Supplementary Materials

Can Agriculture Balance Its Energy Consumption and Continue to Produce Food? A Framework for Assessing Energy Neutrality Applied to French Agriculture

This supporting information provides additional details on the energy conversion efficiency calculation of biomass to fuel. There is a great variety of fuels produced from biomass. The capacity of a fuel to produce mechanical power is commonly known as free energy and is proportional to its energy density. Energy density greatly varies among fuels. When comparing different fuels and their capacity to displace fossil fuels, it is crucial to use a common reference energy density for all fuels.

The energy density of crude oil is about 42 GJ/t, which is about three times higher than the energy density of dry biomass (16 MJ/kg) including plants and manure [1]. Dry biomass can be converted to gas and liquid fuels of different energy densities through various pathways and conversion technologies [2,3]. The energy density of biofuels produced from agricultural biomass is not necessarily comparable to that of the fossil fuels used as inputs to agriculture. Therefore, more units of biofuel are needed to displace one unit of fossil fuel.

Calculation of the energy recovery potential from agricultural residues in terms of oil equivalent fuel

For instance, the energy density of ethanol is 26 MJ and ethanol can be produced from crop biomass, including grain and residues, and from manure. The energy conversion efficiency of biomass to fuel relates to the fermentation or gasification potential per ton of dry matter (DM). For straw, the gasification potential is 220 m^3 CH_4/t DM [4] which is 7700 MJ. For manures it is about 170 m^3 CH_4/t of DM [4] and so 6000 MJ. Considering an energy content of dry organic matter at 16 MJ/kg [1], the biomass to ethanol efficiency from agricultural residues is about 42%. This efficiency is in agreement with the efficiency of 45 to 55% for corn fermentation to ethanol and with the efficiency of 50 % for cellulosic sugar to ethanol [1,3] given differences in the chemical composition of feedstock. To express ethanol production in terms of an oil-equivalent fuel, ethanol production has to be multiplied by 26/42. This factor represents the energy density difference between ethanol and the oil-equivalent fuel. Accordingly, by assuming an energy efficiency of 50 % from biomass to ethanol, the energy efficiency from biomass to an oil-equivalent fuel is 50%*26/42 = 30%.

We use this energy conversion efficiency to assess the primary biomass equivalent of current fuel consumption for mechanical work.

Calculation of current biofuel production of French agriculture in terms of oil equivalent fuel

Today, French agriculture produces about 100 PJ (in terms of oil equivalent) [5] of first generation biofuels, mainly biodiesel, from rapeseed. The biomass to biodiesel efficiency is about 42-52% [1]. We use the rounded equivalence of 50% between biodiesel and primary biomass feedstock, meaning that the primary biomass equivalent of the current 100 PJ French biodiesel production is 100/50%=200 PJ.

References

1. *Nutrient requirements of dairy cattle*; National Research Council, Ed.; Nutrient requirements of domestic animals; Seventh revised edition.; National Academy Press: Washington, D.C, 2001; ISBN 978-0-309-06997-7.

2. Huang, W.-D.; Zhang, Y.-H.P. Energy Efficiency Analysis: Biomass-to-Wheel Efficiency Related with Biofuels Production, Fuel Distribution, and Powertrain Systems. *PLoS ONE* **2011**, *6*, e22113, doi:10.1371/journal.pone.0022113.
3. McKendry, P. Energy production from biomass (part 2): conversion technologies. *Bioresour. Technol.* **2002**, *83*, 47–54, doi:10.1016/S0960-8524(01)00119-5.
4. Ademe *Estimation des gisements potentiels de substrats utilisables en méthanisation*; Ademe; 2013;
5. Ademe, I Care & Consult, Blézat consulting, CERFrance, Céréopa *Agriculture et énergies renouvelables : état de l'art et opportunités pour les exploitations agricoles.*; Ademe, 2017; p. 70.