



Assessing land-use impacts by clean vehicle systems



Patricia Pontau^{a,b}, Yi Hou^{a,c}, Hua Cai^{a,d,*}, Yi Zhen^{a,d}, Xiaoping Jia^e,
Anthony S.F. Chiu^f, Ming Xu^{a,d}

^a School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI, United States

^b Alfred Taubman College of Architecture and Urban Planning, University of Michigan, Ann Arbor, MI, United States

^c ENVIRON International Corporation, Ann Arbor, MI, United States

^d Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI, United States

^e School of Environment and Safety Engineering, Qingdao University of Science & Technology, Qingdao, China

^f Department of Industrial Engineering, De La Salle University, Manila, Philippines

ARTICLE INFO

Article history:

Received 17 July 2014

Received in revised form

18 December 2014

Accepted 19 December 2014

Keywords:

Renewable transportation fuels

Land-use

Clean vehicles

ABSTRACT

Transition of the current gasoline-based transportation system into a renewable fuel-based clean vehicle system has the potential to reduce greenhouse gas emissions and improve national energy security. However, the realized net environmental benefit or energy security improvement is tightly linked to the electricity fuel mix (for electric cars and plug-in hybrids) and fueling strategy (for cars using alternative liquid fuels). In addition, different types of transportation fuels have significantly different demands on land resources, both on land type and quantity. For example, biofuel production requires large quantities of agricultural land, while wind farms require land with sufficient wind density. Furthermore, there is substantial regional variation in the quality of necessary resources. Regions with higher wind speeds require less land to produce the same amount of electricity than those with lower wind speed, assuming the same turbine design. Similarly, regions with optimal soil conditions and climate for crop cultivation require less land to produce the same amount of biofuel. To enable comparison of land demand among different fuel choices for clean vehicles, this research provides a county-scale assessment of land demand based on a “per-vehicle-mile-traveled” basis. Potential clean vehicle fuels assessed in this study include ethanol produced from different feedstocks (corn and switchgrass), biodiesel from algae cultivated in open ponds and closed systems, and electricity produced from renewable sources (wind and solar). Our results show that, in general, engineered systems (wind electricity, solar electricity, and biodiesel from closed-system algae) are more land efficient than natural systems (corn ethanol from corn starch and stover, switchgrass ethanol, and biodiesel from open-pond algae). Solar electricity is the dominant regional optimal fuel choice from the land-use perspective for engineered systems while lowland switchgrass ethanol and biodiesel from open-pond algae are the major optimal choices for the natural systems. These results shed light on developing both federal and state level policies to minimize land-use impact for the development of a clean vehicle system.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

A renewable fuel-based U.S. transportation system has the potential to address climate change and energy security issues by reducing greenhouse gas (GHG) emissions and alleviating dependence on foreign oil imports. In 2011 over 27 quadrillion Btu of energy, almost one-third of total U.S. energy consumption, was attributed to the U.S. transportation system (U.S. Department of

Energy EIA, 2013a). The current transportation system is highly dependent on gasoline, with 93% of transportation energy sourced by petroleum, making the transportation sector particularly vulnerable to disruptions in oil markets (Congressional Budget Office, 2012; U.S. Department of Energy EIA, 2013b). In addition, the transportation sector is one of the major contributors for GHG emissions, responsible for over 1800 million metric tons of CO₂ equivalent in 2011 (U.S. Department of Energy EIA, 2013b; U.S. EPA, 2013). Various federal and state policies were enacted to facilitate renewable fuel production in order to change these trends. The policies particularly driving this research are the updated national-level Renewable Fuel Standard (RFS2) which was passed as part of the Energy Independence and Security Act of 2007, and the various

* Corresponding author at: 440 Church Street, Ann Arbor, MI 48109-1041, United States. Tel.: +1 734 764 1412; fax: +1 734 647 5841.
E-mail address: caih@umich.edu (H. Cai).

state-level Renewable Portfolio Standards (RPS) (Congress, 2007; NREL, 2008; Schnepf and Yacobucci, 2010). The RFS2 mandates that a minimum 36 billion gallons of biofuels be used in the U.S. transportation system by 2022, and includes specific requirements for corn ethanol, cellulosic biofuels, and advanced biofuels (Schnepf and Yacobucci, 2010). RPS mandates vary by state but generally require a certain percentage of state energy to come from renewable sources, like wind and solar electricity, by a certain year (DSIRE, 2014). Although the RPS mandates are not limited to transportation energy, they will likely affect the electrical grid mix and therefore will play a role in renewable energy development for clean vehicle systems.

Clean vehicles refer to vehicles that use alternative fuels instead of gasoline or diesel. Promising renewable fuels for clean vehicle systems include bioethanol (e.g. from corn starch, corn stover and switchgrass), biodiesel (e.g. from algae), and electricity generated from renewable sources (e.g. solar and wind). Depending on the fuel type and source, each fuel option has different advantages and disadvantages. Corn starch based ethanol can leverage existing fueling infrastructure and engines when blended with gasoline, but competes with food supply and may not significantly reduce net energy use and GHG emissions over the lifecycle of fuel production and use (Geyer et al., 2013; Schnepf and Yacobucci, 2010). Ethanol from cellulosic feedstock such as switchgrass is often considered more promising because switchgrass maintains high yields in a variety of growing conditions, including on marginal lands, and does not compete with food (Valentine et al., 2012). However, the cellulosic ethanol conversion process is still costly and highly uncertain, requiring significant research and investments to reach the commercial scale (Gunderson et al., 2008; Schnepf and Yacobucci, 2010). Biodiesel extracted from algae boasts a high energy yield but will also require a considerable amount of research to reach industrial-scale production levels and its production raises concerns about high water and nitrogen requirements (Quinn et al., 2012; Wigmosta et al., 2011). Renewable electricity from wind and solar has a better record for reducing energy use and GHG emissions with fewer environmental concerns, but its development faces uncertainties with electricity storage/transmission and trade-offs related to high technology and infrastructure costs (Arent et al., 2011). Therefore, uncertainties and trade-offs exist with the development of renewable transportation fuels. A better understanding of the advantages and disadvantages of different fueling strategies for a clean vehicle system is necessary to inform policy decisions and avoid negative unintended consequences.

In addition, large scale renewable transportation fuel production could significantly impact natural resource demand, such as water (Cai et al., 2013; Chiu and Wu, 2012) and land (Elliott et al., 2014; McDonald et al., 2009). McDonald et al. (2009) estimate that the land-use intensity of biofuels will continue to be 10–20 times more than that of conventional fossil fuels into the year 2030, suggesting that the development of a clean vehicle system may have a profound demand for land (McDonald et al., 2009). The authors also estimate that to meet the RFS2 alone will require upwards of 206,000 km² of new land devoted to biofuel development (an area larger than the state of Nebraska) (McDonald et al., 2009). The expansion of renewable fuel production can cause direct and indirect land-use change that potentially lead to increasing deforestation, loss of biodiversity, and increased GHG emissions (Dunn et al., 2013; Lambin and Meyfroidt, 2011; Rathmann et al., 2010; Sarkar and Miller, 2014; Searchinger et al., 2008). Furthermore, this impact could be more significant at the regional scale because the land-use intensity (the amount of land required to produce one unit of fuel) of potential renewable transportation fuels is not only significantly different depending on the fuel type, but also varies geographically due to climatic and topographical conditions. Because transportation infrastructure development is path

dependent, it is important for policy makers to consider potential land-use impact when planning for fueling strategies for regional clean vehicle system development. However, much of the current literature regarding renewable transportation fuels focuses on net energy use and life cycle GHG emissions of each individual fuel (Fthenakis and Kim, 2009; Miller, 2010) and average land requirement based on different units (Cherubini et al., 2009; Fthenakis and Kim, 2009; Geyer et al., 2013; Horner and Clark, 2013; Miller, 2010). Little attention has been paid to regional fueling strategies from the perspective of minimizing land-use impact. This research aims to fill this gap by comparing land-use demand of different renewable transportation fuels at regional scale and identify land-efficient fueling options.

This research compares the direct land-use intensities of different renewable fuels by assessing land-use on a “per-vehicle-mile-traveled” basis. In other words, the amount of land required to be occupied for a year to fuel a light-duty vehicle to travel one mile (for simplicity, the unit of m²/VMT is used in this paper). The land-use intensities are measured on a county-level basis to assess regional variations for each renewable fuel, as well as the regional variation in the optimal renewable fuel choice. Understanding regional patterns of land-use intensities among renewable fuel alternatives and the land demand to meet travel demand on renewable fuels will aid implementation of policies like the RFS2 and RPS by helping states develop better fueling strategies. Because transportation infrastructure development is path dependent, fueling strategy decisions made today will have impacts on regional resources and energy uses in the long term.

2. Materials and methods

2.1. Land-use intensity and efficiency

In this study, land-use intensity is defined as the amount of land needed to produce enough fuel in a year to power one mile of vehicle travel (m²/VMT). Using one vehicle-mile-traveled (VMT) as the reference unit is a common approach to enable comparison of land-use demand of different renewable transportation energy options (Choudhary et al., 2014; Geyer et al., 2013). The system boundary includes only the land needed for crop cultivation or electricity generation. Indirect land demand (e.g. road for fuel transportation, extraction or mining of raw materials) is not accounted for because they are insignificant compared to direct land-use for energy generation (Fthenakis and Kim, 2009). Land-use efficiency is the complementary way of describing land-use intensity in this study. Higher land-use efficiency indicates lower land-use intensity and vice versa. The renewable transportation fuel options examined in this research include: (1) corn ethanol (from both corn starch and stover), (2) lowland switchgrass ethanol, (3) upland switchgrass ethanol, (4) biodiesel from open-pond algae, (5) biodiesel from closed-system algae, (6) solar photovoltaic electricity, and (7) onshore wind electricity. These options were chosen to represent the different categories of fuels mandated in the RFS2 and the most common and promising renewable electricity sources. This research studies county-level land-use intensity of above mentioned fuels in contiguous states, including the District of Columbia. Spatial variations of productivity of each fuel option impacted by factors including radiation, soil quality, temperature, and wind speed, are incorporated in the analysis. We use 0.35 kWh/mile vehicle fuel economy (DOE, 2013) and 0.88 charging efficiency (Kelly et al., 2012) for electric vehicles. Corporate Average Fuel Economy (CAFE) standards of light-duty vehicles in 2011 at 30 mpg for gasoline vehicles is used as the baseline for liquid fuels (Bureau of Transportation Statistics, 2011; EPA, 2012). Fuel

Download English Version:

<https://daneshyari.com/en/article/7495228>

Download Persian Version:

<https://daneshyari.com/article/7495228>

[Daneshyari.com](https://daneshyari.com)