CNA SUMMARY

LIFECYCLE EMISSIONS OF NUCLEAR, WIND AND NATURAL GAS POWER GENERATION

The Future is NU.
Canadian Nuclear Association

A study by Hatch Ltd.

The Canadian Nuclear Association (CNA) commissioned Hatch Ltd. to evaluate current literature on the carbon emitted by nuclear, wind and gas-powered electrical generation.

Hatch Ltd. is a global engineering and management consultancy, headquartered in Toronto, which serves several industries. Hatch's energy unit has nine decades of continuous service in hydro, wind, solar, thermal and nuclear power, and transmission and distribution.

Lifecycle analysis

Lifecycle analysis (LCA) is the study of an industrial process through all its stages, for example, of emissions at each stage from resource exploration to waste disposal. LCA is the most widely accepted, comprehensive measure of environmental performance.

LCA is a specialized analytical field, one that has evolved over time and that has generated its own technical and professional standards, such as ISO14040.

The 2008 CERI study

In 2008, the CNA commissioned a third-party analytical team at the Canadian Energy Research Institute (CERI) to perform a comparative LCA of base load electricity generation in Ontario from nuclear, coal and natural gas. CERI followed ISO14040 methodological standards in this work. While acknowledging that nuclear produced more radionuclides, its study concluded that "GHG emissions and criteria air contaminants from coal and natural gas power generation are several orders of magnitude higher than those from nuclear." Key results of that study are reproduced in Appendix B.

An ideal LCA would require data from all phases of a process – "cradle to grave." While CERI's 2008 study covered uranium mining and power generation, it did not include data on the exploration phase (searching for deposits of uranium, oil, or coal), the construction of nuclear power plants, nor of plant decommissioning or waste disposal.

Mineral exploration and waste disposal were considered by CERI to be outside the scope of the study, which was specific to the Ontario electricity generating sector and its fuel supply. There was a lack of current Canadian empirical data available in the areas of decommissioning and heavy water manufacture. Emissions from the construction of plants was considered to be similar across fuel types, and negligible compared with emissions in other phases of the cycle, so construction emissions could be ignored.

Objectives of the 2014 meta-analysis

CNA's objectives in commissioning the Hatch meta-analysis in 2014 were:

- To gather the best available peer-reviewed LCA work on power generation from international sources through a comprehensive literature review.
- To shift the focus of comparison from coal-fired generation to wind generation. Coal's negative environmental effects are now widely appreciated, and are the reason why it is now being eliminated from the power supply mix in Ontario. On the other hand, wind's environmental effects remain poorly understood, though it is an increasing portion of the supply mix in many jurisdictions.
- To cover the exclusions from the 2008 CERI study insofar as possible.
- To update and verify the information generated by the 2008 study.

Oversight

The Hatch Meta-Analysis was conducted by a team of analysts employed by Hatch, under a research contract funded by CNA. The analytical work was overseen by the CNA's Greenhouse Gas Working Group (GHG WG). The GHG WG consists of CNA staff and representatives from CNA member organizations; they are listed in Appendix C.

Scope

LCA is inherently resource-intensive and tends to be costly, and CNA's research resources are limited. From its early planning, the study's focus was on seeking information of greatest relevance to near-term supply mix choices. This is why the study's scope did not attempt to cover hydroelectricity, solar, geothermal or other power sources. Such information is of interest, but researching it would have taken resources better applied on a narrower field.

Type of analysis

Another key methodological decision, following the literature review, was whether to do a "literature based" or a "scoping level" LCA. A scoping level analysis would have involved data collection, data estimation, and calculations based on engineering estimates. Alternatively, a literature based analysis involved compiling data from some 250 existing peer-reviewed studies, and synthesizing that data to conform to similar system boundaries.

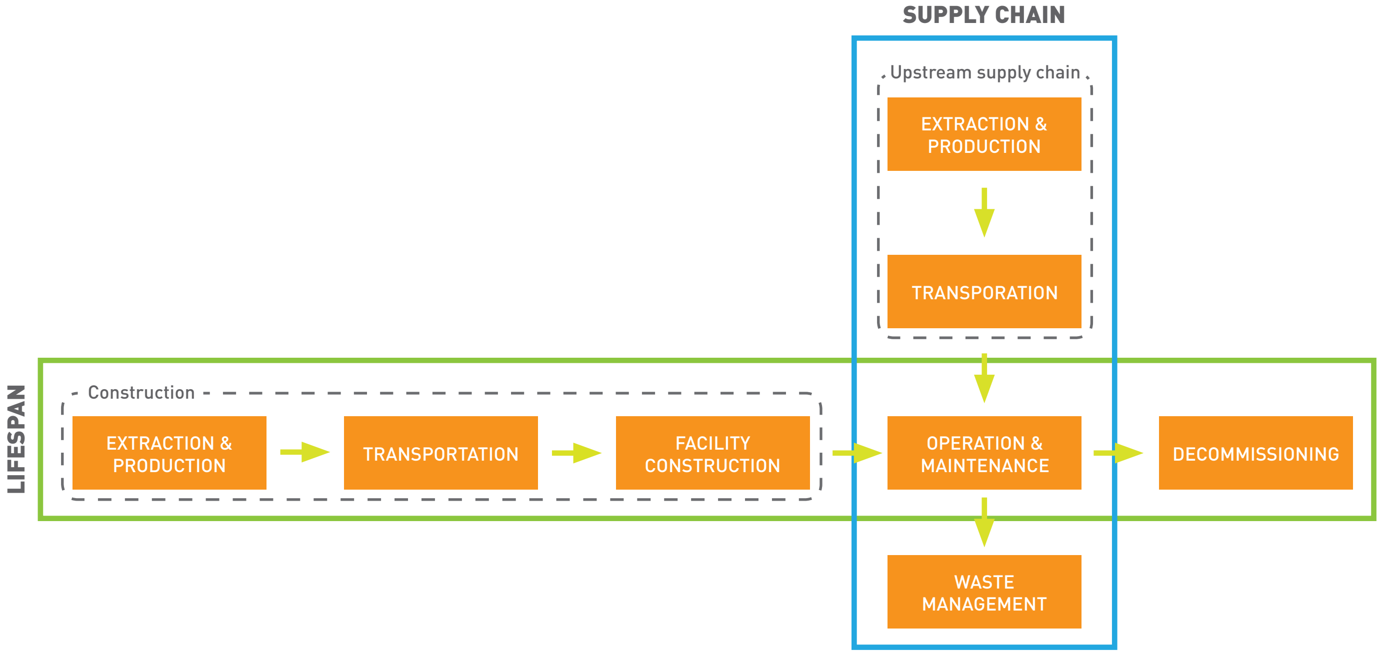
The GHG WG considered these options and, after consulting with the Hatch analytical team, a decision was made to take the literature based approach.

System boundaries

There are two intersecting lifecycles involved in most industrial processes, both of which must be captured in an LCA. These are illustrated below.

- Lifespan – the lifetime of the power plant from inception to decommissioning.
- Supply chain – the upstream systems associated with fuels and consumables, and the downstream systems associated with management and disposal of wastes.

Environmental indicators measured included greenhouse gases, particulate matter, sulphur oxides, nitrogen oxides, and ionizing radiation.



SCHEMATIC OF THE SYSTEMS TO BE CONSIDERED IN A LIFECYCLE STUDY (FROM HATCH, 2014, P. 6)

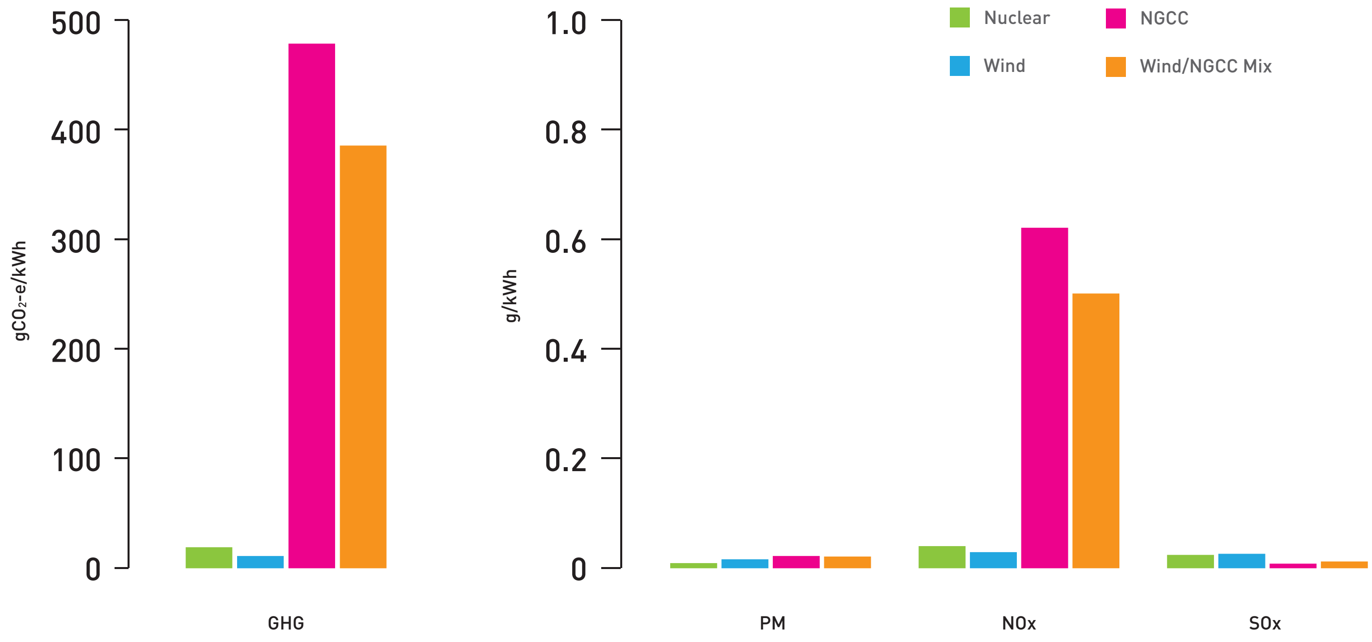
Literature coverage

The evaluation considered 246 studies of considerable variety. The data was compiled, assessed, and grouped into categories representing segments of the system boundaries shown in the schematic above. Although the coverage of some process stages was limited, coverage improved in line with a stage's importance in terms of the emissions it contributed to the total.

In terms of emissions, most studies addressed greenhouse gases, with fewer addressing the other environmental indicators. Regionally, most studies were from North America or Europe. Temporally, all studies admitted were from 2000 or later.

Results

Following are key results as stated in Hatch's final report. NGCC refers to gas-fired power generation ("Natural gas combined cycle").



TOTAL LIFECYCLE EMISSIONS OF GREENHOUSE GASES (GHG), PARTICULATE MATTER (PM), NITROGEN OXIDES (NOX) AND SULFUR OXIDES (SOX) FROM POWER GENERATION BY VARIOUS TECHNOLOGIES (FROM HATCH, 2014, P. 47)

"Nuclear and wind power are similar in magnitude for each emission category and an order of magnitude less than natural gas with respect to GHG and NOx emissions." (p. 46)

"The wind-NGCC scenario reflects a potential grid mix based on current grid infrastructure in Canada that (in the absence of energy storage) uses [gas] to compensate for the intermittent nature of electricity generation from wind power." "Emissions from the 20-80 mix of wind-NGCC is more comparable to NGCC, where emissions of GHG and NOx exceed nuclear." (p. 48)

"The range of GHG and NOx emissions for natural gas and a mix of natural gas and wind power are in every case, significantly higher than for [the nuclear scenario]." (p. 49)

"The results of the assessment show that the lifecycle of nuclear and wind power generation produces a small fraction of the GHG and NOx emissions of the natural gas combined cycle (NGCC) lifecycle... Emissions of PM were more comparable across generation sources... Emissions of SOx were similarly comparable..." (p. 70)

"When considering wind backed by natural gas power (20%/80%) to compensate for intermittency, emissions from the modified grid mix closely resembles that of natural gas production, diluted by a low-emissions power source." (p. 71)

Conclusions

Hatch's meta-analysis reinforces four facts of which citizens and policymakers already are – or should be – aware about emissions from our electricity supply mix.

- Nuclear is very clean: its emissions are similar to pure wind, and far lower than natural gas, a fossil fuel. Natural gas, on the other hand, is only low-emitting when compared to other fossil fuels such as coal.

- In the real world today, wind generation does not supply power grids by itself. Because the wind blows intermittently, wind generation must be backed up by another power source - often natural gas.
- To measure environmental effects from power generation, while it may be relevant to compare nuclear directly against natural gas, it is not relevant to compare nuclear or gas with wind alone. A more realistic comparison is between nuclear, natural gas, and/or a mix of wind with its likely backup power source.
- The Hatch team used a 20/80 wind-gas mix for this comparison. This mix has an emission profile similar to natural gas, a fossil fuel. While the emissions from this mix are somewhat cleaner than straight natural gas generation, they are still far above those from nuclear power. While we agree with the Hatch team's use of a 20/80 wind-gas ratio, mixes closer to 50/50 would still involve greater emissions than nuclear. See Appendix A for more discussion.

CNA urges readers to refer to the Hatch report itself for a complete presentation of the study's methodology, data, and conclusions.

APPENDIX A: WIND INTERMITTENCY

Today's power grids, which cannot economically store power at grid scale, must balance generation exactly with demand from hour to hour. In Ontario, power demand is highest during the day and in the summer. On the other hand, the wind blows most during the night and in the winter and spring. Wind power production is inherently out of time with power demand.

Once an investment has been made in wind farms, there are three ways the power authorities can resolve these mismatches:

- Dispatch (turn off) wind generation when the wind blows and there is too much baseload power.
    - In general the Ontario Power Authority's contracts with wind producers are not dispatchable, so this is not an option.
- Dispatch (turn off) customers when the wind does not blow and there is too little baseload power. Demand response programs "increase the amount of flexible resources on the system to balance the variations that can be caused by intermittent resources such as wind or solar." (Ont IESO, DR Public Session #2, July 2014).
    - Normally customers dispatched are those who have agreed by contract to accept this risk, usually in return for lower electricity rates.
- Raise and lower some other source of generation to compensate for wind's intermittency.

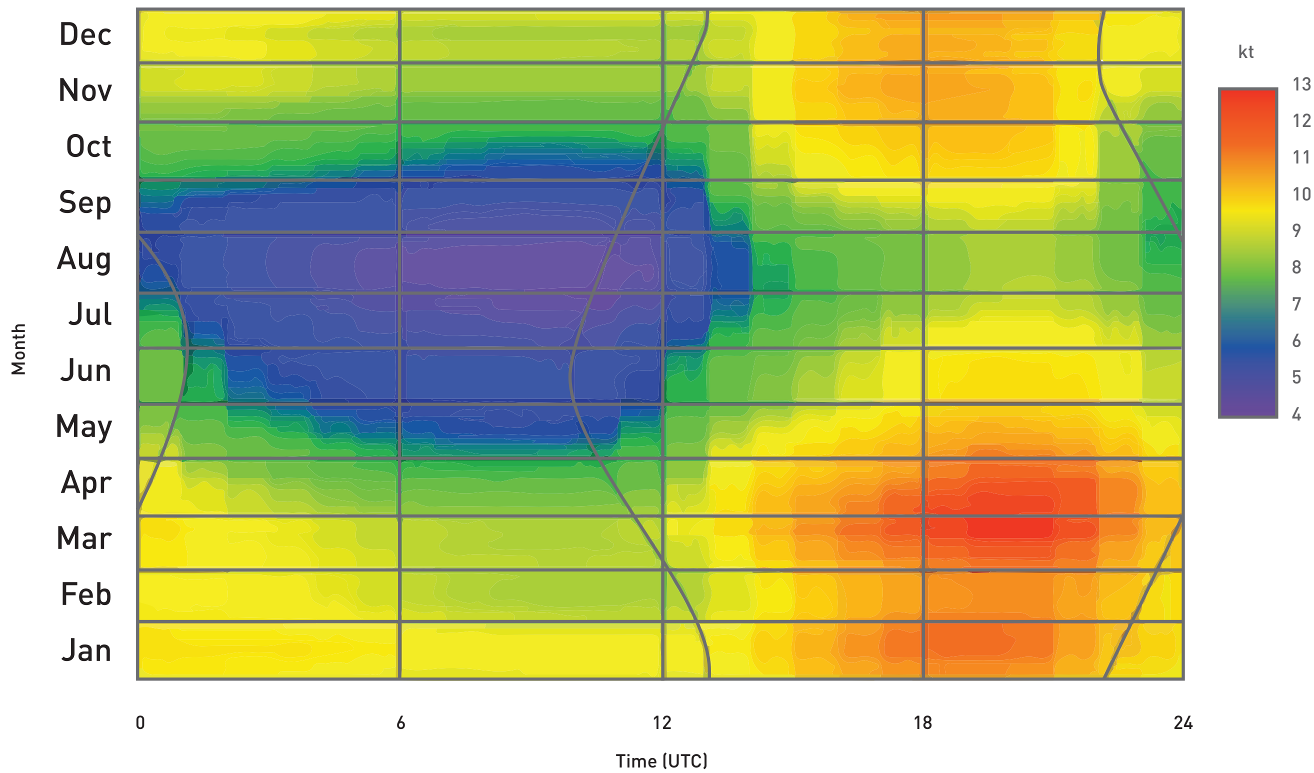
Energy storage is a potential alternative to natural gas backup in the long run, but was not considered in the study because it is not currently available on a relevant scale. Energy storage would come at some additional environmental cost over wind, and it would also likely require transformative changes to existing grid infrastructure to accommodate significant increases in wind generation. These additional costs would have to be considered in an LCA.

Following is part of a discussion of wind intermittency by the Ontario Society of Professional Engineers (OSPE) (*Wind and the Electrical Grid: Mitigating the Rise in Electricity Rates and Greenhouse Gas Emissions*, 2012, pp. 12-13):

> *Environment Canada data shows that wind has similar variability across most of southern Ontario where most of the wind turbines are presently located. There is some smoothing of overall generation variability compared to individual wind turbines over minutes and hours but* ***the daily and seasonal variation must be managed by a backup source of energy****. Presently,* ***Ontario is using gas-fired generation to provide that backup*** *with a lesser contribution from some hydraulic and nuclear generation that have some limited maneuvering capability…Because of wind's variability, the remaining generating stations see a residual demand that is much more variable… We can export some but not all of the surplus generation. We will likely have to shut down several nuclear units on a frequent basis in the future if we don't dispatch wind generation. The following day the lost nuclear capacity would need to be replaced by* ***gas-fired generation at considerable extra fuel cost and GHG emissions****. In addition, the peak portion of the residual load*

*demand will have risen…That extra peak demand will need to be supplied by peak generation resources. Therefore, not requiring wind generation to be dispatched means **electricity will be produced with more natural gas generation at higher fuel costs and higher GHG emissions**.*

Windsor, average wind speed (kt)



A TIME-BASED "WIND MAP" FOR PART OF SOUTHERN ONTARIO. DARK AREAS REPRESENT TIMES WITH LITTLE OR NO WIND. (FROM OSPE, 2012)

APPENDIX B: KEY RESULTS OF THE 2008 CERI STUDY

Pollutants	Unit	Power generation options		
		Nuclear	Coal	Natural gas
Total criteria air contaminants (CAC)	t/TWh	12.42	6,712.78	1,452.63
Oxides of nitrogen (NO_2)	t/TWh	2.45	1,676.58	720.12
Sulphur dioxide	t/TWh	8.54	3,907.36	363.32
Carbon monoxide	t/TWh	0.00	418.11	247.47
Total particulate matter	t/TWh	0.61	685.68	20.91
Volatile organic compounds (VOC)	t/TWh	0.81	25.05	73.81
Other air pollutants				
Lead and its compounds	kg/TWh	0.09	22.21	0.61
Mercury and its compounds	kg/TWh	0.00	10.59	0.00
Arsenic and its compounds	kg/TWh	0.00	23.07	0.61
Radionuclides	TBq/TWh	39.85	0.06	0.92
Water pollutants				
Lead and its compounds	kg/TWh	0.00	0.47	0.00
Mercury and its compounds	kg/TWh	0.00	0.13	0.00
Arsenic and its compounds	kg/TWh	0.19	1.56	0.00
Radionuclides	TBq/TWh	21.04	0.00	0.01
Greenhouse gas (GHG) emmissions (CO_2 equivalent)	**t/TWh**	**1,836.74**	**1,051,215.33**	**540,391.16**

LIFECYCLE POLLUTIONS FROM POWER GENERATION IN ONTARIO (FROM CERI, 2008)

APPENDIX C: MEMBERS OF THE CNA GREENHOUSE GAS WORKING GROUP

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