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Geographic Variation in Environmental Benefits Achieved by Plug in Electric Vehicles and Electric Vehicles in U.S and Canada

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Abstract

The geographic variations in environmental benefits of operation of a plug in hybrid electric vehicle (PHEV) and Electric Vehicle (EV) are analyzed in terms of reduced CO_2 emissions. The environmental benefits of operating a PHEV or EV vary depending on the electricity mix that is being utilized to charge the vehicle and the manner in which the vehicle is driven and operated. This analysis is carried out for each state in the United States and each Province in Canada. In one extreme, the PHEV may be driven exclusively in all electric mode if the range required allows such operation. In the other extreme, the vehicle may be driven in hybrid mode where the electric capabilities are used solely to increase fuel mileage. It will be analyzed whether there is a preferred method of operation for delivery of environmental benefits and how the ultimate decision is based on the geographic location of charging. The magnitude of the dependence on geographic location on emissions savings will also be assessed. The baseline used for CO2 emissions savings will be a typical internal combustion engine vehicle operating at an average 25 miles per gallon.

Results show that there are a number of states where PHEVs or EVs yield a considerable environmental benefit in terms of reduced CO_2 emissions. However there are also many states where a PHEV yields negligible savings when operated in all electric mode, as would be the case for an EV. Some of the most environmentally advantageous states are Washington, Oregon, Idaho, Connecticut, New Jersey, New York, Vermont and California, while the worst include West Virginia, Wyoming, Kentucky, Indiana and Ohio. There are benefits in large cities where the majority of drivers would be operating the vehicle in all electric mode and thus while they may not be contributing an environmental benefit to the state as a whole, would contribute locally to the city by displacement of emissions to less populated regions that house generation facilities.

The basic analysis is the done through identification of each state or province's electricity mix. This is then converted to an equivalent CO_2 emissions figure per kWh generated. This number is determined through reference to Life Cycle Assessments of each form of generation.

The results of this paper are significant to the design and implementation of incentive programs for PHEVs and EVs if coordinated at the national level. Higher incentives should be given in regions where the environmental benefits are the greatest such that the fixed amount applied to incentives are delivered with maximum economic efficiency.

Keywords: EV (Electric Vehicle), PHEV, emissions, pollution, V2G (Vehicle to Grid), energy source, Canada, California, efficiency, LCA (Life Cycle Assessment)

1 Introduction

With the introduction of the Chevrolet Volt and Nissan Leaf a common public perception is that these vehicles will provide significant environmental benefits wherever they are applied. However the benefits achieved depend greatly on the energy source used to generate the recharging for the vehicle battery. There is large geographic variation in generation mixes due to varying public policy and/or cost pressures in different environments. This paper will evaluate the benefits on the state and provincial level using generic generation mixes for average energy production.

2 Methodology

The basic analysis is the done through identification of each state or province's electricity mix. This is then converted to an equivalent CO_2 emissions figure per kWh generated. This number is determined through reference to Life Cycle Assessments of each form of generation. A number of life cycle assessments have been consulted to determine the values that will be used as summarized in Table 1 and have been consolidated from [1-11].

Generation mixes have been determined for the year 2009 for each state and province using [4] and [12]. Some representative generation mixes in the U.S. are shown in Table 2 that demonstrate the wide variety of mixes that are utilized throughout the U.S. A more complete view is provide in Figure 1 and Figure 2 which show the generation mixes across most of the U.S. and Canada.

Table1: Lifecycle greenhouse gas emissions for electric generators (in units of grams equivalent CO_2 per kWh generated]

Generation Source	g CO_2/kWh
Coal	1025
Oil	770
Natural Gas	450
Photovoltaic	35
Wind	20
Hydroelectric	20
Nuclear	30
Biomass	45

Table 2: Electricity Generation Mixes for Selected U.S. States and Lifecycle greenhouse gas emissions for electric generation in each state.

Generation Source	Electricity Mix [%]						
	US	CA	ID	OR	NJ	LA	WV
Coal	47.0	0	0	6.5	6.0	38.2	97.1
Geothermal	0.4	7.8	0.62	0	0	0	0
Hydroelectric	7.4	16.8	84.8	67.0	0.06	2.1	1.5
Natural Gas	19.8	48.8	12.0	19.4	26.1	29.4	0.2
Nuclear	21.9	19.2	0	0	66.0	27.8	0
Biomass	0.4	1.1	0	0.12	1.14	0.1	0
Petroleum	0.9	0.63	0	0.01	0.33	2.5	0.2
Photovoltaic	0.02	0.39	2.6	0	0.02	0	0
Wind	2.03	3.52	0	7.0	0.04	0	1.1
g CO_2/kWh	586	238	72	168	202	552	998

These mixes from Figure 1 and Figure 2 are used in conjunction with the data from Table 1 to compute the average emissions per kWh contributed by each state and province. These results are shown in Figure 3 and Figure 4.

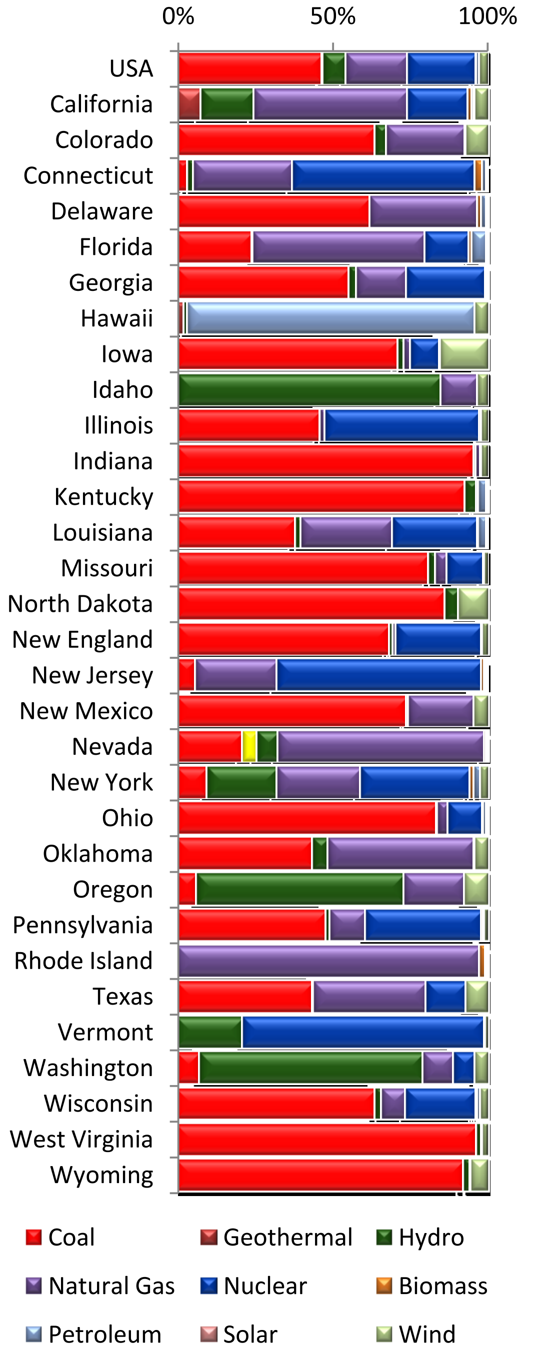

Figure 1.: Generation mix for representative U.S. States in percent.

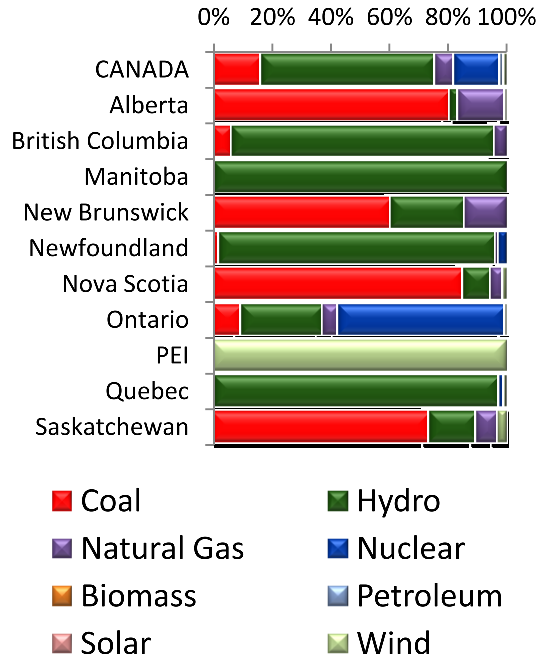

Figure 2.: Generation mix for Canadian Provinces in percent.

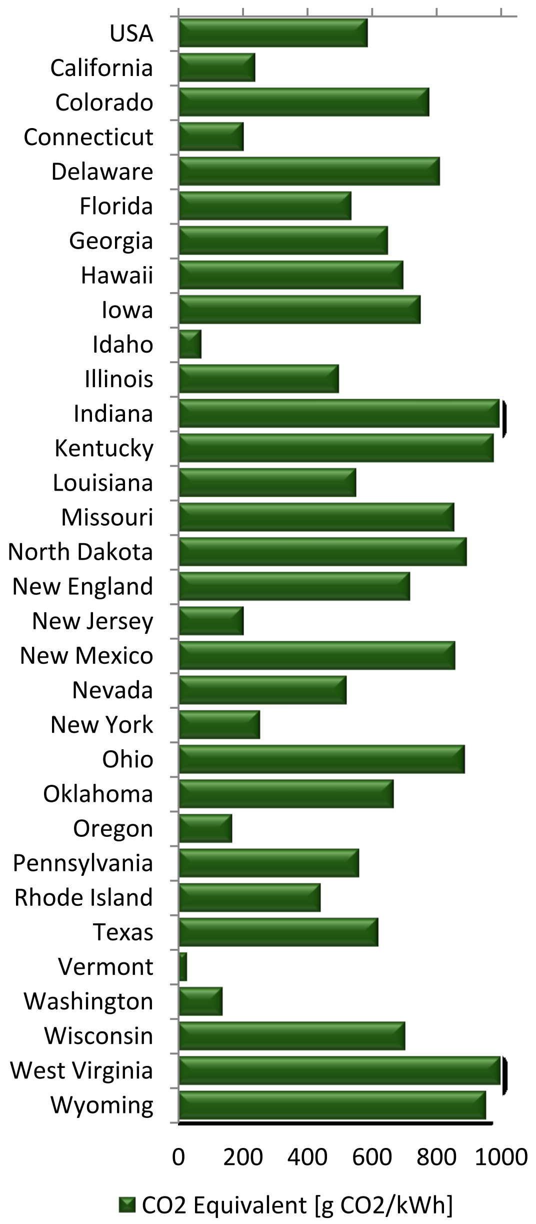

Figure 3.: Emissions per kWh in units of g CO_2/kWh for representative U.S. States based on generation mix.

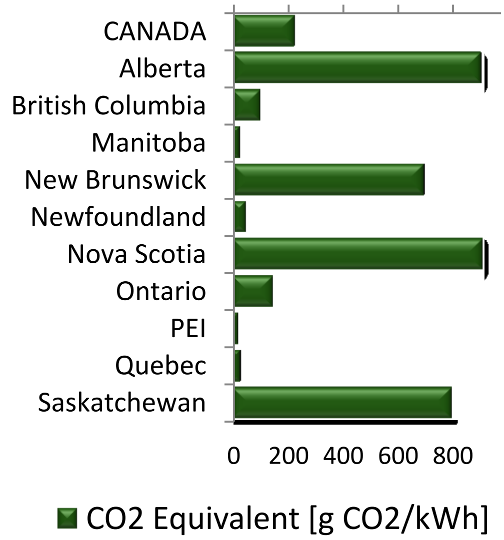

Figure 4.: Emissions per kWh in units of g $C0_2$/kWh for Canadian Provinces based on generation mix.

2.1 Limits to Analysis

There are several limits to this analysis. It should be clear that emissions should be based on the actual energy used to power the electric vehicle. This would more accurately be based on incremental generation but this adds a level of uncertainty on smaller geographical scales that it would make such analysis much more difficult. Use of average state and province generation mixes is an approximation of this incremental generation. Also the source of generation is dependent on the time of day that charging occurs. This brings the analysis down to the level of individual drivers and the variations they bring to the scenario. It is also possible that electric vehicle charging might instead be met with imports or exports by various states. This analysis includes a generalized approximation of the efficiency of distribution and charger efficiency. For more accuracy a complete analysis of each vehicle could be performed. It is assumed that the differences in vehicles will alter the environmental benefits attributed but not the general conclusions.

3 Analysis

To compare the environmental benefits of operating an EV or PHEV a baseline case of an average 25 mpg passenger vehicle is used. The emissions attributed to this vehicle are based on both the fuel combustion and the emissions associated with the delivery of the fuel to the vehicle. A value of 0.784 lb of equivalent CO_2 / mile is used [12]. This equates to 356 grams equivalent CO_2 / mile. To determine the equivalent emission rate for the EV or PHEV a simple case is used based on the parameters of the Chevrolet Volt running in full electric mode. Although the PHEV has a battery capacity of 16kWh, only ~75% of that capacity is used in to deliver the approximate 35 mile range. To recharge this vehicle after a 35 mile trip will require the 12kWh + 10% lost in transmission/distribution + 15% loss in charger and battery monitoring. This gives a total of 15.2kWh of generated energy to recharge the vehicle. This amount is increased to 16kWh to make certain that the emissions attributed to the EV or PHEV are not underestimated. Measurements of the average range and recharge rates of a Nissan Leaf give reasonable agreement to this rate of electric energy use per mile.

The emission rates attributed to each state and province for generation of a kWh are applied to the amount of energy consumed per mile in the EV. The final results are shown in Figure 5. For the United States average as well as to each state and these are compared to the emission rate for both a 25 mpg vehicle and a 37 mpg vehicle (the Chevy Volt is quoted at 37 mpg when operating in hybrid mode). The same comparison is shown in Figure 6 for the Canadian average as well as each individual province. It can be seen that there are a number of cases (the worst being West Virginia) where a standard internal combustion vehicle with a 25 mpg efficiency would be superior in terms of efficiency to an electric vehicle due to high emissions associated with the energy used to recharge the vehicle. This is consistent with conclusions reached in [13,14]. It can be seen that in a number of states that it would be preferred to operate the vehicle as a hybrid vehicle instead of in full electric mode. These are typically states with a high reliance on coal and to a lesser extent natural gas. Several states such as Idaho, California or Connecticut would see a large environmental benefit from operating vehicles in full electric mode. These states are those that typically have a large hydroelectric component in their state generation profile but also include those states with a large nuclear component such as New Jersey. Most Canadian provinces would show large environmental benefits due to large hydroelectric resource available to many provinces. The exceptions are Alberta, Saskatchewan and Nova Scotia which have heavy fossil fuel consumption.

4 Conclusion

In contrast with common public perception the application of electric vehicles does not yield environmental benefits in all areas due to the geographic variability in electric generation. A vehicle recharged in an area that is heavily reliant on fossil fuels is unlikely to provide any environmental benefits and is possible to increase emissions in comparison to a standard ICE vehicle. The majority of Canadian provinces have suitable generation mixes such that application of electric vehicles would provide a benefit in Canada with the exception of Alberta, Saskatchewan and Nova Scotia. There are many states in which application of electric vehicles would not be wise until a substantial shift in those states energy generation mixes takes place. Several of the worst states for emissions include West Virginia, Wyoming, Ohio, New Mexico, Indiana, and Kentucky. Wise application of federal incentives to electric vehicle owners would place vehicles in areas where they can provide the country the most benefit.

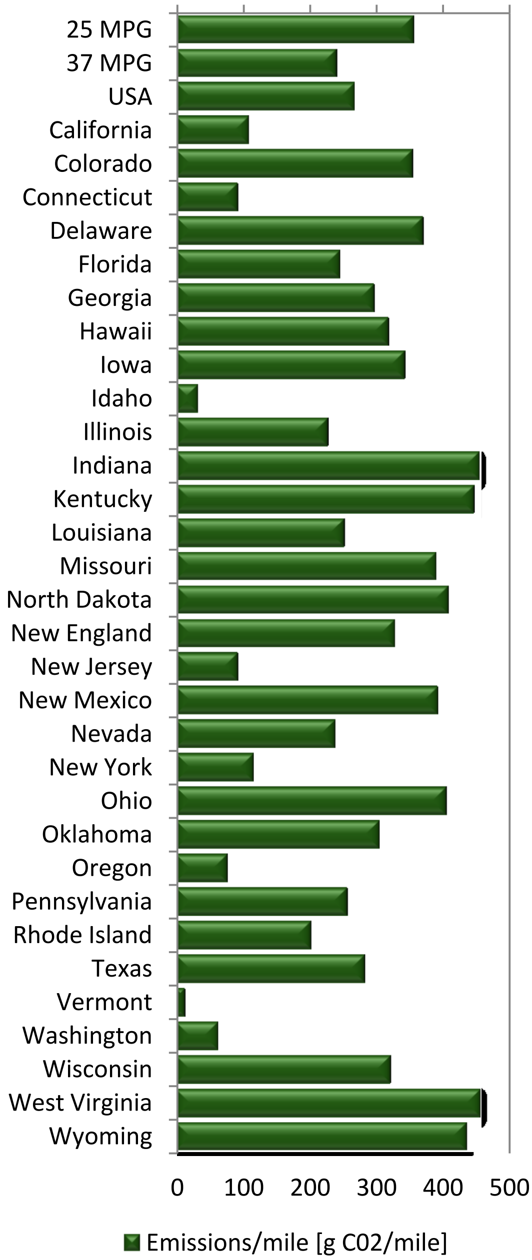

Figure5: Emissions per mile in units of g CO_2/mile for representative U.S. States and a 25 MPG and 37 MPG internal combustion engine vehicles.

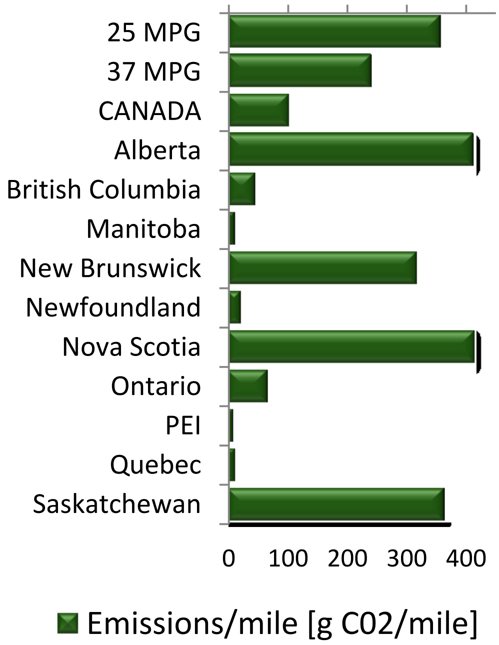

Figure 6. Emissions per mile in units of g CO_2/mile for Canadian Provinces and a 25 MPG and 37 MPG internal combustion engine vehicles.

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