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Are we ready for alternative fuel transportation systems in Canada: A regional vignette

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ABSTRACT

Road transportation is responsible for 23% of Canada's Greenhouse Gas (GHG) inventory due to complete dependence on fossil fuels. Decarbonizing the transportation sector using alternative energy sources is one of the most effective strategies to achieve GHG emission reduction targets. Alternative transportation modes such as electric and hydrogen fuel cell based vehicles are considered as scalable technologies for decarbonizing the transportation sector. However, there is a knowledge gap for a systematic investigation approach on regional viability of aforementioned vehicles.

The main objective of this paper is to evaluate the financial feasibility and environmental impact of the electric light duty vehicles (LD-EVs) and hydrogen fuel cell light duty vehicles (LD-HFCVs) use in Canada. A life cycle thinking based approach has been proposed to compare costs and emissions of transportation based on electric and Hydrogen with traditional fossil fuel. The carbon offset saving was used to quantify the economic impact of GHG reduction. The carbon taxes for selected provinces were recommended as a potential policy implementation to reduce transport based GHG emissions. The results indicate that the provinces with low emission factor electric grids have a higher potential for LD-EV based transportation system in terms of costs and footprint. Presently LD-HFCVs are less desirable due to high purchase and operational cost. Development of a Hydrogen based transportation system through the production of cost effective hydrogen is preferable for provinces with a higher emission factor electric grids.

1. Introduction

Climate change has become one of the key social concerns around the world. Ozone depletion, deforestation, high temperature and the greenhouse effects are contributing to climate change (Brunner, 1991). This is primarily caused by excessive increase in anthropogenic greenhouse gas (GHG) emissions (Mann et al., 1998), (Lucas et al., 2015). Global attention towards reducing GHG emissions has increased in recent times. Hence, reducing national GHG inventory has become a national priority for Canada. Accordingly, Canada introduced the Greenhouse Gas Reduction Targets Act (GGRTA) to actively reduce GHG emissions in provincial level. According to GGRTA, GHG emissions in all provinces in Canada should be reduced by 33% in 2020 and by 80% by 2050 from 2007 levels (Ministry of Environment BC, 2014).

The GHG emissions in Canada amount to 732 MT CO2e which is 2% of the world GHG emission in year 2014 (Environment and climate change Canada, 2015). Canadian emissions trends for 2011 indicates that transportation collectively is one of the largest contributors to national GHG inventory which accounts for 24% (Environment Canada, 2011a). Road transportation can be considered as the highest GHG contributor which accounted for 82.5% of national transportation emissions which is predominantly catered by the consumption of high amount of fossil fuels (Hirsch et al., 2007).

The consumption of fossil fuel results in GHG emissions such as CO_x,NO_x and other carcinogenic/non-carcinogenic emissions (Harrison et al., 1998) (Manabe and Wetherald, 1980). However, the demand growth of fossil fuels has been a topic of major discussions in the past few years mainly due to its adverse environmental consequences and possibility of running out in the near future. Reducing the consumption of fossil fuel per kilometer, improving

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List of abbreviations

GHG	Gdreenhouse gas
HFCV	Hydrogen fuel cell Vehicle
EV	Electric vehicle
PEV	Plug-in electric vehicle
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
PHEV	Plug-in hybrid electric vehicles
AFV	Alternative fuel vehicle
LCA	Life cycle assessment
LCC	Life cycle cost
PV	Photovoltaic
LD-EV	Light-duty Electric vehicle
LD-HFCV	Light-duty hydrogen fuel cell vehicle
LDV	Light-duty vehicle
GGRT	Greenhouse Gas Reduction Targets Act
GREET	Greenhouse gases, regulated emissions, and energy use in transportation
W2P	Well to Pump cycle
W2W	Well to Wheel cycle
CoC	Carbon off-set cost
CoC_f	Carbon off-set cost factor

active transportation while reducing automobile dependency, shifting to lower-carbon or non-carbon power trains such as Hydrogen Fuel Cell Vehicles (HFCVs), Electric Vehicles (EV) and Plug-in Electric Vehicles (PEVs) (Nilsson et al., 2012) are considered as core solutions to reduce the fossil fuel for Canadian transportation.

The recent statistics shows that, development of the low-carbon or non-carbon energy based transportation methods are very popular in urban planning and infrastructure development in Canada (Canadian Press, 2016) (Van Santvoort, 2016). Battery operated PEVs and HFCV are the most popular alternative fuel vehicles (AFVs) developed to reduce the aforementioned transportation based emissions (Freedman, 2014). However, there are various barriers to the aggressive growth of AFVs such as high vehicle purchasing price and operating cost (Axsen et al., 2015), (Romm, 2006), limited range (Romm, 2006), (Franke et al., 2012), safety concerns (Romm, 2006), limited re-fuelling infrastructure (Axsen et al., 2015), (Romm, 2006), (Mak et al., 2013). The life cycle assessment (LCA), life cycle cost assessment (LCC) and understanding of consumer behaviours are the key elements, which need to be addressed to eliminate the above barriers. Literature reveals that, there are significant amount of studies available to evaluate the life cycle emissions of AFVs including the fuel life cycle (Wang et al., 2010) (Cai et al., Elgowainy). The Greenhouse gases, regulated emissions, and energy use in transportation (GREET) model developed by Argonne national laboratory can be considered as a one of the popular models available in the peer-review literature (Cai et al., Elgowainy) (Burnham et al., 2006). However, aforementioned models are only considered the life cycle emissions of the alternative and conventional vehicles for a specific electric grid mix. Hence, there is a knowledge gap in terms of decision support perspective, where there is a need of life cycle cost to evaluate the market feasibility of the vehicle.

The main objective of this paper is to develop a decision support mechanism to identify the eco-efficiency of AFVs in terms of LCA, LCC and consumer behaviors. Spatial based life cycle emission and cost assessment approach have been employed to identify the emissions and the costs of AFVs and conventional vehicles. Carbon offset cost was used as an extension to the typical LCC to explain the cost of potential GHG emissions. According to the analysis, the provincial carbon footprint and market feasibility of hydrogen and electric based transport infrastructure investment were discussed. This study can drive policy decision making related to provincial alternative transport infrastructure planning in Canada. An excel based tool was developed in this study which can be used globally to identify the spatial viability of EVs or HFCVs.

2. Literature review

The use of conventional fuel began with the exploration and production of crude oil, which is refined into fuels, stored, and distributed to supply chain networks of retail stations (Freedman, 2014). The crude oil refining process was developed in 1850, which became popular after the development of Internal Combustion Engine Vehicles (ICEV) (Bott, 2007). Although, Gasoline and Diesel are used as energy sources for the conventional road transportation, Gasoline can be considered as the main fossil based fuel used in Canada which are mainly used for private light-duty conventional vehicles such as cars, SUVs, trucks etc. (National Energy Board of Canada, 2009).

Vehicle fuel efficiency improvements were considered as a very popular marketing tool by the vehicle manufacturers and marketers in recent past. Hence, the government expected a significant energy saving and emission reduction. However, the enhancement of fuel efficiencies and affordability of fossil fuels have not reduced energy consumption as whole and potential GHG emissions due to high population growth and increase of vehicle dependency (Environment Canada, 2011b). Hence, an aggressive energy reduction methods were focused by all the Canadian provinces such as alternative fuel vehicles with low and zero carbon emissions (Freedman, 2014). The alternative fuel based transportation can be compared and evaluated the viability of AFVs by explaining the life cycle based emission and cost of each vehicle and fuel cycle (ISO 14040:2006(en), 2006a).

2.1. Life cycle assessment

The life cycle assessment (LCA) is considered as an important process development technique in terms of environmental sustainability (ISO 14040:2006(en), 2006b), (Khan et al., 2004). This technique focuses on the environmental impacts of a process/product in its total life cycle (Khan et al., 2004) (Azapagic, 1999), which enables decision makers to improve the environmental performance of a particular product and strategic planning (ISO 14040:2006(en), 2006a).

According to GREET, the overall life cycle impacts of a vehicle are discussed using two types of basic life cycles. There are.

2.1.1. Vehicle life cycle

The vehicle life cycle study is comprised of vehicle manufacturing, vehicle operations and vehicle end-of-life (Eriksson et al., 1996) (Soo et al., 2015). The vehicle life cycle (LCA_V) emissions can be explained as Equation (1) as follows,

$$\text{LCA\_V} = E + E_{recurring} + E_{end-of-life} \tag{1}$$

where.

E – Vehicle manufacturing emissions (kgCO2e)

$E_{recurring}$ – fuel based operational emissions and maintenance/repair emissions (kgCO2e)

$E_{end\text{-}of\text{-}life}$ - End-of-life emissions (kgCO2e)