Energy Policy 56 (2013) 41–50

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

# Addressing uncertainty in life-cycle carbon intensity in a national low-carbon fuel standard

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## HIGHLIGHTS

- ► Fuel LCA models are used to describe the uncertainty and variability in GHG emissions.
- ► Opt-in programs reduce uncertainly but considerable uncertainty remains.
- ► We discuss policy approaches that can be used to account for uncertainty in a robust policy design.

## ARTICLE INFO

*Article history:*
Received 3 January 2012
Accepted 4 August 2012
Available online 1 September 2012

*Keywords:*
Uncertainty
Life-cycle analysis
Environmental policy analysis

## ABSTRACT

Policies formulated to reduce greenhouse gas (GHG) emissions, such as a low-carbon fuel standard, frequently rely on life-cycle assessment (LCA) to estimate emissions, but LCA results are often highly uncertain. This study develops life-cycle models that quantitatively and qualitatively describe the uncertainty and variability in GHG emissions for both fossil fuels and ethanol and examines mechanisms to reduce those uncertainties in the policy process. Uncertainty regarding emissions from gasoline is non-negligible, with an estimated 90% confidence interval ranging from 84 to 100 g $CO_2e$/MJ. Emissions from biofuels have greater uncertainty. The widths of the 90% confidence intervals for corn and switchgrass ethanol are estimated to be on the order of 100 g $CO_2e$/MJ, and removing emissions from indirect land use change still leaves significant remaining uncertainty. Though an opt-in policy mechanism can reduce some uncertainty by incentivizing producers to self-report fuel production parameters, some important parameters, such as land use change emissions and nitrogen volatilization, cannot be accurately measured and self-reported. Low-carbon fuel policies should explicitly acknowledge, quantify, and incorporate uncertainty in life cycle emissions in order to more effectively achieve emissions reductions. Two complementary ways to incorporate this uncertainty in low carbon fuel policy design are presented.



## 1. Introduction

Life-cycle assessment (LCA) endeavors to characterize the environmental impacts of a product or service throughout its full life cycle, from the extraction of raw materials through manufacturing, use, and disposal (Williams et al., 2009). LCA has become an important and prevalent tool for environmental policy makers, playing a crucial role in the development of the California low-carbon fuel standard (LCFS) (Farrell and Sperling, 2007a), the U.S. national renewable fuel standard (RFS) in the Energy Independence and Security Act of 2007 (U.S. Congress, 2007), as well as biofuel policies in other countries, particularly the UK renewable energy directive (RTFO) and the European Union's renewable energy directive (RED). These policies promote the use of biofuels and other fuels that promise life-cycle greenhouse gas emissions reductions compared to petroleum-based fuels in the transportation sector.

During the course of any LCA, modelers must make many decisions regarding things that will or will not be included in the system, data sources most appropriate to characterize the system, and methods to estimate values for which no data are available. As a result, analysts looking at the same product or service can make different decisions in these areas, thereby arriving at different and sometimes disparate conclusions that may suggest different courses of actions for decision makers. Large, complex systems frequently have many decisions to be made in these

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0301-4215/$ - see front matter 
http://dx.doi.org/10.1016/j.enpol.2012.08.012

areas, which can make it difficult to arrive at the "true" value to quantify the impact of product or service under investigation. Understanding and addressing the magnitude of the uncertainty in the model output is essential for robust decision-making.

Uncertainty in the life-cycle assessment context can be broadly categorized as either parameter uncertainty or model uncertainty. The first, parameter uncertainty, results from not precisely knowing a specific model input value. This can result from: data which are simply unavailable and for which proxy data must be used; measurement error on collected data; poor scientific understanding of how some part of the model works; or, data that vary temporally or geographically for the system under analysis. The second category, model uncertainty, is broader in scope. It results from not knowing how to construct (parts of) a mathematical model to represent a real-world process. Some examples of model uncertainty are: how to allocate emissions from one process across multiple co-products; how economically-mediated production impacts will evolve over space and/or time; what global warming potentials to use for greenhouse gas emissions; and, what processes to include in the system boundary.

Quantitative methods to deal with uncertainty in LCA, as suggested by many previous studies and summarized by Lloyd and Ries (2007) and Williams et al. (2009), include probabilistic simulation, intervals, scenario modeling, fuzzy data sets and analytical uncertainty propagation. When dealing with parameter uncertainty, probability distributions are specified using data and/or expert judgments, then simulation methods and uncertainty importance analyses are used to establish uncertainty in output (Huijbregts et al., 2003). Quantifying the range or impact of model uncertainty is often more challenging than parameter uncertainty. This is because many difficulties of model uncertainty cannot be addressed by any amount of data collection, especially those projecting future system developments. Often the best that can be done is to construct all reasonable and feasible models and use the least and greatest output values to establish bounds on quantitative model results. Recognizing uncertainty complicates a decision maker's task of choosing among fuel types; however, neglecting uncertainty in favor of (relative) simplicity leads to less robust decisions on policy. For example, if an opportunity fuel improves upon an incumbent, even without precise emissions estimates for either fuel, then a recommendation to displace the incumbent can be made with improved confidence. See Mullins et al. (2011) for further discussion.

In the United States, both the RFS and LCFS aim to increased biofuel usage, and therefore reduced greenhouse gas emissions when compared to a business as usual case, but each takes a different approach at achieve reductions. The RFS aims to reduce GHG emissions from the transportation sector with specific biofuel volume mandates, whereas the LCFS reduces GHG emissions from the transportation sector by mandating a state-wide fuel mix GHG reduction target (10% in California), letting blenders decide how much of each fuel type to use to meet this target. These fuel types are more precisely defined for the LCFS than the RFS, so the LCFS design may offer an improvement over the RFS with regards to emissions uncertainty.

To assess this hypothesis, this study employs previously developed life-cycle fuel emissions Monte Carlo models to examine the effectiveness of a low-carbon fuel policy design in reducing the uncertainty in calculated carbon intensity (the grams of $CO_2$-equivalent emissions per MJ of fuel energy). These results can, in turn, provide a better estimate of achievable emissions reductions and a more robust decision-making framework for low-carbon fuel selection.

This analysis is motivated by a national LCFS, which is proposed to operate in a manner that is largely similar to the LCFS currently enacted in California, where transportation fuels are assigned a carbon intensity and regulated fuel blenders are required to sell fuel that collectively does not exceed a given carbon intensity threshold (UC (University of California) Davis, 2012). However, many of the ideas and results can be adapted to any carbon policy (such as RFS, a carbon tax, or a cap-and-trade program) that relies on LCA to generate GHG emissions estimates.

The paper proceeds by first describing the previously developed Monte Carlo models and presenting summary results for corn ethanol, switchgrass ethanol, and gasoline. Next, the paper qualitatively discusses sources of uncertainty and presents spatially disaggregated results the carbon intensity of the transportation fuels modeled here. With these initial results in mind, the paper explores the impacts of an "opt-in" policy mechanism on reducing uncertainty and quantifies the problem of adverse selection that could result, and summarizes some suggested policy mechanisms for handling the remaining uncertainty.

## 2. Modeling variable and uncertain greenhouse gas emissions

This study uses two models developed previously to quantitatively characterize uncertainty in life-cycle greenhouse gas emissions from fossil- and bio-based transportation fuels using Monte Carlo simulation. The fossil fuel model comes from Venkatesh et al. (2011), who defined the life cycle to include crude oil extraction, transport, refining, product transport and fuel combustion. This model has been slightly updated to include the emissions of petroleum fuels produced from Canadian oil sands. Emissions due to the extraction of Canadian oil sands are taken from Charpentier et al. (2009). The lower, median and upper bounds summarized in Charpentier et al. (2009) were used as the parameters of a triangular distribution representing emissions from oil sands production (60, 100, 170 kg $CO_2e$/bbl). Results for gasoline are presented in Fig. 1. The mean values of life-cycle GHG emissions factors are 90 g $CO_2e$/MJ for gasoline and 94 g $CO_2e$/MJ for diesel. Of the total for gasoline, nearly 80% consists of combustion emissions, with contributions of 9% from crude extraction and transport, 11% from refining, and 1% from product transport. The 90% confidence intervals of these fuels indicate that parameter uncertainty, previously ignored by most LCA studies, is indeed non-negligible. For example, the 90% confidence interval for gasoline ranges between, 84 and 100 g $CO_2e$/MJ, 17% of the mean value.

The biofuels model used comes from Mullins et al. (2011), who include the following stages in their life-cycle assessment: Direct and indirect land use change; Feedstock production; Feedstock

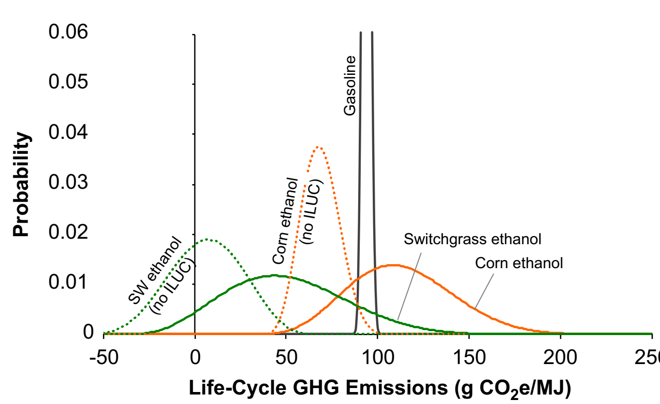


**Fig. 1.** Probability distributions for total GHG emissions for corn and switchgrass ethanol with and without ILUC, and a truncated distribution for gasoline. Produced using models from Mullins et al. (2011) and Venkatesh et al. (2011).