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Renewable fuels – A comparative assessment from economic, energetic and ecological point-of-view up to 2050 in EU-countries

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ABSTRACT

Fuels based on renewable energy sources (RES) such as a variety of first and second generation biofuels as well as electricity and hydrogen from RES, are considered an important means of coping with the environmental problems of transport. The objective of this paper is to investigate the "renewable fuels" from economic, energetic and ecological perspective within a dynamic framework until 2050.

The key results show that all fuels analysed have lower CO_2 emissions than gasoline, but drawbacks include the high costs of hydrogen- and electricity-driven vehicles. By 2050 however these costs could be reduced due to technological learning effects and efficient policy measures (e.g. CO_2-based tax). We conclude that "renewable fuels" will only play a significant role if CO_2 taxes, intensified R&D and technological learning are strategically implemented.

1. Introduction

In recent years the major challenges for EU climate and energy policy have been to implement effective policies and measures to mitigate global warming, improve air quality and reduce energy consumption. Since about one quarter of EU greenhouse gas emissions comes from the transport sector, a significant number of EU measures for reducing CO_2 emissions are directed to this sector with renewable fuels playing an important role. According to EU "20–20–20 targets", by 2020 at least 10% of fuels used in transport should come from RES [1,2].

Transport is the fastest growing sector in terms of energy use. It plays a central role in the European economy and accounts for almost 20% of the total gross energy consumption in Europe. 98% of the energy consumed in this sector is fossil energy [3]. The European Commission has recognized this problem, see e.g. a White paper "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system", [4].

How this will develop in the future depends on technological progress and policy measures implemented. The environmental, economic and energetic benefits of alternative fuels have been discussed in numerous scientific papers. Important contribution to literature have been provided by Huo et al. [5] who focus on a life-cycle assessment of energy use and GHG emissions from biodiesel. The environmental, economic and energetic benefits of biodiesel and bioethanol are discussed by Hill et al. [6]. Hydrogen as a renewable fuel for a transport is analysed by Specht et al. [7] and Ajanovic [8]. Biofuels have been compared with electricity and hydrogen from biomass by Ohlrogge et al. [9] and Campbell et al. [10].

In this paper we analyse and compare all relevant renewable fuels, biofuels and RES-based electricity and hydrogen.

The most important renewable fuels in the EU today are the first generation biofuels, biodiesel and bioethanol. They are however, often criticized due to the relatively bad ecological performance and their competition with food production. Currently there are higher expectations of second generation biofuels which can be produced using different kind of lignocellulosic materials, as well as from RES-based electricity and hydrogen.

The objective of this paper is to investigate the "renewable fuels" from economic, energetic and ecological points of view in a dynamic framework until 2050 in EU-countries. A comparison has been conducted of selected fuels, as well as of total energy service provided by these fuels, (see Fig. 1). The three categories of "renewable" fuels investigated are: biofuels, and RES-based electricity and hydrogen.

Biofuels:

The following three types of biofuels have been analysed for 2010:

- first generation biodiesel produced from rapeseed methyl ester (RME);

Abbreviations: FT-Diesel, Fischer–Tropsch diesel; GHG, greenhouse gas; H2, hydrogen; ICE, internal combustion engine; LCA, life cycle assessment; PV, photovoltaic; RES, renewable energy sources; R&D, research and development; RME, rapeseed methyl ester; SNG, synthetic natural gas; TTW, tank-to-wheel; VAT, value added tax; WTT, well-to-tank; WTW, well-to-wheel.

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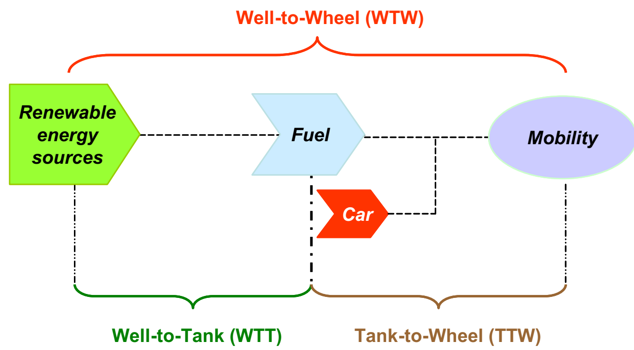

Fig. 1. The energy chain for providing the service mobility (based on [12]).

- first generation bioethanol produced from wheat or corn;
- biogas produced from organic waste, maize silage or grass.

For 2050 the following three types of second generation biofuels have been analysed:

- second generation biodiesel, Fischer–Tropsch (FT) diesel;
- second generation bioethanol produced from different types of lignocellulosic resources;
- synthetic natural gas (SNG).

Electricity:

Three types of RES-electricity have been analysed for 2010 and 2050:

- electricity produced from wind or hydro power: these two sources are treated together as they have virtually the same ecological and economic performance;
- electricity from photovoltaics (PV);
- electricity produced from biomass in combustion plants.

Hydrogen:

Three types of hydrogen have been analysed for 2010 and 2050:

- hydrogen produced from wind or hydro power by electrolysis: again these two sources are treated together as their ecological and economic performance is virtually identic;
- hydrogen produced from PV by electrolysis;
- hydrogen from biomass produced by means of steam reforming.

Currently the most common fuel for cars in Europe is gasoline. However, over the last two decades there has been a continued increase in the use of diesel. Diesel vehicles shown a higher engine efficiency and hence lower CO_2 emissions as reported in literature, e.g. Refs. [11,12]. However, the differences between gasoline and diesel are negligible with regard to economic, ecological and energetic considerations of renewable fuels and alternative automotive technologies. Since the major focus of this paper is on renewable fuels, gasoline has been selected as the comparison fuel.

2. Environmental and energetic assessment

The environmental and energetic assessment in this paper is based on the Life Cycle Assessment (LCA) method. Since the future use of renewable fuels depends on the key features of the energy service provided, the WTW analysis of the complete energy chain is given in addition to WTT analysis of fuels. The calculation of WTW CO_2 emissions is based on the following equation:

$$WTW = WTT + TTW \tag{1}$$

CO_2 emissions from biomass used for energy service are balanced zero according to IPCC [13] guidelines. This is based on the assumption that the balance of net CO_2 fixation of biomass by photosynthesis and the CO_2 emissions during production and conversion of the fuel is zero. In LCA, CO_2-fixation is considered as negative CO_2 emission during agricultural production. Carbon losses in fuel production processes (e.g. carbon in press cake from rapeseed pressing) are accounted for biogenic CO_2 emissions [14]. The LCA was performed in the scope of the project ALTETRÄ with the Global Emission Model of Integrated Systems (GEMIS), version 4.5 [15]. The cumulated primary energy demand (E_{WTW}) has been divided in total fossil energy (E_{FE}) and renewable energy (E_{RE}) demand:

$$E_{WTW} = E_{RE} + E_{FE} \tag{2}$$

This energy demand includes all energy input which is needed to deliver fuel to cars as well as the energy needed for car production and scrappage.

2.1. Greenhouse gas emissions

Fig. 2 shows the WTW CO_2 emissions of different renewable fuels compared to a conventional mobility chain with a gasoline fuelled internal combustion engine (ICE) vehicle which has been chosen as a reference system.

As seen in Fig. 2 all renewable fuels have lower WTW emissions per km driven compared to the fossil reference system. However, the results are very different depending on the fuel as well as on the primary energy sources used for the fuel's production.

The fuels analysed have been divided in three groups: biofuels, electricity and hydrogen.

Biomass-based fuels generally have negative WTT emissions, due to CO_2 fixation during photosynthesis. Negative WTT emissions are also related to non-energy co-products of the renewable fuels system which are used instead of conventional products and thus avoid related GHG emissions. Another contribution to WTT emissions are processes providing auxiliary energy and materials in biofuel production facilities. Relatively high WTT emissions for bioethanol production from wheat result mainly from the electricity and process heat required in the ethanol plant and its distillation unit [14].

WTT emissions of electricity from hydro and wind power are very similar and hence have been analysed jointly. Electricity from PV has higher WTT emissions due to the more energy-intensive production process of PV modules as well as relatively low

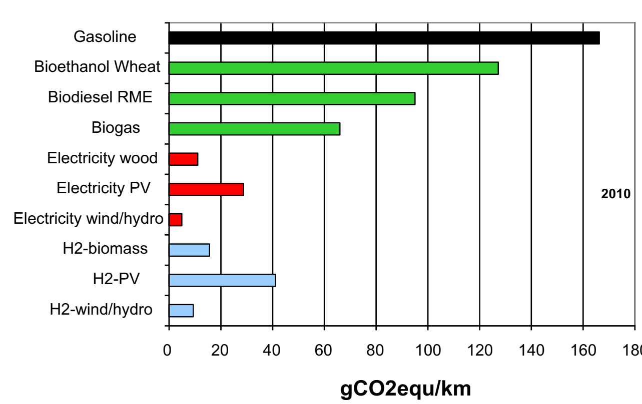

Fig. 2. Comparison of specific WTW CO_2 emissions in 2010 [14].