ENVIRONMENTAL EVALUATIONS OF 2ND AND 3RD GENERATION BIOFUELS: WHAT CAN META-REGRESSION ANALYSIS TELL US ABOUT VARIATIONS IN GREENHOUSE GAS (GHG) EMISSIONS ESTIMATED WITH LIFE CYCLE ASSESSMENT (LCA) APPROACH?

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This paper presents a systematic literature review of previous studies using the LCA approach for the environmental evaluation of advanced biofuels. The main factors influencing the results of these studies are characterized and estimated using a meta-regression analysis. These assessments provide reliable scientific input to the debate over the potential role played by biofuels in the "greening the economy" and "climate change" issues. The term "advanced biofuels" refers, here, to biomass-based transportation fuels produced from lignocellulosic materials (ethanol and synthetic diesel – BTL) and microalgae (fatty acid methyl ester – FAME, hydrogenated vegetable oil – HVO), the 2nd and 3rd generation biofuels respectively.

The transport sector was responsible for 23% of the world's GHG emissions in 2009 and the transport fuel demand is projected to rise steadily in the coming decades. Biofuels are viewed as an alternative to fossil fuels and advanced biofuels are currently being developed, as they seem to be more efficient in terms of land use, GHG emissions and other environmental aspects than 1st generation biofuels produced nowadays. Policy makers have recently developed legislation inciting the production of low-carbon biofuels: one can cite the Renewable Fuel Standard (RFS) in the USA and the European Directive 2009/28/EC (Renewable Energy Directive – RED) in the EU for instance. Both include GHG emissions savings as one of the most important mandatory environmental criteria.

LCA is seen as the appropriate methodology for the environmental evaluation of biofuels and it has been widely applied to estimate the Global Warming Potential (GWP, an impact indicator for GHG emissions) associated to these technologies. However, LCA results can vary significantly depending on various factors. In the case of biofuels, the most important are: the assumptions made to describe the biomass production step (field N2O emissions and land use changes), the biomass conversion into biofuel data and the LCA methodological choices (system boundaries, method used to account for coproducts impacts, etc.).

Here, we propose an alternative approach to previous reviews of biofuel LCA studies. The meta-regression analysis methodology is used to synthesize existing LCA results of advanced biofuels. This quantitative research method has been developed to compare and/or combine outcomes of different empirical studies with and without similar characteristics that can be controlled for. By nature, each result from an individual empirical study may be quoted to illustrate the sampling uncertainty of estimates. Estimates of previous studies are grouped together in a database, according to differentiating characteristics. Then, estimates are assumed to be a function of these variables and their effects are assessed by the mean of specific econometrics methods. This multivariate setup allows to quantify the effect of the characteristics relating to the sample or to the author's methodological choices that impact on the results. Besides, this framework gives the possibility to produce a “mean” estimate after controlling for its moderators by establishing the extent to which the variation is systematic.

Our database contains a vector of previous studies estimates for life cycle GWP of biofuels (dependent variable), and a vector of explanatory variables. We choose GWP as the dependent variable because GHG emissions reduction is the most important of the environmental criteria in the RFS and the RED. The factors that can potentially influence LCA results (see above) are among the explanatory variables, as well as some study characteristics (country, year of publication, etc.), included to account for potential publication biases. Peer reviewed articles, research reports and regulatory texts following the ISO 14044 guidelines to conduct an LCA are included in the database. Finally, 43 LCA studies (585 estimates) are retained. Results show, ceteris paribus, that the mean GWP of ethanol, BTL and algae fuels are 27, 21 and 83 gCO2eq/MJ of biofuel, respectively. In the RED, the reference value for fossil diesel and gasoline is 83.8 gCO2eq/MJ. This shows a clear advantage of 2nd generation biofuels compared to 3rd generation in terms of GHG reductions. The factors responsible for the variability in the GWP estimates are also examined in this work. The meta-regression analysis indicate that studies that take explicitly into account the estimates' uncertainty and land use changes or that included infrastructures in the system boundaries globally obtain higher estimates, whereas studies accounting for other impact categories than only GHG emissions generally estimate a lower GWP. Last but not least, our results indicate that regulatory texts (RFS and RED) provide lower GHG emissions estimates than peer reviewed studies and that there is a localization effect on these estimates: European studies results are statistically higher than American ones.