: Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (31 January 2018, and in 2017).

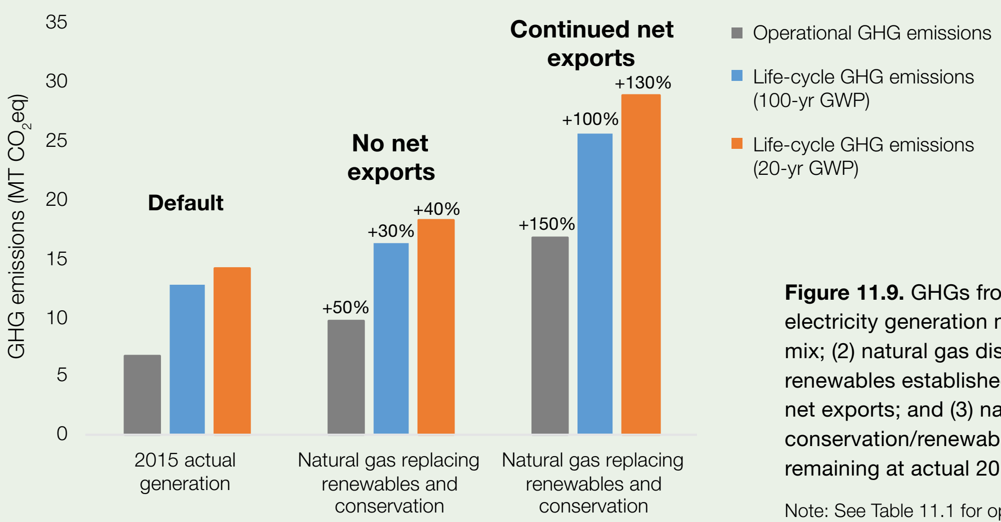

Figure 11.9. GHGs from three Ontario 2015 electricity generation mix scenarios: (1) the actual mix; (2) natural gas displaces all conservation/renewables established post-2005, without any net exports; and (3) natural gas displaces all conservation/renewables, but with net export levels remaining at actual 2015 levels.

Note: See Table 11.1 for operational GHG intensity sources. Life-cycle emissions factors for natural gas are those illustrated in Figure 11.7 and use a 1.2% leakage assumption.

The simplistic alternative 2015 generation scenarios presented above show that Ontario's electricity sector emissions would have been lower than 2005 levels even without increased investments in conservation and non-hydro renewables. 2005 electricity operational GHG emissions were about 32 Mt, and in 2015 they were about 7 Mt. The natural gas only scenario would have resulted in about 10-17 Mt of operational GHG emissions in 2015, depending on the assumptions about exports.

Ontario's use of conservation programs and renewable electricity generation sources saved the province an additional 3-10 Mt of GHG emissions during the operation of the facilities alone, as compared to relying on natural gas alone. If entire life-cycles of electricity generation facilities are considered, then the emissions reductions are even greater, at 4 to 15 Mt (20-yr GWP) or 4 to 13 Mt (100-yr GWP).

What Figure 11.9 does not capture is that the GHG emissions and air pollution would rise in other jurisdictions if Ontario stopped exporting electricity. Both Michigan and New York's electricity systems have much higher emissions intensities than Ontario due to the use of coal- or gas-fired electricity generating facilities. Ontario's exports reduce the use of these fossil-fuelled generation plants.

Going forward, the greater opportunity for GHG reductions is fuel switching from transportation, building and industrial sectors to conservation or low-carbon electricity.

GHG emissions going forward

Because Ontario has already phased out coal plants and reduced its reliance on natural gas-fired electricity generation, opportunities to further reduce GHG emissions from the electricity system are hard to find. Going forward, the greater opportunity for GHG reductions in Ontario is fuel switching away from fossil fuel use outside the electricity system (i.e., the transportation, building and industrial sectors) to conservation or low-carbon electricity, as discussed in Q15.

Electricity demand in Ontario continues to fluctuate due to daily and seasonal shifts, as a result a certain amount of flexible capacity is necessary to balance the grid, particularly during extremely hot and cold times of the year (high temperatures will be exacerbated by climate change). Figure 11.10 highlights how, on a hot summer day Ontario's natural gas generators are turned on primarily to meet peak air conditioning demand.

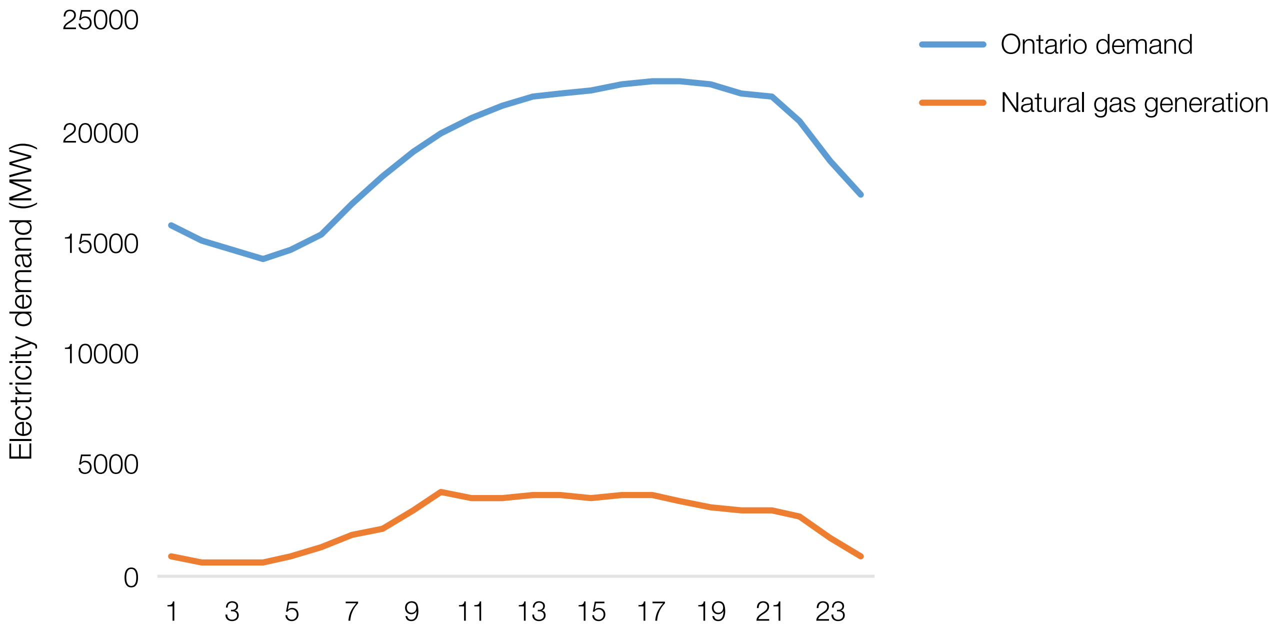

Figure 11.10. Ontario's hourly electricity demand and natural gas generation (4 August 2016).

Note: Natural gas generation captures most transmission-level natural gas generation in Ontario. Neither category captures embedded generation. Most embedded generation in Ontario is solar, which has reduced daily summer peaks.

Source: "Data Directory, Generator Output and Capability" (for natural gas generation) and "Data Directory, Ontario and Market Demand" (for Ontario demand), both online: Independent Electricity System Operator <www.ieso.ca/en/power-data/data-directory>.

Until sufficient amounts of other forms of low-emission peak management (i.e., resources that can reliably be turned on or off quickly to respond to shifts in electricity demand) are procured (e.g., grid-level battery storage, pumped storage hydroelectricity, ceramic brick heat storage, and/or electric vehicle storage), some emissions from natural gas peaking plants will be unavoidable.

However, natural gas emissions can be kept to a minimum, by both stabilizing and reducing electricity demand in the hours when natural gas generation is needed (roughly 17% of hours in 2017, see Q19).[35]

Natural gas emissions can also be lowered by reducing upstream methane leaks and by maximizing the amount of natural gas produced from renewable sources, including power-to-gas from renewable electricity.[36] Future opportunities to better balance supply and demand with limited GHG emissions are explored in Q16.

Natural gas emissions can be kept to a minimum.

Endnotes

1. Total provincial GHG emissions were 211 Mt in 2000 (Environment and Climate Change Canada, National Inventory Report 1990-2013: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2015) Table A10-12). Ontario GHG emissions were 166 Mt in 2015, falling by 45 Mt since 2000. Canadian annual emissions fell by 16 Mt between 2005 and 2015, from 738 Mt to 722 Mt (Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 1 (Ottawa: ECCC, 2017), Table 2.2 and Part 3, Table 11-12).

2. From 41.9 Mt in 2000, to 32.3 Mt in 2005, to 6.2 Mt in 2015. (Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2017) Table A13-7.)

3. Environment and Climate Change Canada, National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada, Part 3 (Ottawa: ECCC, 2017) at Tables A11-12.

4. According to IESO, natural gas generation reduced from 15.5 TWh in 2015, to 12.9 TWh in 2016, to 5.9 TWh in 2017 (a 62% total reduction). (Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (February 2018).

5. Ibid.

6. Ministry of Energy, Ontario's Long-Term Energy Plan 2017: Delivering Fairness and Choice (Toronto: Ministry of Energy, 26 October 2016) at 109.

7. Beginning in 2001 with a regulation requiring the Lakeview coal plant shutdown by 2005, and followed in 2007 with legislation requiring the 4 remaining coal plants to close by 2014.

8. From 147 TWh grid demand in 2000 to 137 TWh grid demand in 2016 ("Demand Overview: Historical Demand", online: Independent Electricity System Operator <www.ieso.ca/power-data/demand-overview/historical-demand>); About 10 TWh of electricity demand was reduced by conservation efforts in Ontario in 2015, due to publicly funded conservation programs and codes and standards (Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (31 January 2018)).

9. As of December 2015, MENG has had a policy not to extend any expiring baseload natural gas contracts beyond their current term. (Directive from Ontario Ministry of Energy to the Independent Electricity System Operator, Re: Non-Utility Generation Projects […] (14 December 2015)). Several plants have or will soon come off-line as contracts have expired. In addition, in December 2016 the IESO renegotiated five natural gas plant contracts, which were contracted for baseload generation. The renegotiated contracts provide for "enhanced dispatchability" for the remainder of their contract term (Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (22 December 2017)). The fact that natural gas use has declined by about 79% in the bottom hours shows that it is being used less to supply baseload (see endnote 30). ("Data Directory: Generator Output and Capability reports (annual, 2015-2017)", online: Independent Electricity System Operator <www.ieso.ca/power-data/data-directory>).

10. Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (22 December 2017); "Data Directory: Generator Output and Capability reports (annual, 2015-2017)", online: Independent Electricity System Operator <www.ieso.ca/power-data/data-directory>.

11. "Carbon dioxide equivalent is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential. For example, the global warming potential for methane over 100 years is 21. This means that emissions of one million metric tons of methane is equivalent to emissions of 21 million metric tons of carbon dioxide." (Per the "Glossary of Statistical Terms", online: Organisation for Economic Co-operation and Development <stats.oecd.org/glossary/detail.asp?ID=285>. Note that the estimated global warming potential of methane over 100 years has been revised to 34, according to the Intergovernmental Panel on Climate Change (IPCC) Working Group 1 report from 2013 (G. Myhre et al. Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press 2013) at 714.)

12. Ontario Power Generation, Greenhouse Gas Emissions Associated with Various Methods of Power Generation in Ontario by Intrinsik (Toronto: OPG, October 2016) at Table 3-3, online: <www.opg.com/darlington-refurbishment/Documents/IntrinsikReport_GHG_OntarioPower.pdf>; However, combined cycle plants take longer to ramp up and down than simple cycle plants, and when operating at lower capacity levels, use more energy and produce more emissions per unit of energy generated than when operating at higher capacities. (M.A. Gonzales-Salazar et al., "Review of the Operational Flexibility and emissions of gas- and coal-fired power plants in a future with growing renewables" (2018) 8 Renewable and Sustainable Energy Reviews 1497 at 199, Table 2, Figures 8, 11 and 12.)

13. The figures from the Alberta report are supported by M.A. Gonzales-Salazar et al., "Review of the Operational Flexibility and emissions of gas- and coal-fired power plants in a future with growing renewables" (2018) 8 Renewable and Sustainable Energy Reviews 1497 at Figures 11 and 12.

14. California is already working towards replacing natural gas as a source of peaking power with batteries or other non-fossil fuel resources. (Mark Chediak, "California Regulators Direct PG&E to Prioritize Storage for Peak Demand" (12 January 2018) Renewable Energy World, online: <www.renewableenergyworld.com/articles/2018/01/california-regulators-direct-pg-e-to-prioritize-storage-for-peak-demand.html>.)

15. These other emissions, should they originate from Canada, would be reported elsewhere in the national GHG inventory.

16. The upstream stages include the production and transportation of infrastructure, equipment and fuels, as well as the construction and installation processes. The downstream stages include decommissioning and waste disposal. The ECO has recommended that life-cycle GHG emissions be incorporated into all government procurement decisions (see Environmental Commissioner of Ontario, "8. Low-Carbon Procurement" in Ontario's Climate Act From Plan to Progress, Annual Greenhouse Gas Progress Report 2017 (Toronto: ECO, January 2018)). In its 2017 Long-Term Infrastructure Plan, the government recently took a positive step in this direction by mandating the consideration of life-cycle environmental impacts for all major infrastructure project procurement decisions by mid-2020. (Ontario Ministry of Infrastructure, Building Better Lives: Ontario's Long-Term Infrastructure Plan 2017 (Toronto: Ministry of Infrastructure, 2017) at 26.)

17. As methane emissions are non-negligible for natural gas and coal, (IPCC 2014, WG3, ch.7, p. 539), the literature-based life-cycle GHG estimates (based on global warming potentials applied in older Intergovernmental Panel on Climate Change Assessment Reports) have been converted to more current values applied in the IPCC Fifth Assessment Report (i.e., GWP of 34 over 100 years). (See Environmental Commissioner of Ontario, "3.2.1 Methane" in Facing Climate Change, Annual Greenhouse Gas Progress Report 2016 (Toronto: ECO, January 2018) at 52.); Life-cycle emission estimates (excl. operation) of coal and wind power are from Amor et al. 2014, based on Mallia and Lewis 2013 (M.B Amor et al., "Influence of wind power on hourly electricity prices and GHG (greenhouse gas) emissions: Evidence that congestion matters from Ontario zonal data" (2014) 66 Energy 458 at 462, with the coal emission estimate revised to take into account the IPCC AR5 GWP for methane). The life-cycle emissions from natural gas were estimated using a model described in endnote 23.

18. According to research cited by the Intergovernmental Panel on Climate Change. (T. Bruckner et al., Energy Systems. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [O. Edenhofer et al. (eds.)]. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2014) at 538.)

19. For a discussion of appropriate methane global warming potential calculations, see Environmental Commissioner of Ontario, "3.2.1 Methane" in Facing Climate Change, Annual Greenhouse Gas Progress Report 2016 (Toronto: ECO, January 2018) at 50.

20. (S&T)² Consultants, GHG Emissions for Ontario Natural Gas Buses (Delta, B.C.: (S&T)² Consultants, 2016a) at 23.

21. P. Balcombe et al., "Characterising the distribution of methane and carbon dioxide emissions from the natural gas supply chain" (2018) 172 Journal of Cleaner Production 2019 at 2030.

22. According to research cited by the Intergovernmental Panel on Climate Change. (T. Bruckner et al., Energy Systems. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [O. Edenhofer et al. (eds.)]. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2014) at 538.)

23. The ECO put together a model to estimate emissions (per IPCC AR5) based on 2015 data on the upstream CO_2 and CH_4 emissions from Western Canada and U.S. gas supplies, as cited in an (S&T)² Consultants (2016b) report ((S&T)² Consultants, Lifecycle Analysis of GHG Emissions from Natural Gas in Ontario (Delta, B.C.: (S&T)² Consultants, 2016b) at 19 and 20). The upstream GHG emissions from the U.S. and Western Canada natural gas supply sources were weighted based on the claim that about 25% of Ontario's natural gas supply is from the United States, with the remainder almost entirely from Western Canada. For the emission estimate using a 2.65% global mean upstream leakage rate (P Balcombe et al., "Characterising the distribution of methane and carbon dioxide emissions from the natural gas supply chain" (2018) 172 Journal of Cleaner Production 2019 at 2030), the ECO model uses the upstream CO_2 intensity (67.1 g CO_2eq/kWh) estimated from the Western Canada and U.S. data supplied in ((S&T)² Consultants 2016a at 19 and 20). The ECO model also uses (1) the measured gross heating value (dry basis) of Ontario natural gas (38.7 MJ/m³) from Union Gas ("Chemical Composition of Natural Gas", online: Union Gas <www.uniongas.com/about-us/about-natural-gas/Chemical-Composition-of-Natural-Gas> [Accessed 6 March 2018]; (2) a 40% electrical efficiency for natural gas power plants in Ontario ((S&T)² Consultants 2016 at 26); and (3) the methane content of raw natural gas – 19.23 g methane/standard cubic foot (R.A. Alvarez, "Great focus needed on methane leakage from natural gas infrastructure, Supporting Information" (2012) Proceedings of the National Academy of Sciences of the United States of America, in Supporting Information Excel File, Worksheet: "EDF Analysis of FW Data").

24. A peer-reviewed study published last year revealed the potential for substantial natural gas leaks from the power plants themselves, with estimates ranging from 0.11% to 0.56% of natural gas inputs (T.N. Lavoie et al., "Assessing the Methane Emissions from Natural Gas-Fired Power Plants and Oil Refineries" (2017) 51 Environmental Science & Technology 3373 at 3373).

25. Based on the ECO model described in endote 23.

26. Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (31 January 2018).

27. **Annual natural gas plant electricity production (GWh)**

2015	15,366.13
2016	12,760.11
2017	5,029.06

Note: These numbers are slightly different than our usual supply mix statistics because they do not include a very small amount of gas-fired generation embedded within the distribution system.

Source: Independent Electricity System Operator, Generator Output by Fuel Type Monthly Reports (Toronto: IESO, 2016, 2017 and 2018).

28. See Note 9 above.

29. Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (22 December 2017).

30. It can be assumed that the reduction seen in the bottom 200 hours from less use of baseload gas-fired generation likely extends to most of the 8,760 hours, thus the overall reduction due to this factor could be as much as 6 TWh between 2015 and 2017.

Natural gas plant supply*	2015 (GWh)	2016 (GWh)	2017 (GWh)	Delta % 2015-2017
Top 200 hours of demand/year	801,306	784,326	447,014	-44%
Bottom 200 hours of demand/year	176,170	76,857	37,420	-79%

*Note: may not capture all natural gas plants.

Source: "Data Directory: Generator Output and Capability reports (annual, 2015-2017)", online: Independent Electricity System Operator <www.ieso.ca/power-data/data-directory>.

31. Additional production from hydro and nuclear that was curtailed in 2015 may have been able to fill a small amount of the gap (see Q7).

32. "Supply Overview: Imports and Exports", online: Independent Electricity System Operator <www.ieso.ca/power-data/supply-overview/imports-and-exports>.

33. Generally, gas generators will only produce power if the hourly wholesale price is high enough to cover fuel costs. Much of Ontario's current exports are during hours when price is low, as a large source of exports are renewables, which have very low "marginal operating costs" (i.e., fuel costs). Low export prices drive up demand. If natural gas was setting the wholesale price, the price would be higher, which would potentially drive down demand.

34. The Ministry of Energy has estimated greenhouse gas emissions factors for electricity production from these jurisdictions (NYISO for New York, and MISO for Michigan) and both are many times higher than Ontario, even in off-peak hours. ("Default Emissions Factors for 2018 for Ontario's Cap & Trade Program", online: Ontario Ministry of Energy <www.energy.gov.on.ca/en/ontarios-electricity-system/climate-change/default-emission-factors-for-2018-for-ontarios-cap-trade-program/>.)

35. Independent Electricity System Operator, information provided to the ECO in response to ECO inquiry (31 January 2018).

36. Environmental Commissioner of Ontario, "6.3 Shifting Freight Away from Fossil Fuels" in Ontario's Climate Act from Plan to Progress, Annual Greenhouse Gas Progress Report 2017 (Toronto: ECO, January 2018) at 209-214.