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A standardized well-to-wheel model for the assessment of bioethanol and hydrogen from cellulosic biomass

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HIGHLIGHTS

- ► We generate the standardization transport model (STM).
- ► We measure the uncertainty of well-to-wheel results with the use of biomass.
- ► Hydrogen from waste wood is a very attractive second generation transport fuel.
- ► Bioethanol from sugar is a promising first generation transport fuel.

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ABSTRACT

The well-to-wheel (WtW) results of biomass-based chains are found to be significantly sensitive to changes in the elements of the chain model such as the land use change. Our new standardization model is based on the conviction that the synthesis of a statistical aggregate of the possibilities that are defined by the major models in the field including GREET and GEMIS would build reliability into the result by buffering against the changes in the elements of the chain model. In this paper we assess a chosen set of biomass-based chains in terms of energy and GHG emissions using the innovative concept of the standardization transport model (STM). Hydrogen was found to be very attractive with the use of waste wood. On the other hand, sugar ethanol was found to be a promising fuel for the reduction of GHG emissions. Unfavorable land use changes and high fertilizers use should be avoided to maximize confidence in significant reductions from sugar ethanol.

1. Introduction

Life cycle assessment (LCA) is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (GDRC, 2011). Well-to-wheel (WtW) is the specific LCA used for transport fuels (e.g., bioethanol) and vehicles. The model elements of a biomass-based WtW chain are divided into three types: (i) input data, (ii) assumptions, and (iii) modelling choices. First, input data refers to the model parameters such as the amount of fertilizers used in biomass farming and fermentation yield in biomass processing. Second, assumptions include process design (e.g., fermentation with or without co-production), type of land use, and type of electricity displaced for when calculating the electricity co-generation credit. Third, modelling choices include the allocation method (Curran, 2007) in the case of co-products and decisions on the system boundary such as whether to include the greenhouse gas (GHG) emissions from land use change (LUC) and if so, whether direct or indirect LUC (Fritsche, 2010).

In the past much attention was given to the integration of stochastic applications in WtW models to address the uncertainty linked to input parameters and little attention was given to the incorporation of different databases, assumptions, modelling choices and perspectives into one model to generate an objective analysis for the study of strategic options. In the late 1990s LCA authors started to practically address the type of uncertainty that is linked to the input data of WtW models led by the incorporation of Monte Carlo simulation in GREET version 1.6 using a commercial software Crystal Ball (Wang, 2001). Following the first step by Argonne National Laboratory (ANL) stochastic applications were incorporated in the MIT model (Weiss et al., 2000), the GM European model (GM et al., 2002) and others until today when nearly all WtW tools can address uncertainties in the input data. Nevertheless, the problem that is being tackled in this paper is not limited to the uncertainty linked to the input data of the

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List of Nomenclature

CCS	Carbon capture and sequestration
CG	Conventional gasoline
CGH2	Compressed gaseous hydrogen
EC	Energy consumption
EM	GHG emissions
FCV	Fuel cell vehicle
HEV	Hybrid electric vehicle
ICEV	Internal combustion engine vehicle
LCA	Life cycle assessment
LH2	Liquid hydrogen
STM	Standardization transport model
WtW	Well-to-wheel
WtT	Well-to-tank

WtW model. The uncertainty linked to variations in the elements of the model, which as described above are not limited to input data and include various modeling assumptions and choices, is the subject matter. In fact the LCA community has been circulating around this problem and only recently some sounds reflected the importance of addressing this new level of uncertainty.

The IEA was one of the first to acknowledge the problem of using fuel chain analysis with default elements in policy making because no single reference can adequately describe the chain in terms of energy consumption and GHG emissions. Different situations cause differences in fuel chain analysis (IEA, 1999). Recently others have started to address the same problem. These stirrings mainly stem from the surging controversy in literature over the net benefits of biofuels. Cherubini et al. (2009) in their work on the key assumptions and methodological choices in biofuels LCA made an important intervention by stating that LCA results based on default model elements may significantly increase the risk of drawing misleading conclusions and therefore uncertainty analysis should take into account all the different assumptions and variables. Similarly acknowledged by Gnansounou et al. (2009) which expanded the work of various authors who have demonstrated the significant effect of methodological choices on the GHG and energy balance of biofuels through review papers and other similar studies (Farrell and Sperling, 2007; Börjesson, 2009). Nevertheless, the ranges presented by Cherubini et al. (2009) and Gnansounou et al. (2009) are only a demonstration of the effect of variation in the model elements of a biomass-based chain and indeed cannot be claimed to be an actual quantification of the resulting uncertainties. The range is a non-probabilistic portfolio which is used to demonstrate the impact of changes in the model elements of a chain on the result but does not provide an insight into the probability distribution. This type of result does not allow the type of sensitivity analysis which relates the variability of the result to the contribution of different factors. Also as uncertainties are not statistically measured and described, any relationship between the resulting portfolios cannot be described and embedded in the analysis.

The WtW assessment of biomass-based chains is largely affected by changes in the model elements. This is an example to demonstrate the effect of the changes in the model elements on the results. The WtW GHG emissions of sugarcane ethanol fuelling an internal combustion engine vehicle (ICEV) is found to range from 26.7 to 267 g of CO_2 equivalent per kilometre taking into account results from major models in the field including GEMIS, GREET, GHGenius and JRC WtW (Öko-Institut, 2008; (S&T)[2] Consultants Inc., 2009; JRC, EUCAR, and CONCAWE, 2008; JRC, EUCAR, and CONCAWE, 2008; ANL, 2009). This range is shown around a factor of 10 and is a result of the differences in the model elements across the reference models. The authors can see that with the direct use of current WtW tools to aid policy making it is difficult to resolve controversies and a solution has yet to be presented. Policy makers are confronted with tools that only provide subjective evaluation and do not allow for the consideration of changes in the model elements. Moreover, a subjective assessment does not look outside the box of one tool to consider different perspectives. The latter point is very important to increase confidence in the accuracy of the data, the completeness of the assumptions and the soundness of the choices made in the model.

The standardization transport model (STM) that is introduced more fully elsewhere (El-Houjeiri, 2011) has been developed to quantify the probabilistic ranges of WtW energy consumption (MJ/km) and GHG emissions (in grams of carbon dioxide equivalent per kilometre) for 48 chains of passenger car transport. The probabilistic results of the STM consider the variation in the model elements and are very beneficial for energy policy making by providing more objective evaluation than single-point results. This is based on the combination of different models from the major WtW tools in the field including GREET (ANL, 2009) and GEMIS (Öko-Institut, 2008). The scope of this paper is to draw an analysis from the output uncertainty of biomass-based chains and deduce conclusions that would not have been possible from a non-probabilistic range of WtW results nor from single-point results.

Although the STM, at least in its general form, lacks specificity of geographic location and time frame this is seen as an advantage and not a disadvantage. The geographic location and time frame are significant factors in biomass-based chains. The changes in the climatic conditions, farming practices and type of land use with different geography and time have significant impact on the GHG emissions during the growing of energy crops. This indeed questions the validity of directly using classic WtW tools, which have a limited geographic scope and provide only a snapshot in time, in making energy policies that should serve for many decades from now. According to a report of The European Organization for Packaging and the Environment (EUROPEN, 1999), on the use of LCA as a policy tool, one of the limitations of LCA in any policy or decision-making process is time specificity. An LCA study relates to one specific system at one defined point in time and thus would not reflect future changes that are not always apparent at the point when the study is conducted. Moreover, WtW tools are used to quantify global impacts such as the total GHG emissions as a result of a domestic activity (e.g., driving one kilometre). Therefore a WtW chain is not confined to one region of the world and may involve factors in another region. For instance, in the case of US importing sugarcane ethanol from Brazil the US policy makers are significantly affected by changes in the amount and timing of fertilizers use and type of land use associated with growing sugarcane in Brazil, if US policy makers were to adopt a global approach in their assessment of the future of passenger car transport. The results from the STM account for unpredicted changes in geographic location and time by combining established models of different geographic context and time frame. This buffers against future changes in geographic location of resources and time specific conditions (e.g., land use type, farming practices, technology, etc.).