Documentation of the Carbon Footprint of Hydro Québec's Hydropower

Bradford H. Hager
Cecil and Ida Green Professor of Earth Sciences
Department of Earth, Atmospheric and Planetary Sciences
Massachusetts Institute of Technology

Summary

The purpose for building NECEC is to provide a conduit for ~ 10 TWh/yr of electricity to Massachusetts. The premise used to justify NECEC is that this power would result in much less net emission of greenhouse gasses than what would be produced from electricity generated using modern natural gas power plants (~ 400 g CO2/kWh). Yet despite claims that its power is "low-carbon," Hydro Québec (HQ) has provided no formal documentation of this claim.

In this white paper I provide relevant references, as well as giving a road map through these references to finding values of CO2e emissions of HQ reservoirs. The information in the peer reviewed literature demonstrates that a large fraction of HQ power is not low carbon.

A growing number of peer-reviewed articles in the scientific literature address the carbon footprint of hydro reservoirs worldwide. By studying these papers and the on-line supplementary materials accompanying them, I have assembled sufficient information to determine the greenhouse gas emissions of 18 of HQ's major reservoirs – those that generate in excess of 1 TWh/yr of electricity each. There is a tremendous range in HQ emissions – from 5 g CO2/kWh (half that produced by wind) to 2265 g CO2/kWh (twice that produced by coal). About half of HQ generation is comparable in emissions to natural gas. These estimates are given in a table and illustrated in a figure in the final two pages of this document.

Relevant literature

About 20 years ago. scientists began to recognize the possibility that reservoir greenhouse gas emissions are significant (e. g., St. Louis et al., 2000). In particular, HQ undertook an extensive research program to measure the fluxes of CO2, CH4, and N2O in their reservoirs and surroundings. Tremblay et al. (2005) published measurements of greenhouse gas fluxes for many Canadian reservoirs, including most existing HQ reservoirs. Fluxes were reported in mg/m^2/d. (There is tremendous scatter in the observations for a given reservoir because emissions vary greatly in space and time. The standard deviation of the values reported are approximately equal to the values themselves.)

Teodoru et al. (2012) measured variations in emissions as a function of time over the three years following the filling in 2006 of the new Eastmain-1 reservoir in Québec. They found that initially the CO2 footprint was comparable to a coal fired power plant, but decreased to that of a modern gas plant after 3 years. They extrapolated the data to conclude that, over 100 years, the cumulative emissions of this reservoir would be about half that of a gas plant

Barros et al. (2011) compiled data from about 100 hydro reservoirs worldwide, concluding that emissions were correlated with reservoir age and latitude. His data set included Tremblay's (2005) data.

Hertwich (2013) made an important advance by making estimates from the web of the amount of energy generated by these reservoirs. This made it possible to convert the conventional measurements of emissions per unit area to obtain emissions per kWh.

Scherer and Pfister (2016) used the ~150 reservoirs in the Hertwich (2013) data set to fit a general linearized model, explaining most of the CO2 emission variation using only two variables: Hertwich's area/electricity ratio and the logarithm of reservoir area. They then used the recently developed Global Reservoir and Dam Database (GRAND, see Lehner et al., 2011) to estimate model-based fluxes for ~ 1500 reservoirs worldwide. The supplementary data files of Scherer and Pfister (2016) provide a convenient source for the Hertwich (2013) data set, as well as an alternative estimate (from GRAND) for energy generation in 2009.

Deemer et al. (2016) also augmented the Barros et al (2011) data set with more recent measurements. However, they focused on reservoirs where methane is the main greenhouse gas, and their study does not add substantially to information about HQ reservoirs.

Estimates of Hydro Québec CO2e footprint

Table 1 gives estimates, using four approaches, for the CO2 equivalent emissions (g CO2e/kWh) for the 18 HQ reservoirs generating > 1 TWh/yr. Because generation by any power plant varies from year to year, there are two estimates used: H13 is the older value provided by Hertwich (2013), while S&P is the value for 2009 provided by Scherer and Pfister, 2013. Systems are ranked by using the larger of these two values. (Note that the H13 value for the Robert Bourassa system is anomalously large, and not in line with others in the La Grande system, making me skeptical of this value.)

The values of CO2e (g/kWh) in the columns labeled "S&P data" were calculated using the two estimates of energy (in TWh) with data for reservoir emissions in the Scherer and Pfister (2016) table. The "S&P model" column gives Scherer and Pfister's (2016) values for their two parameter model. The "T12 data" gives Teodoru et al.'s (2012) observed emissions for the Eastmain-1 reservoir in 2009, three years after it was flooded. Cells where there was no information are left blank. Cells where greenhouse gas emissions exceed that of natural gas are highlighted in yellow. Cells where greenhouse gas emissions exceed that of coal are highlighted

in red.
Even though HQ's two top power producers, Robert-Bourassa and Churchill Falls, are over 40 years old, they both have carbon footprints approximately equal to that of modern natural gas. Brisay/Caniapiscau is two times dirtier than coal. Most of HQ's power has a much greater carbon emissions than wind.

Table 1: Estimates of CO_2e for Hydro Québec's reservoirs > 1 TWh/yr

System	**Area (km2)**	**TWh**			**CO2e g/kWh**			
		Max	H13	S&P	S&P data H13 TWh	S&P data S&P TWh	S&P model S&P TWh	T12 data H13 TWh
Robert-Bourassa (La Grande-2)	2835	37.4	37.4	5.2	57	412	576	
Churchill Falls*	4816	30.8		30.8			436	
Bersimis	798	12.5	12.5	7.8	35	56	313	
La Grande 4	765	10.1	10.1	8.9	46	52	309	
Manic 5	1973	9.8	9.8		124			
La Grande 3	2420	8.7	8.7	8.4	210	217	451	
La Grande 2A	2835	7.1	7.1		222			
Manic 2	124	6.5	5.1	6.5	10	8	180	
Manic 3	236	5.8	4.9	5.8	6	5	219	
Bersimis 2	38	5.5		5.5			119	
La Grande 1	70	4.5	4.5	2.7	12	20	165	
Outardes 3	11	4.5	3.2	4.5			42	
Outardes 4	625	3.7	2.6	3.7	194	138	329	

Laforge-1	960	2.7	2.7	1.7	371	588	605	
Eastmain-1	600	2.7	2.7		309			275
St-Marguerite 3	253	2.6	2.6		197			
Outardes 2	26	2.0		2.0			102	
Brisay/Caniapiscau	4318	1.2	1.2	0.8	1501	2265	2250	

* Churchill Falls is in Labrador, but almost all of its power goes to HQ.
Figure 1 illustrates the range of estimates for these reservoirs in a bar graph. For reference, the line showing 400 g CO2e/kWh is the value for a modern natural gas power plant.

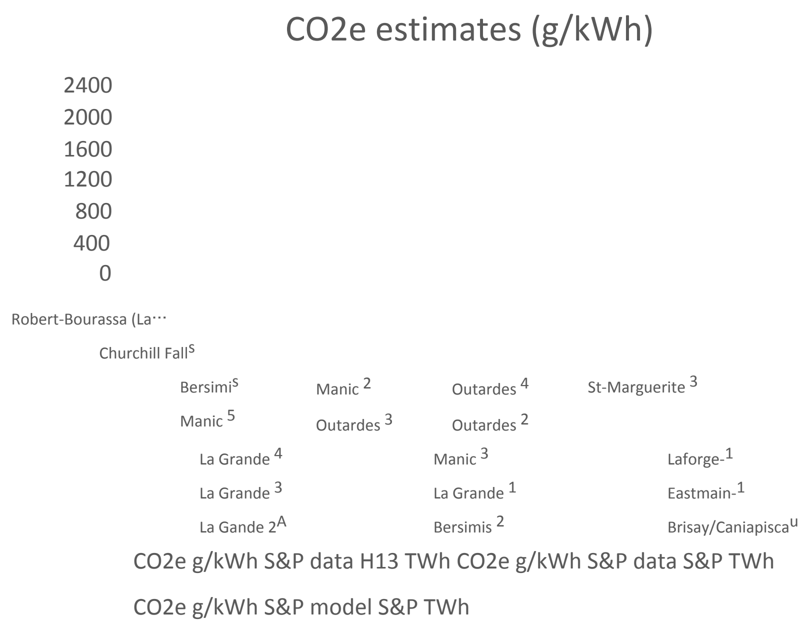

Figure 1: CO2e (g/kWh) estimates for HQ's reservoirs generating > 1 TW/y.

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