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The role of a low carbon fuel standard in achieving long-term GHG reduction targets

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ABSTRACT

A low carbon fuel standard (LCFS) has been implemented in several regions to reduce the well-to-wheel carbon content of transportation fuels. This study explores the potential role of an LCFS in achieving deep, long-term greenhouse gas (GHG) reduction targets in a region's transportation sector, when implemented with other climate policies such as fuel economy regulations, a zero emission vehicle mandate, and carbon pricing. We develop a dynamic vehicle adoption model coupled with a fuel supply optimization model, applied to the personal and freight vehicle sectors in British Columbia, Canada. Results demonstrate that a combination of the most stringent policies is required to achieve 2050 GHG targets, including an LCFS. Further, the LCFS appears to be complementary to the other modeled policies, resulting in incremental GHG reductions in all modeled policy scenarios. The LCFS has an additive but lower impact in the personal vehicle sector, where a zero emission vehicle mandate induces a substantial transition to low carbon fuels without the LCFS. LCFS impacts are larger in the freight sector, where a switch to zero emission vehicles does not necessarily cut GHGs. Overall, with careful policy design, the LCFS could play an important role in decarbonizing the transportation sector.

1. Introduction

In discussions of transportation climate policy, researchers often identify three distinct levers for reducing greenhouse gas (GHG) emissions within the road transport sector: improve vehicle technologies, reduce GHGs associated with fuels, and reduce vehicle travel (Sperling and Eggert, 2014; Sperling and Yeh, 2009). While all three levers will likely be necessary to achieve significant GHG reductions, our research focuses on the potential to reduce emissions through the supply of low carbon alternative fuels. In particular, we focus on the low carbon fuel standard (LCFS), a policy that requires fuel suppliers to progressively decrease the average GHG intensity of their fuels on a life cycle basis (Government of British Columbia, 2008). An LCFS focuses on the life cycle emissions of each fuel, which is commonly measured in grams of carbon dioxide equivalent per megajoule (gCO_2e/MJ). This paper uses a simulation model to explore the potential role of an LCFS policy in achieving deep GHG reductions in the transportation sector over the long-term, including personal and freight transport.

An LCFS is regulation-based in the sense that there is a carbon intensity target (or limit) that fuel providers must comply with, and it is market-based in that fuel suppliers can trade and bank emission credits, thus promoting cost-effectiveness (Farrell and Sperling, 2007b). Although the LCFS prescribes a limit for the average carbon intensity of a fuel supplier's fuel mix in a given year, it allows firms the freedom to choose from any available fuels to meet the target (Andress et al., 2010; Sperling and Yeh, 2009). A fuel supplier generates credits under the LCFS by supplying a fuel with a carbon intensity below the limit, and they incur debits by supplying a fuel with a carbon intensity above the limit (e.g. petroleum gasoline and diesel) (Farrell and Sperling, 2007b).

Versions of an LCFS have been used in Europe, the Canadian province of British Columbia, and the U.S. States of California and Oregon. California pioneered the LCFS in 2007 as part of enacted legislation requiring the state to reduce its GHG emissions by 80% below 1990 levels by 2050. Specifically, the California LCFS requires fuel suppliers to reduce the carbon intensity of transportation fuels sold in the state by 10% by 2020 (Farrell and Sperling, 2007a). The LCFS program has been successful, where the average carbon intensity of the alternative fuels supplied in 2011–2015 decreased 21%, from 86 down to 68 gCO_2e/MJ (Yeh and Witcover, 2016). In 2008, British Columbia implemented its own LCFS, largely based on California's policy with the same 2020 target, and is currently exploring the potential to require a 15–20% reduction in carbon intensity by 2030 (Government of British Columbia, 2018). Transportation is an integral part of the economy and is responsible for 39% of GHG emissions in British Columbia, more than any other economic sector (British Columbia Climate Action Secretariat, 2017). Moreover, British Columbia's GHG emissions from

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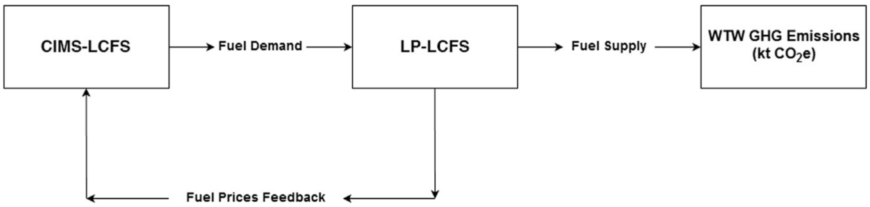

Fig. 1. Excel-based simulation model structure (per period).

transport have increased 36% from 1990 to 2015 (British Columbia Climate Action Secretariat, 2017). Despite this increase, British Columbia is in a unique position to significantly reduce emissions through the electrification of transport, with more than 90% of electricity being produced by hydroelectric generation (BC Hydro, n.d.). To date, British Columbia's LCFS has had some success in reducing GHG emissions: from 2010 to 2015, the average carbon intensity of ethanol supplied to the province decreased 11% from 56 to 49 gCO_2e/MJ; the average biodiesel carbon intensity decreased 55% from 35 to 16 gCO_2e/MJ; and the average hydrogenation-derived renewable diesel (HDRD) carbon intensity decreased 65% from 48 to 17 gCO_2e/MJ (British Columbia Ministry of Energy & Mines, 2016).

Despite this evidence of short-term, incremental success, no published studies have directly simulated the long-term effectiveness of an LCFS in the context of deep climate targets. Several studies have used modeling exercises to indicate that there will be sufficient quantities of low carbon fuels to achieve a 10% carbon intensity reduction by 2020 (Farrell and Sperling, 2007a; ICF International, 2013; Malins et al., 2015). Although useful for short-term to near-term analyses, these modeling approaches rely on static assumptions that limit their usefulness for long-term applications.

There are studies that have taken a more comprehensive, longer-term view of low carbon fuels, without focusing on the LCFS directly. Two of those studies used the CA-TIMES optimization model to explore the potential evolution of California's energy system, analyzing the least-cost technology options for achieving California's 80% GHG reduction by 2050 (McCollum, 2011; McCollum et al., 2012; Yang et al., 2016, 2015), finding that low carbon biofuels, hydrogen, and electricity play an important role in reducing long-term GHG emissions. However, such optimization-based models are limited in that they model the 2050 GHG target as a constraint, thus forcing the reduction target to be met in every "successful" scenario simulation. It then becomes difficult to determine if the resulting vehicle market shares and fuel consumption occurred as a result of policy (e.g. from the LCFS or the zero emission vehicle mandate) or as a result of the CA-TIMES model constraining the market to fulfill the 2050 GHG target constraint.

Our present study aims to improve insights into the long-term effects of an LCFS using a simulation model of vehicle adoption and fuel supply. In doing so, we offer several unique contributions to LCFS literature. Our model incorporates a number of endogenous factors including vehicle technology adoption, vehicle cost reduction as a result of learning by doing and economies of scale, changes in travel demand as a result of changes to the cost of purchasing a vehicle and driving, and endogenous fuel supply decisions based on the financial costs of different feedstocks and fuels. Further, this study is the first to model the LCFS in the unique context of the Canadian province of British Columbia, and to focus on the effects of the LCFS across two distinct subsectors of transportation: personal travel and freight transport.

A particular novelty of our approach is that we examine the potential complementarity of the LCFS with other transportation policies—a zero emission vehicle (ZEV) mandate (like that in California and Quebec), vehicle GHG and fuel economy standards, and a carbon tax. We explore the effectiveness of British Columbia's LCFS at reducing GHG emissions when accompanied with these other transportation policies—specifically to identify which affects are "additive" or incremental to the effects of other policies, and which are redundant. We consider the LCFS "complementary (increasing)" if it has an increasing incremental emission reduction effect in every period of the simulation when included in a policy package scenario, "complementary (decreasing)" if it has a declining incremental emission reduction effect, and "redundant" if it does not have a positive incremental effect on GHG emission reductions at any point during a simulation (i.e. from 2015–2050).

In summary, our research objectives are:

1. To simulate the overall effects of British Columbia implementing a suite of transportation policies, specifically in achieving its 2050 GHG targets; and
2. To assess the potential incremental effectiveness of the LCFS at reducing GHG emissions when accompanied with other types of transport policy (complementary or redundant), highlighting potential differences in each subsector (personal and freight).

2. Methods

In this section, we provide an overview of our modeling approach. The following subsections outline specific techniques and assumptions regarding vehicle adoption, technological change dynamics, fuel switching choices, fuel supply optimization, energy prices, and policy scenarios.

To accomplish our research objectives, we use a vehicle choice model of the British Columbia transportation sector coupled with a fuel supply optimization model to explore the effects that the LCFS and other policies have on vehicle composition, fuel supply, and GHG emissions (Fig. 1). The vehicle choice model (which we call "CIMS-LCFS") is adapted from the energy-economy model CIMS, which has been used to evaluate climate policies within a number of sectors (Jaccard et al., 2003; Mundaca et al., 2010; Murphy and Jaccard, 2011). Some recent research has similarly applied versions of CIMS to studies of the transportation sector (Fox et al., 2017; Sykes and Axsen, 2017). CIMS-LCFS simulates the composition of both the personal and freight transportation sectors in British Columbia out to 2050. Consumers make vehicle purchase decisions based on perceptions of both monetary and non-monetary attributes. To better model decision-making in the fuel sector, we add a linear programming optimization model (which we call "LP-LCFS") that simulates fuel supply decisions for meeting consumer demand for fuel from CIMS-LCFS, under different policy scenarios.

CIMS-LCFS simulates vehicle composition in British Columbia in five year periods beginning in 2015 and ending in 2050. In each five year period, a portion of the existing vehicle stock is retired according to exogenous retirement schedules derived from literature, and demand for new vehicle technologies is assessed based on the current vehicle stock and an exogenous growth factor. Total vehicle demand for the personal transportation sector is measured in personal kilometers travelled (PKT) and vehicle kilometers travelled (VKT) while total vehicle demand for the freight transportation sector is measured in tonne kilometers travelled (TKT). To satisfy the demand for new vehicles, the model simulates how heterogeneous consumers purchase different vehicle technologies based on relative costs: capital costs, energy costs, maintenance costs, and intangible costs (described in Section 2.2). CIMS-LCFS is calibrated by adjusting vehicle technology capital costs and intangible costs in order to align vehicle technology market shares and total vehicle demand with the *Reference Case* of the U.S. Energy