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Short communication

Climate consequences of low-carbon fuels: The United States Renewable Fuel Standard

Jason Hill [a,*], Liaila Tajibaeva [b], Stephen Polasky [b]

[a] Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN, USA
[b] Department of Applied Economics, University of Minnesota, St. Paul, MN, USA

HIGHLIGHTS

- Low-carbon fuels partially displace petroleum via fuel market rebound effect.
- Synthesis of recent analyses shows incomplete petroleum displacement by biofuels.
- Fuel market rebound effect can reduce or reverse climate benefit of low-carbon fuels.
- Fossil fuel displacement must exceed relative carbon footprint of a low-carbon fuel.
- The Renewable Fuel Standard increases greenhouse gas emissions when mandate is met.

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ABSTRACT

A common strategy for reducing greenhouse gas (GHG) emissions from energy use is to increase the supply of low-carbon alternatives. However, increasing supply tends to lower energy prices, which encourages additional fuel consumption. This "fuel market rebound effect" can undermine climate change mitigation strategies, even to the point where efforts to reduce GHG emissions by increasing the supply of low-carbon fuels may actually result in increased GHG emissions. Here, we explore how policies that encourage the production of low-carbon fuels may result in increased GHG emissions because the resulting increase in energy use overwhelms the benefits of reduced carbon intensity. We describe how climate change mitigation strategies should follow a simple rule: a low-carbon fuel with a carbon intensity of X% that of a fossil fuel must displace at least X% of that fossil fuel to reduce overall GHG emissions. We apply this rule to the United States Renewable Fuel Standard (RFS2). We show that absent consideration of the fuel market rebound effect, RFS2 appears to reduce GHG emissions, but once the fuel market rebound effect is factored in, RFS2 actually increases GHG emissions when all fuel GHG intensity targets are met.

1. Introduction

RFS2 requires increasing biofuel production, up to 36 billion gallons annually by 2022 (Table S1). It defines four biofuel categories—conventional biofuel, advanced biofuel, cellulosic biofuel, and biomass-based diesel—each of which must have a GHG emission intensity of no more than 80, 50, 40, and 50%, respectively, compared to that of the petroleum-based fuel for which it may substitute. In this paper, we consider the first three of these biofuels, all of which primarily substitute for gasoline. Together, these total 35 billion gallons, or 23 billion gasoline-equivalent gallons, in 2022. (Ethanol is approximately two-thirds as energy dense as gasoline.) Our analysis covers 96% of total RFS2 2006–2022 volumes, exclusive of biomass-based diesel.

2. Methods

To estimate the net GHG emissions associated with increased low-carbon fuel production, two key variables must be considered: the amount of fossil fuel that a low-carbon fuel displaces and the life cycle carbon intensities of these fuels. Supplying more low-carbon fuel results in additional GHG emissions. However, this additional supply may displace some amount of fossil fuel. Clearly, if the displacement of fossil fuel by low-carbon fuel is one-for-one, the savings in GHG emissions is equal to the reduction in carbon intensity. (For example, assuming full displacement, a low-carbon fuel with a GHG intensity 20% lower than that of a fossil fuel will

* Corresponding author.
E-mail address: hill0408@umn.edu (J. Hill).

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reduce GHG emissions by 20%.) If, on the other hand, there is no displacement, then GHG emissions increase by the amount of GHG emissions from the additional supply of low-carbon fuel. In general, increasing the supply of low-carbon fuel only partially displaces fossil fuel. This results in lower GHG emissions only when the savings from the reduction in carbon intensity outweighs the increase in GHG emissions from additional fuel use.

The amount of fossil fuel displaced by a low-carbon fuel is determined by the economic forces of supply and demand. In general, an increase in fuel supply causes a decrease in fuel prices, which in turn encourages greater fuel consumption. A growing literature analyzes the effects of biofuel production on domestic and international fuel markets (Bento and Klotz, 2014; Bento et al., 2015; Chen and Khanna, 2012; de Gorter and Drabik, 2011; de Gorter et al., 2015; Drabik and de Gorter, 2011; Grafton et al., 2012; Grafton et al., 2014; Hochman et al., 2010, 2011; Rajagopal et al., 2011; Rajagopal, 2013; Rajagopal and Plevin, 2013; Smeets et al., 2014; Stoft, 2010; Thompson et al., 2011). Our survey of these studies finds that biofuel production results in only a partial displacement of gasoline on an energy-equivalent basis, thereby increasing global energy use. Estimates of the amount of gasoline displaced globally by production of an energy-equivalent gallon of biofuel under a mandate policy such as RFS2 vary, with a majority falling under 0.50 gallons. Both empirical and theoretical assumptions drive this variation. Empirical assumptions differ on parameter values such as the elasticity of demand, supply, and substitution. Theoretical assumptions differ on the underlying modeling frameworks, fuel market structure, disaggregation of petroleum products, and concurrent biofuel policies. In this analysis, we select a conservative gasoline displacement rate of 0.50, allowing for a high level of displacement of gasoline by biofuels under a mandate policy.

The carbon intensity of low-carbon fuels relative to fossil fuels is determined using life cycle assessment, which, in EPA's final rule for RFS2, considers both supply chain and land-use change effects, including the cycling of biogenic carbon (U.S. Environmental Protection Agency, 2010). In this analysis, we use the mandated maximum life cycle carbon intensities of RFS2 biofuels, which are 80% (conventional biofuels), 40% (cellulosic biofuels), and 50% (advanced biofuels) that of gasoline. The life cycle carbon intensity of gasoline is estimated at 25 pounds of CO_2 equivalent GHG emissions per gallon.

We calculate total GHG emissions from RFS2 both with and without consideration of the fuel market rebound effect. RFS2 mandated biofuel volumes for 2006–2022 (Table S1) are converted to gasoline energy-equivalent volumes. We compare annual GHG emissions where mandated volumes are met by biofuels to annual GHG emissions where mandated volumes are met by gasoline. Estimates of total RFS2 GHG emissions without consideration of the fuel market rebound effect are calculated as the difference between these two assuming complete gasoline displacement. Estimates of total RFS2 GHG emissions with consideration of the fuel market rebound effect are calculated as the difference between these two assuming 50% gasoline displacement.

3. Results

Assuming that each gasoline-equivalent gallon of biofuel produced meets the GHG emissions intensity standard and reduces the production of gasoline by one gallon (that is, no fuel market rebound effect), RFS2 would reduce GHG emissions by 110 million metric tons (CO_2 equivalent) in 2022, and by 749 million metric tons cumulatively from 2006 to 2022 (Fig. 1) (Tables S2 and S3.) This is the interpretation taken by EPA in its final rule, which estimates a reduction in GHG emissions of 133 million metric tons in

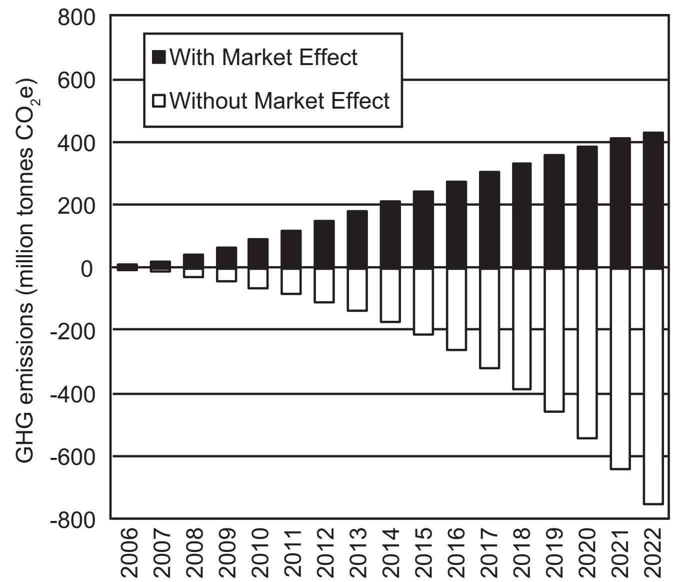

Fig. 1. Cumulative change in GHG emissions by biofuels qualifying for the Renewable Fuels Standard (RFS2).

2022, due in part to projections that some fuels will exceed minimum GHG reduction standards, with a statutory provision exempting biofuel produced at certain older facilities from RFS2's GHG emissions reduction requirements (U.S. Environmental Protection Agency, 2010).

In reality, substantially less than 23 billion gallons of gasoline will be displaced from biofuel production in 2022 due to the fuel market rebound effect. As previously described, a conservative assumption from our survey of recent literature is that only 0.5 gallons of gasoline are displaced per gasoline-equivalent gallon of biofuel produced. Taking this fuel market rebound effect into account and assuming the biofuels in RFS2 achieve their targeted GHG emissions reductions in all years, RFS2 actually leads to a net increase in GHG emissions of 22 million metric tons in 2022, and of 431 million metric tons cumulatively from 2006 to 2022 (Fig. 1). In sum, this mandate for the production of less GHG intense fuels actually increases net GHG emissions to the atmosphere relative to no action due to the low amounts of gasoline being displaced. In other words, RFS2 increases GHG emissions instead of reducing them when individual fuel GHG reduction targets are met.

Given the 50% displacement of gasoline, the use of conventional biofuel, which is almost all corn ethanol, increases net GHG emissions even with a 20% lower carbon footprint than gasoline. The use of advanced biofuels with a carbon intensity 50% that of gasoline generates no net change in GHG emissions. Only the use of cellulosic biofuels with a carbon intensity 60% lower than that of gasoline reduces net GHG emissions. A net increase in GHG emissions would also result from RFS2 as it has been implemented to date, with EPA waiving large volumes of those biofuels with the lowest carbon intensities. All else equal, requiring that biofuels have a reduction in carbon intensity greater than 50% compared to gasoline would result in climate change mitigation. More generally, a low-carbon fuel with a carbon intensity of X% that of a fossil fuel must displace at least X% of that fossil fuel to reduce overall GHG emissions. A basic sensitivity analysis of the fuel market rebound effect shows that for displacement rates of 0.33 or 0.66, the net GHG emissions are 824 or 38 million metric tons, respectively, cumulatively from 2006 to 2022. Should all mandated volumes be met, the break even zero net GHG emissions displacement rate is 0.68, which is substantially higher than the range of estimates found in our literature review.

4. Conclusion and policy implications

Here, we have focused on the fuel market rebound effect, but there are also other effects, such as those from indirect land-use change, that contribute to overall GHG emissions (Tilman et al., 2009). Indirect land-use change effects arise when increased demand for crops leads to cropland expansion that results in GHG emissions. As a result, it is unclear whether some biofuels, in particular corn ethanol, actually reduce GHG emissions, even absent consideration of the fuel market rebound effect (National Research Council, 2011). Our work therefore emphasizes the need for engineers and economists to collaborate on strategies to ensure the success of climate change mitigation policies: engineers with their expertise in quantifying supply chain GHG emissions through the use of life cycle assessment and economists with their knowledge of market effects and policy analysis (Bento and Klotz, 2014; Erickson and Lazarus, 2014).

Our results reinforce what has been long known by economists: the best way to reduce pollution is by imposing a tax on pollution-causing activities (Pigou, 1920). Taxes on pollution are preferable to mandates for additional fuel, even low-carbon fuels, because this allows market effects to work in the right direction, namely by increasing the price of pollution-causing activities, which decreases demand, rather than the wrong direction by lowering fuel prices and increasing demand. However, politics often stands in the way of good policy. Mandates are more politically palatable than taxes because mandates offer concentrated benefits to a small group of low-carbon fuel suppliers in the short term, while taxes require concentrated costs and offer diffuse benefits to society over the long term. In the case of biofuels, mandates are unlikely to reduce GHG emissions unless there is a radical breakthrough in technology that greatly lowers their carbon intensity. Until then, carbon taxes or a carbon cap-and-trade scheme present a more immediate option for reducing GHG emissions.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2016.07.035.

References

Bento, A.M., Klotz, R., 2014. Climate policy decisions require policy-based lifecycle analysis. Environ. Sci. Technol. 48, 5379–5387.

Bento, A.M., Klotz, R., Landry, J.R., 2015. Are there carbon savings from US biofuel policies? The critical importance of accounting for leakage in land and fuel markets. Energy J. 36 (3), 75–109.

Chen, X., Khanna, M., 2012. The market-mediated effects of low carbon fuel policies. AgBioForum 15 (1), 89–105.

de Gorter, H., Drabik, D., 2011. Components of carbon leakage in the fuel market due to biofuel policies. Biofuels 2, 119–121.

de Gorter, H., Drabik, D., Just, D.R., 2015. The Economics of Biofuel Policies: Impacts on Price Volatility in Grain and Oilseed Markets. Palgrave Macmillan, New York.

Drabik, D., de Gorter, H., 2011. Biofuel policies and carbon leakage. AgBioForum 14 (3), 104–110.

Erickson, P., Lazarus, M., 2014. Impact of the keystone XL pipeline on global oil markets and greenhouse gas emissions. Nat. Clim. Change 4, 778–781.

Grafton, R.Q., Kompas, T., Long, N.V., 2012. Substitution between biofuels and fossil fuels: is there a green paradox? J. Environ. Econ. Manag. 64, 328–341.

Grafton, R.Q., Kompas, T., Long, N.V., 2014. US biofuels subsidies and CO_2 emissions: an empirical test for a weak and a strong green paradox. Energy Policy 68, 550–555.

Hochman, G., Rajagopal, D., Zilberman, D., 2010. The effects of biofuels on crude oil markets. AgBioForum 13 (2), 112–118.

Hochman, G., Rajagopal, D., Zilberman, D., 2011. The effect of biofuels on the international oil market. Appl. Econ. Perspect. Policy 33 (3), 402–427.

National Research Council of the National Academies, Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy, 2011. The National Academies Press, Washington, DC.

Pigou, A.C., 1920. The Economics of Welfare. Macmillan and Co, London.

Rajagopal, D., 2013. The fuel market effects of biofuel policies and implications for regulations based on lifecycle emissions. Environ. Res. Lett. 8. http://dx.doi.org/10.1088/1748–9326/8/2/024013.

Rajagopal, D., Plevin, R.J., 2013. Implications of market-mediated emissions and uncertainty for biofuel policies. Energy Policy 56, 75–82.

Rajagopal, D., Hochman, G., Zilberman, D., 2011. Indirect fuel use change (IFUC) and the lifecycle environmental impact of biofuel policies. Energy Policy 39, 228–233.

Smeets, E., Tabeau, A., van Berkum, S., Moorad, J., van Meijl, H., Woltjer, G., 2014. The impact of the rebound effect on the use of first generation biofuels in the EU on greenhouse gas emissions: a critical review. Renew. Sustain. Energy Syst. 38, 393–403.

Stoft S., 2010. Renewable fuel and the global rebound effect. Global Energy Policy Center, Berkeley, CA: Research Paper No. 10-06.

Thompson, W., Whistance, J., Meyer, S., 2011. Effects of US biofuel policies on US and world petroleum products markets with consequences for greenhouse gas emissions. Energy Policy 39, 5509–5518.

Tilman, D., et al., 2009. Beneficial biofuels—The food, energy, and environment trilemma. Science 325, 270–271.

U.S. Environmental Protection Agency, 2010. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. (EPA Publication 420-R-10-006. ⟨http://www.epa.gov/otaq/renewablefuels/420r10006.pdf⟩).