A Colorado-specific life cycle assessment model to support evaluation of low-carbon transportation fuels and policy

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Abstract

The transportation sector accounts for over 20 percent of greenhouse gas (GHG) emissions in Colorado which without intervention will grow to over 30 million metric tons (MMT) of GHG emissions per year. This study seeks to develop a specific characterization of the Colorado fuel and transportation system using a customized life cycle assessment (LCA) model. The model (CO-GT) was developed as an analytical tool to define Colorado’s 2020 baseline life cycle GHG emissions for the transportation sector, and to examine Colorado-specific pathways for GHG reductions through fuel types and volumes changes that might be associated with a state clean fuel standard (CFS). By developing a LCA of transportation fuels that is specific to the state of Colorado’s geography, fleet makeup, policies, energy sector and more, these tools can evaluate various proposals for the transition towards a more sustainable state transportation system. The results of this study include a quantification of the Colorado-specific roles of clean fuels, electricity, extant policies, and fleet transition in projections of the state’s 2030 transportation sector GHG emissions. Relative to a 2020 baseline, electrification of the vehicle fleet is found to reduce state-wide lifecycle GHG emissions by 7.7 MMT CO\(_2\)e by 2030, and a model CFS policy able to achieve similar reductions in the carbon intensity of clean fuels as was achieved by California in the first 10 years of its CFS policies is found to only reduce state-wide lifecycle GHG emissions by 0.2 MMT CO\(_2\)e by 2030. These results illustrate the insensitivity of Colorado’s transportation fleet GHG emissions reductions to the presence of CFS policies, as proposed to date.

1. Introduction

Reducing the greenhouse gas (GHG) emissions of the transportation sector in the United States is a key component to achieving global climate goals (McCollum and Yang 2009), but policy-making to achieve GHG emissions reductions in the sector has been largely led by efforts at the level of US states (Lutsey and Sperling 2008). Colorado is a mid-sized US state, where the legislature has adopted aggressive goals for reducing the GHG emissions attributable to the state (including transportation). At present, the transportation sector constitutes 29% of the annual GHG emissions in the US, and 21.5% in the state of Colorado (Taylor 2021 and US Environmental Protection Agency 2021). The Colorado state legislature has established goals to reduce emissions through house bill (HB) 19-1261 (climate action plan to reduce pollution), and aims to reduce 2025 GHG emissions by at least 26%, 2030 GHG emissions by at least 50%, and 2050 GHG emissions by at least 90%, relative to 2005 levels (Becker et al 2019). To achieve these reductions, the state has developed a GHG pollution reduction roadmap that specifies individual sector targets and recommendations for near-term actions (Colorado Energy Office 2021). Relevant to the transportation sector, notable targets for the next decade include an 80% emissions reduction for electricity generation by 2030 relative to 2005, a transition to more zero-emission vehicles (ZEVs) with a goal of 940,000 light-duty electric vehicles (EVs) and an unspecified number of medium-duty ZEVs, heavy-duty ZEVs, and ZEV buses on Colorado roads by 2030, and increasing...
the use of other low-carbon fuels, such as biofuels, hydrogen, and renewable natural gas (RNG), for sectors and vehicles that are difficult to electrify (Colorado Energy Office 2021). The specific plans and policies that will enable these transitions and associated GHG emissions reductions are not clear, but the impact of any proposal must be modeled systematically through modeling tools and methodologies such as life cycle assessment (LCA).

As an example, low-carbon fuel policies in California and other US states are asserted to be effective mechanisms for decarbonizing transportation fuels, increasing the supply of low-carbon fuel alternatives, and reducing GHG emissions from the sector (Witcover 2018, Witcover and Murphy 2019 and Yeh et al 2016). In general, a clean fuel standard (CFS) is a market-based policy and performance standard that requires fuel producers and suppliers to reduce the average carbon intensity (CI) of their fuels over time (Farrell et al 2007a, 2007b, Sperling and Yeh 2010 and 2009). CI is measured as the life cycle GHGs emitted per unit of fuel energy and is generally reported in grams of CO2 equivalent per megajoule (gCO2e/MJ).

The life cycle GHG emissions of a fuel pathway must be modeled to assign a CI value, requiring each CFS program to engage in an LCA modeling effort to define CIs for each pathway through which regulated transportation fuels are produced, supplied, and consumed by the state. While developing the California Low-carbon Fuel Standard (LCFS) and the Oregon Clean Fuels Program (CFP), regulators recognized the need to capture the local conditions and data to accurately attribute CI values to various fuel pathways. To do this, the greenhouse gases, regulated emissions, and energy use in transportation (GREET) model, developed by Argonne National Laboratory, was modified for the states and published as CA-GREET and OR-GREET, respectively (California Air Resources Board 2019, Oregon Clean Fuels Program 2016, Witcover 2018 and Witcover and Murphy 2019). This study uses the techniques of attributional LCA (as do CA-GREET and OR-GREET) to present assessment of the static operations of the two transportation fuel scenarios under consideration. The dynamics, or economics, or policy changes associated with transition are not considered in this study.

In 2020, the state of Colorado completed a study on the feasibility of a CFS to reduce transportation sector GHG emissions and found that the assessment of fuel pathways will require a Colorado-specific model (ICF Resources 2020). In response to this need, this team has developed a Colorado-specific LCA model for fuel pathways relevant to a Colorado CFS and other evaluations of low-carbon transportation fuels and policy in the state. The fuel pathway model is described and demonstrated here in concert with models of Colorado’s vehicle fleet, fuels mix, and electricity generation profile to evaluate baseline CIs for relevant fuels in 2020, to evaluate the state targets established for the transportation sector by 2030, and to evaluate the implications of a potential CFS policy in the state. In addition to the assessment tools, the outcome of this work includes considerations for Colorado legislators and policymakers as the state develops GHG emissions reduction plans and policies for the transportation sector.

2. Methods

This section outlines the development of a Colorado-specific fuel life cycle model, referred to as the Colorado greenhouse gas emission tool (CO-GT) in this paper, including definition of an LCA system boundary and specific model inputs. A Colorado vehicle fleet model is also described, as well as scenario assumptions for analysis of Colorado’s transportation fuels in 2030.

2.1. System definition and modeling framework

CO-GT adopts many of the assumptions and methods of the greenhouse gases, regulated emissions, and energy use in transportation (GREET 2020) model developed by Argonne National Laboratory (Argonne National Laboratory 2020), but excludes regulated emissions and energy use. The system and boundary encompass the energy and transportation fuel system for the state of Colorado. The scope of these analyses is defined as well-to-wheels and is inclusive of GHG emissions for in-state production of fuels, production of imported crude oil and fuels, and consumption of fuels along the fuel life cycle. Figure 1 illustrates the system boundary and processes described.

The system boundary includes the energy use and GHG emissions output for the full life cycle of transportation fuels consumed in Colorado. The full life cycle includes production, transportation, distribution, and combustion of transportation fuels and additional upstream emissions. In our life cycle framework, only domestic biofuels are modeled, therefore only domestic LUC for biofuels imported from Midwest states are included. Additional details on LUC are in the supplementary material (https://stacks.iop.org/ERIS/2/011001/mmedia). Excluded from this analysis are GHG associated with the vehicle cycle, including vehicle materials, manufacturing, and disposal. The functional unit used in this study is one unit of energy of each fuel (1 MJ). In this study, we assess the environmental impact of each transportation fuel, in terms of CI, reported in grams of carbon dioxide equivalent per one unit of energy in megajoule
Figure 1. Framework of the LCA modeling, including the system boundary and processes for Colorado’s fuel and transportation system. CI is presented in units of grams of carbon dioxide equivalent per megajoule (gCO₂e/MJ) and annual GHG emission is presented in units of millions of metric tons of carbon dioxide equivalent per year (MMT CO₂e/year).

(gCO₂e/MJ), and of transportation sector in annual emissions, reported in millions of metric tons of carbon dioxide per year (MMT CO₂e/year).

2.2. Fuel life cycle model (CO-GT)

The transportation fuel CIs from CO-GT are specific to the characteristics of Colorado’s local geography, energy sources, transportation modes, electricity generation profile, and more. The specific inputs to CO-GT (shown in Table 1 and exemplified below) allow for the calculation of Colorado-specific fuel pathway CIs.

For example, due to Colorado’s connectivity to the national and international petroleum pipeline system, the fuel pool in Colorado consists entirely of North American production, with 21.3% of volume coming from Canadian bituminous oil sands, 32.3% from Canadian conventional crude production, and the remainder from US crude oil production. The result is a petroleum fuel pool with relatively high life cycle GHG emissions for fossil fuels relative to the US average (see Table 1).

Colorado’s coal consumption is composed of 72% underground coal and 28% surface coal and represents a significantly different emissions profile when compared to US average coal characteristics, which are composed of 31% underground coal and 69% surface coal (Energy Information Administration 2020). Colorado also has a unique blend of natural gas (NG) which is used for both electricity production and NG vehicles, wherein 65% is derived from coalbed methane and shale gas, and 35% from conventional NG production (Energy Information Administration 2021).

Colorado’s electricity mix (which is an input to various fuel pathways and is a fuel pathway itself for EVs) is undergoing a rapid transformation for which this model represents a snapshot in time. As recently as 2010, 41% of Colorado’s electricity was generated from coal and only 10% from renewable sources (Energy Information Administration 2012). As modeled in CO-GT, the Colorado electricity generation mix in 2020 is composed of 29% coal, 46% NG, and 25% renewable energy, including wind, hydro and solar. Electricity CI analysis is a complex process and there is no standardized methodology for calculating CI (Curran et al 2005). National Renewable Energy Laboratory (NREL) developed the resource planning model that demonstrated how renewable sources for electricity generation and consumption remain mostly in-state (details in the supplementary material) (Trieu et al 2013).

The CI estimates include life cycle and upstream emissions for CO₂ emissions and non-CO₂ emissions converted according to global warming potential (see in the supplementary material).

In addition to the above inputs and those highlighted in Table 1, this comprehensive LCA of fuel pathways in the state includes Colorado-specific datasets on technology, local fuel transportation pathways and distances, local agricultural processes for biofuels production, regional specific crude oil characteristics, methane emissions from NG production, and more. Data quality is assessed using the pedigree matrix approach (see the supplementary material).

2.3. Vehicle fleet model

To translate the fuel pathway specific CIs (outputs of CO-GT) into metrics of transportation sector GHG emissions, this study developed a model of Colorado vehicle fuel consumption with projections out to 2030.
| Inputs | US average energy profile | Colorado energy profile |
|--------|---------------------------|-------------------------|
| Crude oil mix | 73.6% US domestic 6.3% Canada oil sands 7.4% Canada conventional crude oil 2.2% Mexico 3.1% Middle East 2.9% Latin America 1.4% Africa 1.2% others | 46.4% US domestic imports from other PADDs and PADD4 production 32.3% Canada conventional crude oil imports 21.3% Canada oil sands imports |
| Crude oil characteristics | | |
| Crude oil source | API gravity (°B) | Scontent (%) | Crude oil source | API gravity (°B) | Scontent (%) |
| US domestic | 34.7 | 1.4 | US domestic | 34.7 | 1.4 |
| Canada oil sands | 17.6 | 2.9 | Canada oil sands | 17.6 | 2.9 |
| Canada conventional | 26.5 | 1.9 | Canada conventional | 26.5 | 1.9 |
| Mexico | 26.5 | 2.2 | | |
| Middle east | 31.8 | 2.3 | | |
| Latin America | 24.8 | 2.8 | | |
| Africa | 38.3 | 0.3 | | |
| Brazil and others | 32 | 0.8 | | |
| Coal type | Underground coal: 31% Surface coal: 69% | Underground coal: 72% Surface coal: 28% |
| Natural gas source mix | Conventional NG: 49.8% Shale gas: 50.2% | Conventional NG: 35% Shale gas and coalbed methane: 65% |
| Electricity source mix | 0.4% residual oil 36.8% natural gas 22.8% coal 20.3% nuclear power 0.3% biomass 19.4% hydropower, wind and solar | 46% natural gas 29% coal 21% wind 2.5% hydropower 1.5% solar |
| Fuel transport modes | Conventional crude oil transportation to US refineries: Alaska: -Ocean tanker: 2.8% Offshore country ocean tankers, Canada and Mexico, & US domestic: -Barge: 23.3% -Pipelines: 73.9% | Conventional crude oil transportation to US refineries: Canada and US domestic: -Barge: 24% -Pipelines: 76% |
| | | |

*Methane emissions (details in supplementary material)*
Table 2. Modeled Colorado electricity mix in 2030 (Colorado Energy Office 2021).

| Generation source | Percentage of generation |
|-------------------|--------------------------|
| Coal              | 0%                       |
| Natural gas       | 28%                      |
| New firm resources| 3%                       |
| Hydro             | 2%                       |
| Wind              | 53%                      |
| Solar             | 13%                      |

Table 3. Modeled Colorado ZEV sales and stocks share in 2030. ZEVs are defined as inclusive of plug-in hybrid EVs, fuel cell vehicles, and battery EVs, with fleet makeup defined in detail by application in the vehicle fleet model (Colorado Energy Office 2021).

| Vehicles | ZEV sales share targets | ZEV stock share |
|----------|-------------------------|-----------------|
| LDV      | 70%                     | 27%             |
| MDV      | 40%                     | 12%             |
| HDV      | 40%                     | 14%             |
| Buses    | 100%                    | 35%             |

This model estimates the on-road light-duty (LDV) and heavy-duty vehicle (HDV) fuel consumption in the state of Colorado, including gasoline, diesel, ethanol, NG, and electricity as fuels. The fuel consumption model includes consideration and calibration of the number of LDV/HDV registered in Colorado, the share of vehicle types within each of 14 LDV and 60 HDV classes/vocations, annual vehicle miles traveled for each vehicle class, fuel economy specific to each vehicle class and fuel technology, a projection of registered vehicles from 2020 to 2030, and current and projected vehicle technology (fuel type) shares for each vehicle class.

This fleet model was validated by comparing both to 2020 fuels consumption in the state (see supplementary material) and to the future sales, stocks, and technology composition of Colorado vehicles through compliance and comparison with the Colorado GHG pollution reduction roadmap (see table 3) (Colorado Energy Office 2021 and ICF Resources 2020).

2.4. 2030 targets

The state of Colorado has developed prospective models of the transition needed to meet state-level goals for renewable energy and GHG emissions reductions, including the transportation sector. This study adopts these modeled pathways of compliance with HB 19-1261, specifically by modeling the state’s 2030 electricity generation portfolio, vehicle fleet, and transportation fuels mix, as described in the following sections.

2.4.1. Electricity mix

HB 19-1261 compliance targets for the electricity sector requires 80% GHG emissions reduction by 2030 relative to 2005 levels. To achieve these targets, electrical utilities in the state will transition away from coal and NG electricity generation and towards renewable generation, including wind and solar. Table 2 illustrates the modeled electricity mix for the state in 2030, derived from and compliant with the Colorado GHG pollution reduction roadmap (Colorado Energy Office 2021), that will approximately meet the 80% reduction in emissions. New firm resources represent electricity generation resources that may be dispatched when wind and solar generation is not sufficient, and could include NG, bioenergy, the use of renewables to produce hydrogen combined with hydrogen combustion, nuclear power, or a future long-duration energy storage technology. For this study, these new firm resources were modeled as peaking NG generation.

2.4.2. Vehicle fleet

In parallel with electricity sector emissions reductions, HB 19-1261 demands a rapid transition to EVs for both personal and commercial transportation. Notably, the state has set a specific goal of increasing the number of ZEV light-duty cars and trucks to at least 940 000 by 2030 (Colorado Energy Office 2020). Table 3 illustrates the ZEV sales and stock shares for this study’s vehicle fleet model, broadly categorized into LDVs, MDVs, HDVs, and buses (Colorado Energy Office 2021).

2.4.3. Other low-carbon fuels

In addition to electrification, the Colorado GHG pollution reduction roadmap recognizes that other low-carbon fuels, such as biofuels, hydrogen, and RNG, will be necessary to decarbonize sectors and vehicles that
are difficult to electrify (Colorado Energy Office 2021). To comply with HB 19-1261, the roadmap sets targets for conventional biofuels of 15% ethanol blend ratio and 20% biodiesel blend ratio by 2030 (Colorado Energy Office 2021). However, unlike electricity, Colorado does not produce most of the biofuels currently consumed in the state (which is primarily ethanol in 2021), so much of the increased demand would need to be imported from out-of-state unless significant in-state market incentives or direct investment were introduced. Furthermore, although the blend levels are theoretical achievable, increasing the blend of both ethanol and biodiesel to such levels may require extensive modification to fueling infrastructure and vehicles (Unglert et al. 2020). Therefore, for the purpose of this research, the blend levels modeled for 2030 were set to be more conservative at 12% ethanol and only 1% renewable diesel (RD), displacing conventional gasoline and conventional diesel, respectively. Due to the low consumption of NG in Colorado, RNG production and imports are not considered in this study. Biodiesel is not considered in this analysis because it is not a direct drop-in replacement for conventional diesel (Moriarty et al. 2020 and US Department of Energy 2021).

Modeling the Colorado transportation sector’s total fuel consumption and GHG emissions for the 2030 scenario requires allocating 2030 fuels demand to specific fuel pathways within CO-GT. To meet Colorado’s 2030 demand for ethanol, it was assumed that the 140 million gallons of ethanol produced in Colorado at present from Midwest corn would remain unchanged, and the remainder to reach a 12% blend would be imported from corn ethanol production facilities in the Midwest. For RD, it was assumed that the fuel would be produced from soybean oil and imported from existing RD refineries in Southern Wyoming. The CO-GT model also assumes technology and process improvements over time, so the CI values for both ethanol and RD are projected to be lower in 2030 than in 2020 (without a CFS), though even lower CI values may be achievable under a CFS. To estimate what the fuel CI values could be in 2030 under a CFS in Colorado with a competitive credit price, the same percent reduction in average CI for ethanol and RD that has been achieved to-date in the California LCFS program was applied to the 2020 results from CO-GT. A 31% reduction in ethanol CI and a 34% reduction in RD CI are projected between the present and 2030, equivalent to the percent reductions in 2020 relative to the peak yearly average CI values for these fuels between 2011 and 2020 in California (California Air Resources Board 2021).
3. Results and discussion

3.1. 2020 baseline
To evaluate Colorado’s progress in the transportation sector over the next decade, the state’s transportation fuels at present must be modeled. Also, the development of CO-GT was predicated upon the differences in Colorado’s energy and fuel landscape relative to the US average, so a model reflective of the differences was needed. Baseline CI values for the set of transportation fuel pathways consumed in Colorado in 2020 were calculated using CO-GT and compared to values that can be derived from GREET using US average inputs (see table 1). Results are presented in figure 2 and illustrate that the modeled CI of transportation fuels in Colorado are all higher than those of the US average, which demonstrates the need for this Colorado-specific model. For example, Colorado’s CI for electricity is 41.1 gCO₂e/MJ higher than the US average CI for electricity, which is reflective of the higher percentage of coal and NG used for electricity generation in the state. The volume-weighted cross-fuel CIs calculated using the Colorado and US average assumptions were 94.4 and 89.7 gCO₂e/MJ, respectively.

Transportation fuel volumes and their associated GHG emissions were also calculated for Colorado under both 2020, as shown in figures 3 and 4, respectively. Life cycle GHG emissions from the transportation sector in Colorado, which includes both upstream and tailpipe emissions, were estimated to be 40.5 MMT CO₂e in 2020 (comparable to 38.4 MMT CO₂e were US average CIs to be used). In 2020, the state level transportation life cycle GHG emissions are dominated by emissions from conventional gasoline (68.9%) and diesel (29%). Ethanol has a small contribution to state-level GHG emissions (1.8%), while transportation emissions from CNG and electricity combined are less than 1% of the total.

Electricity CI values presented in this paper are not adjusted with an EER that is used in other programs such as the California LCFS to account for powertrain efficiency differences relative to conventional vehicles.
3.2. 2030 outlook

Colorado’s transportation fuels and GHG emissions in 2030 were modeled considering two scenarios: (1) no CFS policy (or one with a low/uncompetitive credit price), and (2) a CFS policy with a high/competitive credit price. The difference between the scenarios is the latter assumes CI reduction for corn ethanol and RD that is proportional to the reductions achieved in the California LCFS program to-date (see section 2.4). Both assume equivalent fuel and electricity consumptions in 2030, and both assume the same vehicle fleet makeup in 2030, as goals have been set in regulations independent of the presence (or absence) of a Colorado CFS. Results for both scenarios are presented in figures 2–4.

Illustrated in figure 2, for the first 2030 scenario with no CFS policy, some CI reduction for liquid fuels and CNG is observed due to technology and process improvements over time, but most notable is the significant CI reduction for grid electricity. Assuming that state targets for GHG reduction in the electricity sector are achieved by 2030 through an increase in renewable generation, the CI for electricity will decrease by 64%. The volume-weighted average CI for all fuels was calculated to be 86 gCO₂e/MJ under the 2030 timeframe with no CFS policy, which is a 9.9% CI reduction relative to 2020. This CI reduction is significant and notable, as both California and Oregon set a goal of 10% average fuel CI reduction over the first decade of their respective CFS programs, and this result suggests that Colorado could achieve the same result with no CFS policy. Illustrated in figure 3, the corresponding fuel consumption decreases by 54.5 petajoules (or 460.5 million gallons of gasoline equivalent), primarily through increased market penetration of EVs and the displacement of gasoline and diesel with electricity, which is a lower CI fuel for transportation. As a result, the estimated life cycle GHG emissions from the transportation sector in Colorado dropped by 7.3 MMT to an annual total of 33.2 MMT CO₂e under the 2030 timeframe with no CFS policy.

For the 2030 scenario including a functional state CFS, further CI reduction is assumed for corn ethanol and RD because of the policy, as shown in figure 2. However, because the increase in volumes for corn ethanol and RD are marginal (up to 12% and 1% blends, respectively), the further reduction in CI amounts to less than 0.2 MMT CO₂e in additional emissions reduction. The CFS policy results in a 0.5% reduction in our prediction of 2030 state-level emissions, perhaps negligible considering the uncertainty implicit in a model combining attributional LCA, land use change, future fleet modeling, and market behavior (Dunn et al 2013, Fingerman et al 2018, Frey 2007, Lemoine 2017 and Plevin et al 2014). These results demonstrate that without a significant transportation fleet changeover to biofuels vehicles, electrification is the dominant pathway to achieve significant reduction in GHG emissions from the transportation sector in Colorado by 2030.

![Figure 4](image-url)
3.3. Considerations for a Colorado CFS

In view of the results derived from the CO-GT model, we offer considerations for Colorado legislators and policymakers regarding a CFS as a policy mechanism for transportation sector GHG emissions reduction over the next decade.

First, the results illustrate that the impact of an CFS on Colorado transportation sector GHG emissions is found to be relatively small, even under assumptions that the technology and process improvements that are documented in other regions of the US can be replicated in Colorado. CFS programs have high costs of implementation and administration (ICF Resources 2020), and the benefits of the CFS program as described using the CO-GT tool may not justify the program’s costs, especially when considered in comparison to other GHG reduction policies (Barbose 2021 and Colorado Energy Office 2021).

Second, if a CFS is to be considered, we must recognize that Colorado’s transportation sector transformation as conceptualized by policymakers to-date is highly reliant on the transition to electrified transportation technologies, with the expressed purpose of realizing reductions in criteria pollutants, water pollution, local air quality damages, environmental quality, and GHGs. Colorado has already established ambitious emissions reduction targets for electricity, as well as targets for vehicle electrification by 2030 (see section 2.4), the combination of which is demonstrated here to realize significant displacement of conventional fuels and reduction in GHG emissions. It is not clear, however, exactly if and how these targets can be achieved, and the extent to which a CFS could stimulate the market for EVs (Fingerman et al. 2018). Numerous connections between CFS policies and increasing the demand for electricity in the transportation sector have been proposed (Yang 2013), and implemented. For example, in 2018 California amended its LCFS policy to incentivize development of additional charging infrastructure and the sale of EVs. The amendments introduced capacity-based credits for fast chargers and a mandate to establish a statewide point-of-sale vehicle rebate program funded by a percentage of LCFS credit revenue generated by electric utilities, respectively (California Air Resources Board 2018). Although it departs from conventional CFS design by allowing credit generation from infrastructure, which is not directly associated with emissions reductions, these capacity credits help to reduce the investment risk of new charging infrastructure (Witcover 2018). Kelly and Pavlenko assessed California’s amended policy in the context of a future national standard and asserted that: (1) clean fuel policies could provide a durable financial instrument for supporting vehicle electrification, (2) EVs would become a cost-effective way to decarbonize the mix of transportation fuels by 2025, and (3) new charging infrastructure could supply credits cost-competitively (Kelly and Pavlenko 2020). If a CFS policy is to be implemented in Colorado, the findings of this study suggest that Colorado’s economic and environmental goals may be well served by an CFS policy that recognizes the primacy of transportation electrification in enabling deep decarbonizing of the transportation sector, and that provides these types of subsidy to transportation electrification preferentially to other low carbon fuels.

Any potential Colorado CFS policy will have to consider its market and policy interactions with the extant low-carbon fuels policies that are present in other US states. Since their inception, the California LCFS and Oregon CFP have primarily generated credits and achieved CI reductions through increased volumes of ethanol, biodiesel, and RD. Recent studies of compliance pathways for Colorado have demonstrated that fuel pathways under a Colorado CFS would likely follow the same trajectory, at least for the first decade (Witcover 2018, Witcover and Murphy 2019 and ICF Resources 2020). If Colorado and other states develop low-carbon fuel policies, a larger market for these fuels would likely stimulate their production through investment, innovation, and competition. At the same time, biofuels production is limited geographically and logistically to a limited set of fuel suppliers, and the potential for shuffling, leakage, and other interactions between clean fuel programs and markets are not well understood (Yeh et al. 2016 and Witcover and Murphy 2019). For example, Colorado is geographically closer to many of the top ethanol-producing states (primarily Midwestern states) than California and Oregon, and is adjacent to Wyoming, where the production capacity of RD is increasing. Whether the prices of credits associated with low-carbon fuels in Colorado will equalize with those in other states is beyond the scope of this study, but by identifying Colorado’s pathways for low-carbon fuels in 2030, we have identified that they may be largely shared with pathways that feed advanced fuels into other US CFS programs. Deeper economic and environmental investigation of the implications of this cross-fuel and cross-program competition should be prerequisite to development of additional CFS policies in US states.

4. Conclusions

To support the evaluation and planning of low-carbon transportation fuels policy in Colorado, a Colorado-specific LCA model (CO-GT) was developed and coupled with models of the state’s vehicle fleet, fuels mix, and electricity generation profile. The models were used to evaluate the impacts of increased renewable electricity generation and vehicle electrification by 2030 (for which the state has established targets), and to evaluate the potential implications of a state CFS policy as a mechanism to reduce transportation sector emissions.
Results of modeling with the CO-GT tools indicate that the electrification of transportation will serve to reduce the GHG emissions from the sector, while a CFS policy that achieves the same CI reductions in liquid fuels as has been achieved in other US states may not contribute significantly to sector GHG reductions. The development of these tools enables researchers and state policy makers to perform life cycle GHG emissions quantification for a variety of fuels and pathways while developing and comparing the mechanisms that are available to achieve local climate goals.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: http://dx.doi.org/10.25675/10217/234117.

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