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Open and Common Approaches for Evaluating Marginal Emission Factors: A Case Study of the Alberta Electric Grid

Presentation to EMI, March 26 2021

Canada

Agenda

- Introduction and Background
- Models and Data Sources
- Results
- Conclusions

Introduction

- **Objective:** Compare different approaches to estimate hourly marginal emission factors (MEFs)
  - Multiple linear regression (MLR) model
  - Canadian Energy Regulator (CER) Energy Futures model
- **Comparison metrics:**
  - Fraction of time that different generator types are marginal on an annual basis vs. data provided by the Alberta Electric System Operator (AESO)
  - Fraction of total generation provided by different generator types vs. data by the AESO
  - MEFs and AEFs by month and hour of the day
- **Team members:**
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  - Canadian Energy Regulator: Matthew Hansen, Mantaj Hundal
  - National Research Council: Farid Bensebaa

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Canada Energy Regulator Régie de l'énergie du Canada

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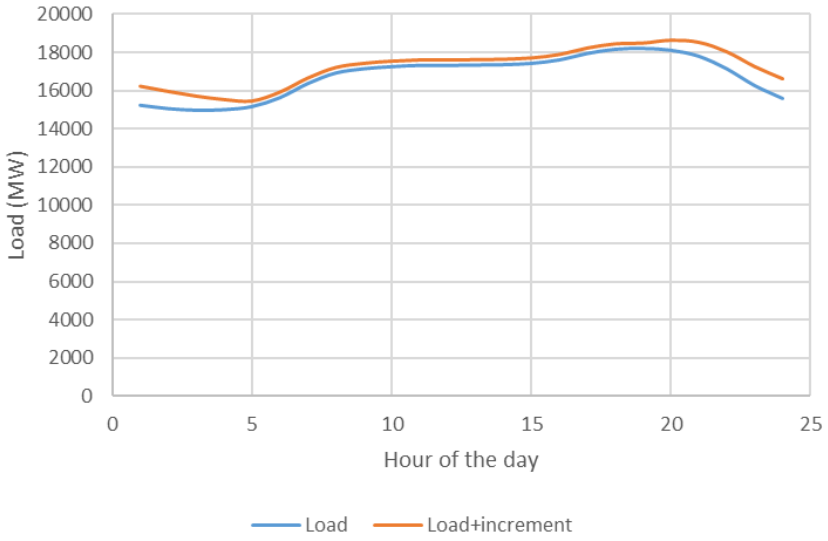
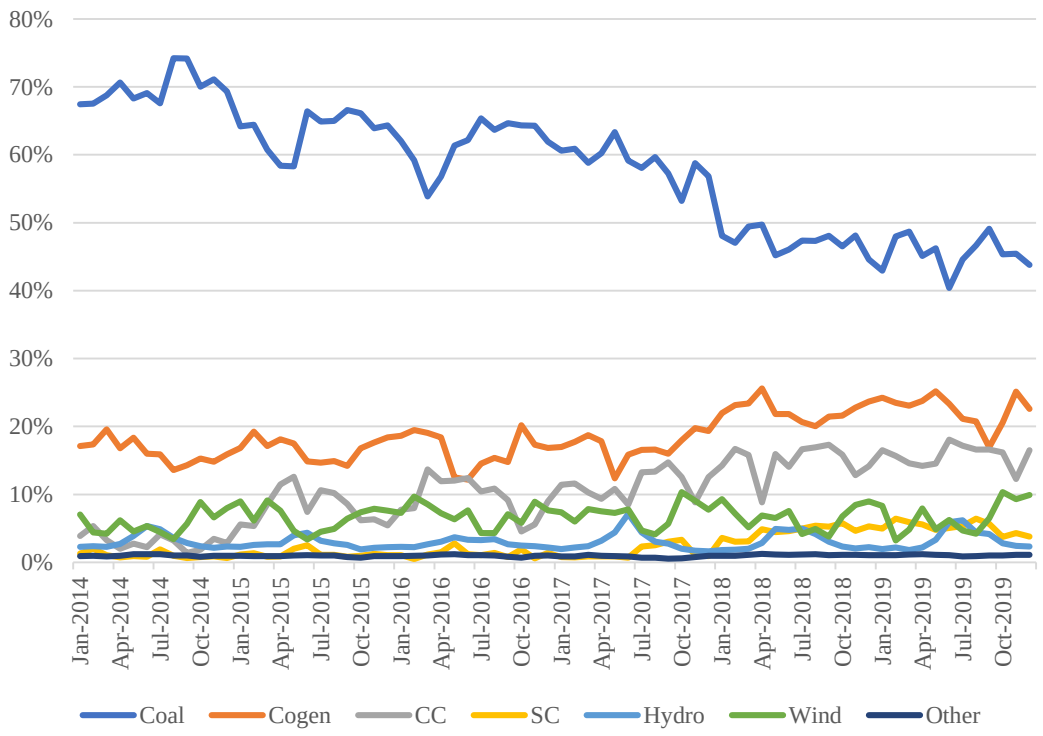
Background

- **Marginal emission factors (MEFs):** change in emissions as a result of a MWh increment in demand
- **Electricity MEFs:** used to quantify impact of programs (e.g. electric vehicle deployment, demand response)
- **Average emission factors (AEFs):** total emissions divided by total electricity demand
- **Marginal generator:** the generator that supplies the next MWh increment in demand



Background

- **Justification**
  - MEFs are often provided simply as annual averages; however, hourly MEFs are needed to better understand and target initiatives
  - Few attempts at comparing different approaches to quantify hourly MEFs
  - Models are often proprietary or incomplete; data often unavailable
- **Why Alberta?**
  - Hourly electric generation data, by unit, available from Alberta Electric System Operator (AESO)
  - Increasingly diverse grid containing renewables, coal, and natural gas generation
  - Fairly small share of electricity generation from interties



Share of Energy Production by Generation Technology, Alberta, 2014-2019
Source: AESO Annual Market Statistics Report

Multiple Linear Regression (MLR) Model

$$\Delta E = \overbrace{(\beta_1 + \beta_2 G + \beta_3 \Delta \mathrm{G})}^{MEF} * \Delta G + \beta_0$$

$$\Delta G_k = \overbrace{(\epsilon_{1,k} + \epsilon_{2,k} G + \epsilon_{3,k} \Delta \mathrm{G})}^{\gamma_k} * \Delta G + \epsilon_{0,k}$$

E: Greenhouse gas emissions; G: Generation

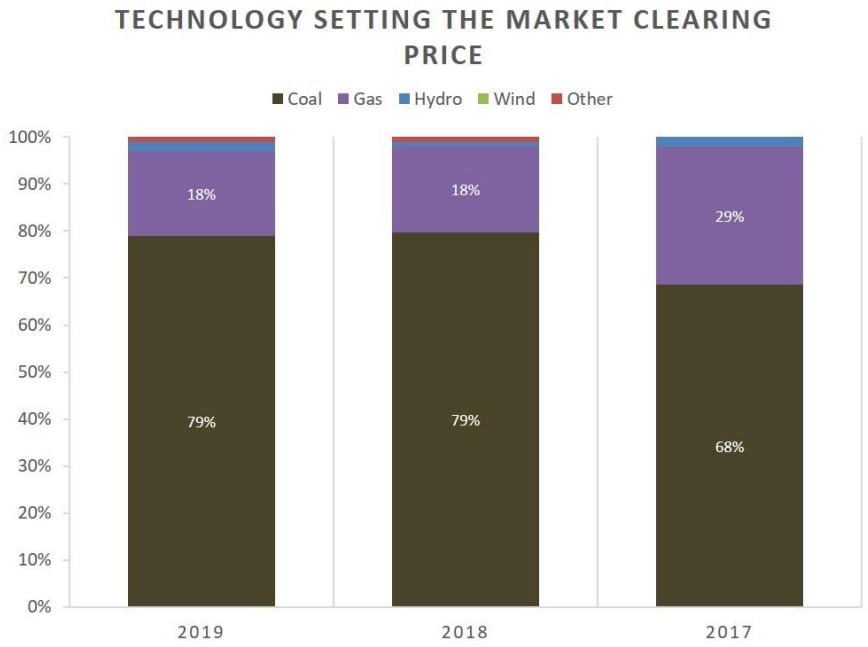
$k \in \{Coal, Gas, Hydro, Wind, Solar, \ldots\}$

Data filtered prior to model fitting to exclude non-marginal generators

MLR Data Selection and Filtering

- Hourly output of all generators in Alberta + hourly imports from all interties (AESO)
- A generator can be marginal for a given hour only if:
  - It is a coal, gas or hydro generator
  - Its change in generation is of the same sign as the total change in generation

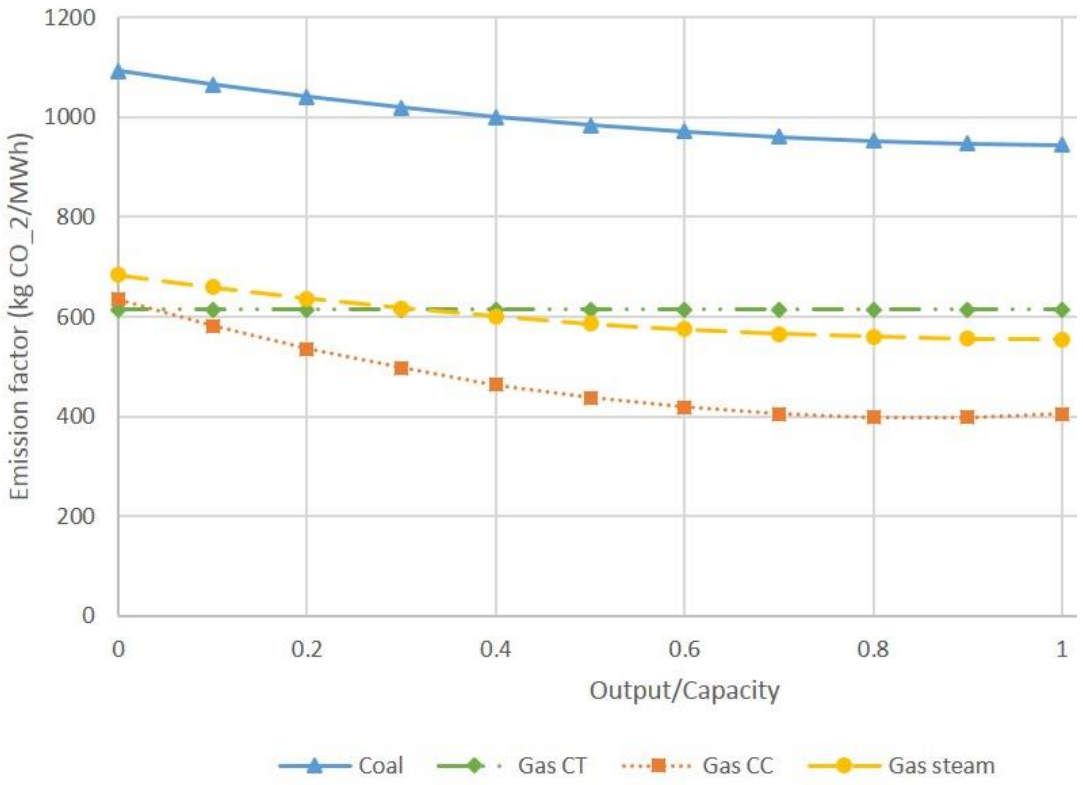
Date	Hour	TOTAL	ABKENORA	ADELAIDE	GUASABO	ALEXANDE	AMARANTH
1-Jan-18	1	18401	16	27	36	49	6
1-Jan-18	2	18082	16	37	36	49	1
1-Jan-18	3	18208	16	40	36	49	3
1-Jan-18	4	17974	16	42	36	49	47
1-Jan-18	5	17797	16	39	36	49	61
1-Jan-18	6	18044	16	39	36	49	82
1-Jan-18	7	19004	16	41	36	49	86
1-Jan-18	8	19280	16	42	36	49	104
1-Jan-18	9	19109	16	40	36	49	101
1-Jan-18	10	19584	16	38	37	50	75
1-Jan-18	11	19330	16	40	33	49	84
1-Jan-18	12	19210	16	50	15	49	90
1-Jan-18	13	19454	16	55	15	49	56
1-Jan-18	14	19282	16	39	14	49	86



Generator CO_2 Emission Factors

Assumptions

- Coal and gas generators have quadratic heat rate curves and emit only when generating
- All other generators have no emissions
- Imports are based on average emission factors



CER Modelling Approach

- Uses existing open-source modelling tool
  - Python for power systems analysis (PyPSA) - a free software toolbox for simulating and optimising modern power system.
- The linear optimal power flow is calculated for Alberta using 2018 data
- PyPSA is also used by the CER for long-term forecasting (e.g. capacity expansion and generation planning)
- Assumptions:
  - One zone
  - No interties

CER Model Inputs/Outputs

- Inputs
  - Hourly load and wind, solar, and hydro capacity factors for 2018 (AESO)
  - For installed capacity, individual units are aggregated up by fuel type
  - Hourly minimum/maximum output and ramping constraints are added for all applicable fuel types
  - Fixed marginal costs are used for all fuel types
- Outputs
  - Hourly optimal generation for each fuel type
  - Marginal and average emissions (using emissions factor curves)

Data Sources

Input	Data Source	
	MLR Model	CER Model
Hourly marginal electricity prices	AESO	
Hourly imports from all interties	AESO	
Type of generator	AESO	
Heat rate curves by type of coal/gas generator (all generators)	Literature	AESO + Literature
CO_2 emissions per unit fuel consumption	U.S. Energy Information Administration (EIA)	
British Columbia average annual emission factor	National Inventory Report (NIR)	
Saskatchewan average annual emission factor		
Montana intertie average annual emission factor	EIA	
Hourly output of all generators in Alberta	AESO	
Hourly load		AESO
Operational information of each type of generator (e.g. ramp, start-up cost)		Literature
Renewable energy availability forecast		AESO

Comparison with AESO Data

- Fraction of year generator type is **marginal**

Generator Type	MLR Model	CER Model	AESO
Coal	57%	73%	79%
Gas	35%	27%	18%
Hydroelectric	9%	0%	1%
Wind	0%	0%	0%
Other	0%	0%	1%

Comparison with AESO Data (cont'd)

- Fraction of total annual generation by generator type

Generator Type	MLR Model	CER Model	AESO
Coal	*Generation data from AESO is an input to MLR*	47%	45%
Gas		43%	40%
Hydroelectric		3%	3%
Wind		7%	6%
Imports		*no interties*	5%
Other		0%	1%

Results - MEFs

Hour \ Month	1	2	3	4	5	6	7	8	9	10	11	12	Average
1	690	688	688	684	681	683	686	687	687	689	690	692	687
2	690	689	688	685	683	684	688	688	687	690	691	692	688
3	690	689	689	685	683	684	688	688	688	690	691	693	688
4	691	690	689	686	683	684	687	689	688	690	692	694	689
5	692	692	691	687	684	685	689	689	689	691	693	695	690
6	694	694	693	689	685	686	689	692	691	693	695	696	691
7	698	697	696	692	688	689	691	693	695	695	697	698	694
8	699	700	697	693	692	692	694	694	695	698	698	700	696
9	699	696	695	692	692	693	696	696	695	695	697	700	696
10	696	696	695	691	692	693	696	697	695	695	697	699	695
11	696	696	694	692	692	693	696	696	695	696	696	699	695
12	696	695	694	691	692	693	695	696	694	695	696	698	695
13	695	695	693	691	692	692	696	696	693	694	694	698	694
14	695	694	692	691	692	692	695	696	694	694	696	697	694
15	695	694	692	690	691	692	695	696	694	693	696	698	694
16	696	695	693	690	691	692	695	696	694	694	697	698	694
17	699	697	694	691	692	693	696	696	694	695	697	701	695
18	701	698	694	691	691	692	694	695	695	695	698	701	695
19	697	699	694	688	689	689	693	694	693	695	696	698	694
20	695	696	695	689	689	690	693	694	694	695	697	698	694
21	695	694	695	691	688	689	691	694	695	693	696	698	693
22	694	693	692	691	688	688	692	694	691	692	693	697	692
23	691	690	689	686	686	688	692	691	688	690	692	695	690
24	690	689	688	684	682	685	689	688	687	690	691	694	688
Average	695	694	693	689	688	689	692	693	692	693	695	697	693
													Annual average

MLR Model

Hour \ Month	1	2	3	4	5	6	7	8	9	10	11	12	Average
1	812	784	875	938	980	908	887	871	915	972	856	790	882
2	902	760	869	959	971	941	880	923	962	970	912	836	907
3	913	772	917	947	952	945	865	926	961	914	915	939	914
4	896	796	806	857	911	902	960	862	765	720	887	908	856
5	706	699	710	734	806	886	856	694	616	638	744	762	738
6	560	637	623	701	754	812	739	621	655	658	638	662	672
7	579	667	771	796	824	778	742	667	797	876	640	737	740
8	716	800	939	875	866	887	841	784	918	957	816	826	852
9	886	932	930	915	867	862	999	883	981	939	909	922	919
10	888	947	809	897	874	885	980	941	942	848	930	980	910
11	758	948	734	779	827	825	941	822	641	669	831	867	803
12	611	783	623	659	652	564	649	726	621	593	693	734	659
13	557	641	574	655	580	508	572	727	646	601	616	679	613
14	530	643	691	790	646	495	482	633	782	754	554	646	637
15	637	730	885	903	799	651	610	652	959	944	677	683	761
16	819	847	918	951	919	889	794	780	964	954	932	871	887
17	925	834	917	973	931	944	915	929	974	960	967	937	934
18	937	822	917	973	954	961	954	957	953	972	954	930	940
19	947	821	907	972	978	974	964	968	961	960	965	949	947
20	930	809	918	973	978	974	942	967	954	953	954	949	942
21	920	813	929	973	978	955	928	949	962	954	965	949	940
22	920	838	903	974	977	954	966	955	973	974	965	942	945
23	883	801	940	961	978	942	965	967	972	971	851	814	920
24	761	782	889	941	978	928	921	921	948	971	802	772	884
Average	791	788	833	879	874	849	848	839	868	863	832	837	842
													Annual average

CER Model

**Units are in kg of CO_2/MWh

Results - AEFs

Hour	Month 1	2	3	4	5	6	7	8	9	10	11	12	Average
1	649	633	676	632	591	609	663	671	695	681	679	671	654
2	646	627	672	629	588	604	667	670	698	684	678	669	653
3	645	624	671	628	589	600	670	672	703	684	675	671	653
4	643	624	671	627	591	597	671	673	706	685	676	672	653
5	647	624	673	627	590	597	671	672	705	685	679	672	654
6	650	624	673	628	588	601	669	673	705	681	675	672	654
7	660	626	681	635	587	608	670	676	704	675	672	665	655
8	659	629	682	631	588	607	660	665	692	660	658	655	649
9	668	636	683	640	600	619	667	670	688	658	662	656	654
10	669	640	683	638	604	624	672	678	689	656	663	658	656
11	663	647	682	644	602	628	668	676	689	662	665	658	657
12	661	646	679	648	608	631	664	673	686	663	666	659	657
13	661	650	681	652	615	629	665	673	683	659	665	659	658
14	657	649	678	653	618	627	661	670	679	658	666	659	656
15	654	651	675	650	618	623	660	666	679	653	667	659	655
16	652	649	674	649	617	621	655	663	679	651	668	656	653
17	650	648	671	647	618	620	656	664	677	651	660	651	651
18	652	647	670	646	618	615	652	661	680	652	656	652	650
19	654	651	669	643	618	608	653	663	682	652	659	650	650
20	652	650	669	640	615	607	648	663	684	652	664	649	650
21	654	647	673	640	611	609	644	665	684	649	666	650	649
22	656	647	677	643	603	610	646	666	691	660	669	653	652
23	650	639	674	637	596	606	652	664	691	664	672	654	650
24	650	636	676	636	600	614	665	668	699	674	681	661	655
Average	654	639	675	639	603	613	661	669	690	665	668	660	653
													Annual average

Derived from AESO

Hour	Month 1	2	3	4	5	6	7	8	9	10	11	12	Average
1	638	664	651	620	604	597	621	625	627	620	634	638	628
2	637	664	650	617	601	590	612	621	628	620	632	634	626
3	634	665	654	618	597	587	605	618	628	617	629	629	623
4	631	663	656	619	590	585	602	614	629	617	624	625	621
5	626	661	652	610	580	576	601	609	622	610	616	621	615
6	617	655	646	601	576	574	600	603	615	602	607	613	609
7	606	647	636	590	565	566	594	593	605	592	601	610	600
8	597	642	630	582	561	558	585	582	597	587	593	606	593
9	592	636	626	578	559	556	583	575	595	584	583	599	589
10	590	632	626	580	561	556	582	576	598	587	579	597	589
11	593	629	632	585	563	562	585	579	607	596	582	599	593
12	605	631	639	593	569	571	592	586	619	606	590	605	601
13	617	636	646	600	577	581	603	597	625	612	599	614	609
14	624	638	652	604	581	587	608	599	624	611	604	618	612
15	627	642	658	614	597	601	622	613	629	619	608	618	621
16	639	651	660	618	599	606	631	627	634	623	617	625	627
17	642	654	661	622	597	612	637	632	637	628	620	628	631
18	641	659	662	626	601	612	639	636	636	629	624	626	633
19	642	662	663	627	605	612	641	634	632	626	625	628	633
20	641	667	662	628	606	609	638	633	630	623	626	628	633
21	640	667	660	625	607	604	636	631	630	618	627	627	631
22	636	667	657	625	607	603	633	630	631	616	629	627	630
23	635	668	656	626	608	602	632	630	630	619	630	628	630
24	636	667	654	624	608	600	630	626	632	620	633	631	630
Average	624	653	649	610	588	588	613	611	623	612	613	620	617
													Annual average

CER Model

**Units are in kg of CO_2/MWh

Conclusions

- Two approaches were used to estimate MEFs for Alberta in 2018.
- The CER model outperforms the MLR model based on comparison with the AESO data.
- Similarity: both rely on detailed historical data for parameters such as load, generation, trade, and prices.
  - Availability of data is a critical component for similar analysis to be done for any region
- Difference: MLR focuses solely on current/historical analysis, whereas CER is able to provide outlooks for future years.

Future Works

- Cover more provinces, starting with Ontario (IESO)
- Investigate other models and approaches, including open-source UC&D models:
  - SILVER (UVic) and E3 Renewable Energy Solutions “RESOLVE” models
  - Critical in planning stage to ensure feasibility, given changes in load characteristics and increased adoption of variable renewables

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