The ‘Renewables’ Challenge - Biofuels vs. Electric Mobility

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Summary

Electric vehicles are considered as a key technology for sustainable transport. The use of biofuels in vehicles with conventional combustion engines, however, also offers the possibility for a substantial reduction of greenhouse gas emissions, without requiring costly batteries and long charging times and without significantly limiting the driving range. A comparison of environmental impacts between both options needs to be based on a life cycle perspective. First screening results presented in this paper show that a diesel car fuelled with RME has considerably lower climate impacts than a comparable battery electric vehicle charged with average German electricity. On the other hand, the use of RME has disadvantages in other impacts categories such as eutrophication. Battery electric vehicles charged with renewable electricity in turn have the best climate impact balance of the considered options and also show among the lowest impacts in eutrophication. However, other biofuels such as palm oil and the use of biomass residues offer further reduction potentials, but possibly face limited resources and land use changes.

1. Introduction

Mobility is an important basis for many economic and private activities and thus a crucial part of our life. In many industrialised countries, the demand for mobility is mostly covered by motorised road transport. Modern vehicles and a well developed network of roads allow for a high degree of individual mobility. However, this mobility also leads to substantial environmental problems: In 2007, transport was responsible for 18% of the direct CO_2 emissions in Germany [1]. The majority of these emissions are due to road traffic, which in turn is dominated by passenger cars. CO_2 emissions from road traffic and especially passenger cars are slightly decreasing in Germany since about 2000 [2]. But the consumption of fossil resources by road traffic still faces limited resources and leads to political dependencies.

Electric vehicles are therefore embraced as a key technology for sustainable transport: Hybrids are already established and regarded as the new clean vehicles. Improvements in battery technology and reduction of prices may soon also lead to the penetration of full electric vehicles into the market. Electric vehicles have quiet engines, are locally emission free and allow for the use of many (also renewable) energy sources in road traffic which so far could not be used. The German Federal Government has therefore set the target of one million electric vehicles in Germany by 2020.

On the other hand, the use of biofuels in vehicles with conventional combustion engines also offers the possibility for a substantial reduction of greenhouse gas (GHG) emissions, without requiring costly batteries, long charging times and without reducing the driving range compared to conventional vehicles. Biofuels for transport are generally considered to be environmentally friendly since they save fossil energy resources, are biodegradable and – at least at first glance – CO_2 neutral. The latter is of course only true for the direct combustion of biofuels which releases the same amount of CO_2 into the atmosphere that earlier has been captured by the plants.

In order to promote the penetration of biofuels into the market, the EU Biofuels Directive (2003/30/EC) [3] set an energy based biofuel target of 5.75% of all fuels brought onto market to be reached in 2010. In Germany, this target first was accompanied by a tax exemption, made possible by Directive [2003/96/EC] [4]. In 2007, however, the ‘German Biofuel Quota Act’ [5] set mandatory quotas to be reached by the petroleum industry and implemented a gradual taxation of biofuels. In 2009, the EU Biofuels Directive was replaced by the Renewable Energy Directive (2009/28/EC) [6] which sets an energy based target of 10% renewable energy in the transport sector to be reached in 2020. Biofuels can contribute to this target by either being blended into conventional gasoline or diesel fuel or by being separately sold.

The development of biofuel volumes and shares in Germany [2] (see Fig. 1) shows a sharp increase until 2007, but then a slight decline in 2008, which can be mainly attributed to the German Biofuel Quota Act. The majority (75% energy based) of the biofuels in 2008 has been biodiesel, 13% bioethanol and 12% vegetable oil. In 2009, about 3.5 million tonnes of biofuels have been brought on the German market, which translates to 5.5% of all fuels [7]. Currently about 65% of the biodiesel in Germany is rapeseed methyl ester (RME) [8].

Though the combustion of these biofuels can be regarded as CO_2 neutral, substantial amounts of (fossil) energy resources are used when looking at the entire life cycle of biofuels: from biomass cultivation (including the input of fertilizers, pesticides etc.) through conversion into biofuels and their energetic use. This in turn causes GHG emissions, so that biofuels are not CO_2 neutral from a life-cycle point of view. The same holds true for other potential environmental impacts.

In order to improve the environmental profile of road traffic, all advantages and disadvantages of renewable electricity and biofuels have to be identified in a life-cycle perspective and addressed at an early stage. Previous IFEU analyses ([9], [10]) have already shown that electric vehicles need to be charged with renewable electricity in order to gain a significant advantage in the GHG balance over vehicles with conventional combustion engines using fossil fuels. This paper presents first results which also includes conventional vehicles fuelled with RME, based on [11] with allocation on calorific value.

Afterwards, the GHG balances of other biofuel options are compared to electric vehicles. These fuels offer further prospects in terms of GHG reductions. Nevertheless, biofuel cultivation faces competing land uses and the life-cycle balance can be significantly affected by potential land use changes. These issues are discussed at the end of this paper.

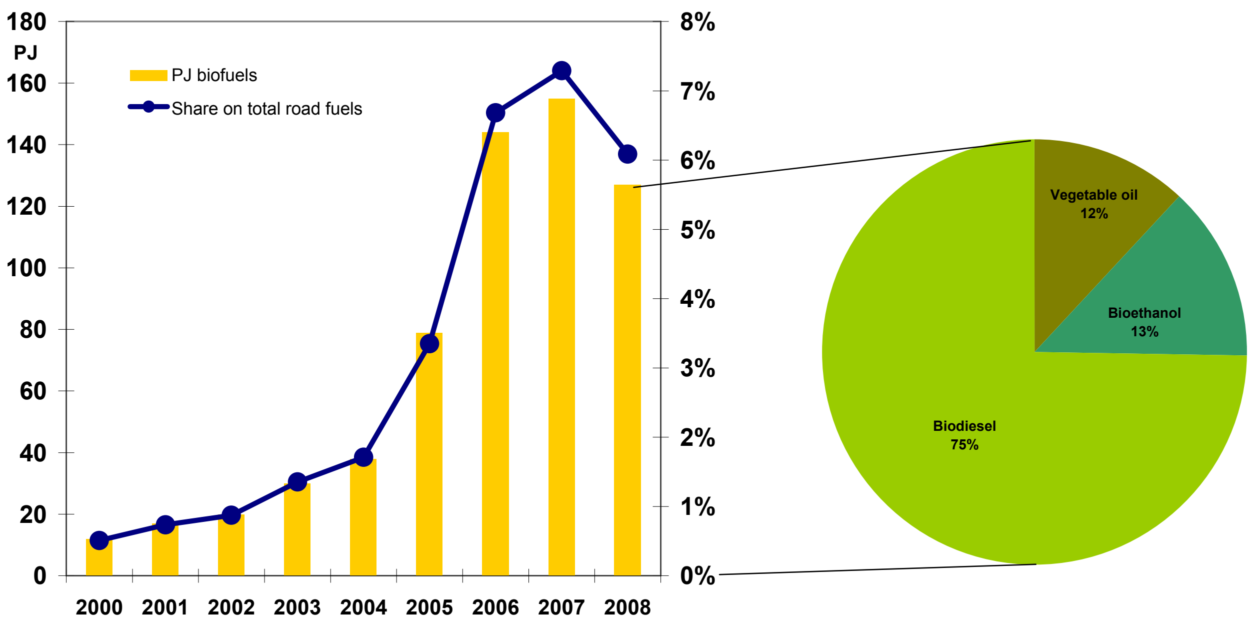

Fig. 1: Development of the biofuels in Germany [2]

2. Scope of the life-cycle analysis

For a comprehensive comparison of different vehicles and different energy carriers, the entire life-cycle of the vehicles needs to be considered. The screening results presented in this paper are therefore based on a comparative life-cycle perspective. That means that the environmental impacts of transport with combustion engine vehicles using fossil fuel or biofuel are compared to the environmental impacts of mobility with battery electric vehicles using different electricity splits. The modelling is undertaken with eLCAr (Electric Car LCA), an LCA model for electric vehicles which is currently being developed by IFEU based on the software UMBERTO.

Functional unit is the vehicle-km of a compact car (VW Golf type) with average characteristics (see [10]), a life-time mileage of 150’000km and a roughly average use pattern of 30% urban, 40% extra urban and 30% highway driving. 1.5 batteries are assumed to be used during the vehicle life-time. The geographical reference is Germany; the represented timeframe is the current to mid-term situation (until 2015).

Vehicle production is based on data from Volkswagen, UBA [12] and IFEU expert judgement. For battery production, besides generic material data from Ecoin-

vent [13], also primary data from different leading battery manufacturers has been used.
Electric vehicle electricity consumption is based on detailed modelling documented in [10]. The fuel consumption of the reference vehicle is also modelled based on energy demand at the wheel complemented by tank-to-wheel efficiencies of the PHEM-model of TU-Graz, which is also used for the Handbook Emission Factors [14]. It is assumed that Euro 6 vehicles suitable for use of 100% RME will be available in the considered time-frame (until 2015). The emissions are thus calculated based on the emission factors for average Euro 6 gasoline and diesel cars in the Handbook Emission Factors [14]. The emission behaviour with RME is assumed to be the same as with fossil diesel.

3. Life-cycle results: RME vs. electric mobility

Life-cycle results based on the data and assumptions described above show that per km GHG emissions of a battery electric vehicle (BEV) charged with average German electricity (2009), are about comparable to the vehicles with conventional combustion engines using fossil fuels. The higher climate impacts from vehicle production due to battery production are somewhat compensated by lower CO_2 emissions associated with the used electricity.

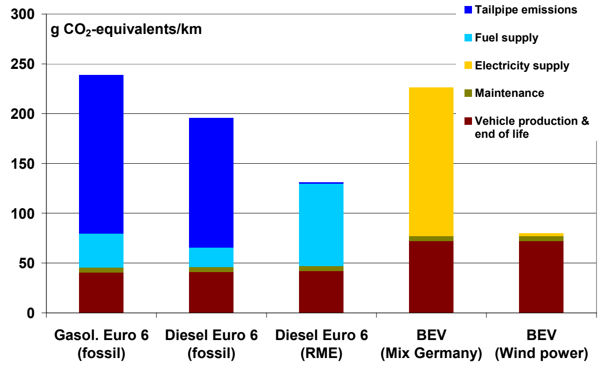

Fig. 2: Greenhouse gas emissions per km

Compared to the BEV charged with average German electricity, the climate impact of cars with 100% fossil gasoline are slightly higher and for cars with 100% fossil diesel slightly lower. The reference diesel car with RME, however, shows considerably lower climate impacts than the BEV charged with average German electricity. This is due to the fact that the direct combustion of RME releases the same amount of CO_2 into the atmosphere that earlier has been taken up by the rapeseed plants. The small amount of direct GHG emissions is due to CH_4 and N_2O tailpipe emissions. The higher climate impact from the production, processing and distribution of RME, however, compensates much of this advantage.
On the other hand, BEVs charged with electricity from renewable sources, such as wind power, demonstrate even lower climate impacts (80 g CO_2 equivalents per km instead of 131 g per km for RME). In this comparison, the BEV charged with renewable electricity, is clearly the most favourable option from the perspective of climate impacts.
For a more complete comparative picture, however, other impact categories also need to be considered. Fig. 3 shows for instance, that the use of RME leads to much higher eutrophication. This is mainly due to agricultural processes. The use of RME also has disadvantages compared to fossil diesel fuel in other impact categories such as acidification.

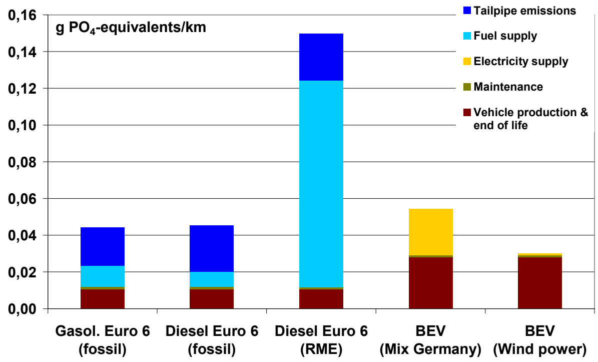

Fig. 3: Terrestrial eutrophication per km

The presented results thus show an inconsistent pattern - especially for RME which has a lower climate impact than most other options, but leads to higher eutrophication. RME can thus only be labelled as ecological advantageous compared to fossil fuels if climate protection is considered as more important than other environmental impacts.
Among the considered options, battery electric vehicles charged with additional renewable electricity show the most straightforward environmental balance: They have the best climate impact balance and also show the lowest impacts in eutrophication. However, other biofuel options offer the possibility for further GHG reductions. This further potential of biofuels will be demonstrated in the following section.

4. Prospects: Climate impacts of other biofuels

Since biofuels are regarded as carbon neutral (as far as the combustion is concerned), impacts from agricultural production and further processing of biomass play an important role in their life-cycle GHG balance. These differ considerably between different types of biomass and production processes. In order to foster good practice as well as to rule out biofuels associated with especially high climate impacts, the Renewable Energy Directive (2009/28/EC) [6] specifies criteria for sustainable biofuels.
The directive also states typical values for life-cycle GHG reductions for a range of different biofuels. These values can be used for a **first evaluation** of the potential climate benefit of different biofuels compared to the use of fossil fuels. Such an overview of life-cycle GHG emissions of selected biofuels is presented in Fig. 4. The underlying data and scope definitions of

the conventional vehicles with fossil fuels and the battery electric vehicle are the same as in the preceding section.
The variations in GHG emissions are considerable and demonstrate how important not only the question of the biofuel shares, but also of the biofuel type and production process will be with increasing biofuel amounts (blended or pure) in the future. Both have a considerable effect on the overall effect of biofuels on road transport climate impacts.

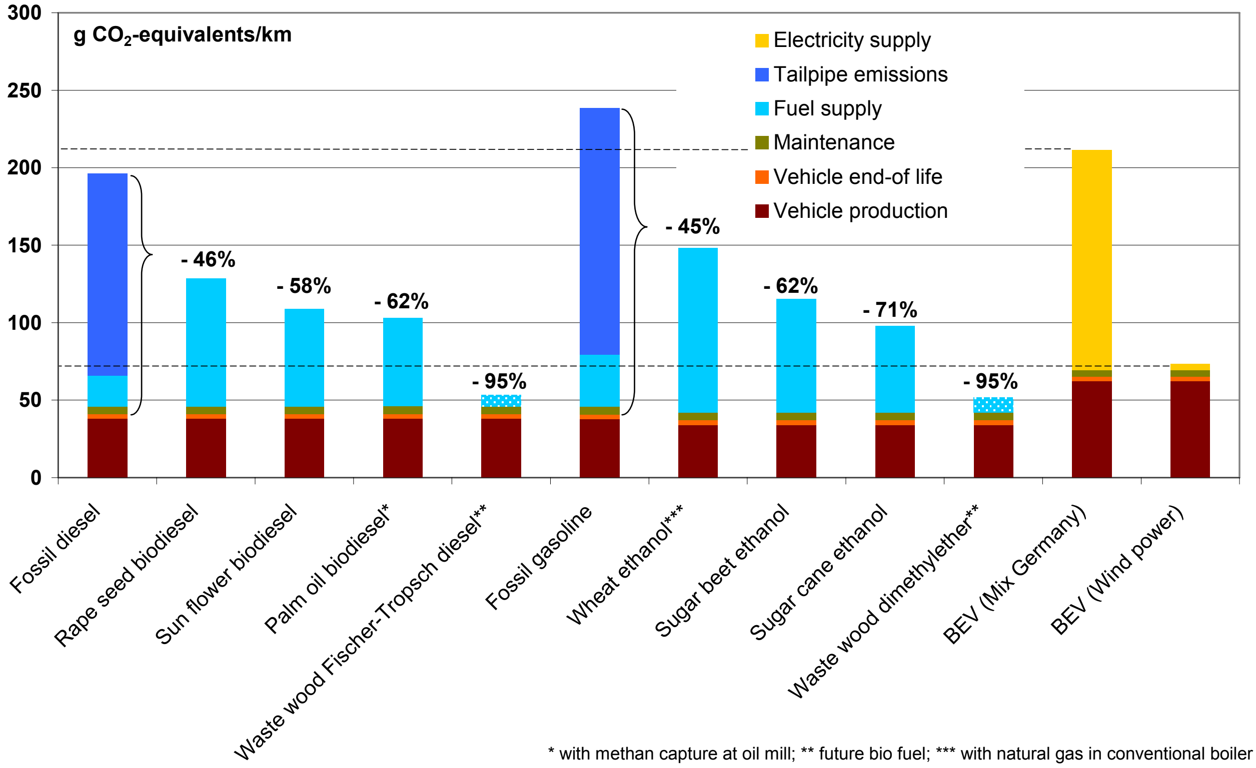

Fig. 4: Life-cycle GHG-emissions of vehicles with different energy carriers (scope and data as described in section 2; GHG-reductions of biofuels based on standard values in [6])

Further reductions in GHG emissions in comparison to fossil diesel can be achieved by the use of sunflower or palm oil biodiesel. Fossil gasoline, on the other hand, can be substituted by wheat ethanol with GHG reductions comparable to RME. Further reductions compared to fossil gasoline can be achieved by using sugar beet or sugar cane ethanol.
Life-cycle GHG emissions for a mobility with these biofuel options are nevertheless higher than for battery electric mobility with renewable electricity. Only biofuels based on biomass residues, such as waste wood, may lead to lower climate impacts since the expenditures for residue collection are much lower than for production of dedicated crops, but the availability of such biomass residues - which are not yet used otherwise - is limited.
Besides the further potential for GHG reductions outlined in this section, other issues have to be considered. Cultivated biomass faces competing land uses such as food production and nature conservation. Furthermore, biomass cultivation for biofuels may lead to land use changes which are associated with environmental impacts and nature conservation issues. Both aspects are discussed in the following section.

5. Further issues: Competing land uses and land use change

The possibility for a substitution of fossil fuels by biofuels is limited mainly by the availability of suitable biomass. Today, mainly cultivated biomass is used for biofuel production. If future biofuel targets are to be achieved with biofuels from cultivated biomass, large land areas are needed. On the other hand, land area is also needed for food production and the realisation of other sustainability target such as an expansion of organic farming or nature conservation.
Furthermore, besides for transportation, biomass is also needed for the production of “green electricity” and “green heat” as well as in other areas. Thus, in addition to competing land uses, which limit the available land area for biomass production, also competing biomass uses limit the available biomass for transportation biofuels.
Furthermore it has to be mentioned that the above results do not take into account GHG emissions from land-use changes. Land-use changes ultimately lead to changes in the carbon stock of above- and below-ground biomass, soil organic carbon, litter and dead wood. Depending on the previous vegetation and on

the crop to be established these changes can be neutral, positive or negative. A distinction is made between direct and indirect land-use change.
Direct land-use changes occur, if natural ecosystems (e.g. forest land) are converted into agricultural land (e.g. an oil palm plantation). Indirect land-use changes arise if agricultural land currently used for food or feed production is used for bioenergy crop cultivation and the food and feed production is displaced to another area where again unfavourable (direct) land-use changes might occur. This phenomenon is also called leakage effect or displacement.
In the 1990s, set-aside land was readily available for bioenergy crop cultivation in the EU, so there was no need to use the basic agricultural land (i.e. where food and feed production took place) nor to convert natural ecosystems such as forests into agricultural land. If set-aside land is transformed, the carbon stock does not change significantly since it remains agricultural land (not subject to natural succession). The carbon stock change is therefore set to zero.
This situation changed with biofuel targets increasing the pressure on both agricultural land in Europe and natural ecosystems elsewhere in the world. The first GHG balance studies to account for GHG emissions due to (direct) land-use change from natural forest to oil palm plantation were published by WWF [15] and Reinhardt et al. [16] showing that GHG balances of palm oil biodiesel could even turn out negative, i.e. that the use of palm-oil biodiesel could cause higher life cycle GHG emissions than the use of conventional diesel fuel.
While direct land use changes are already well recognised and considered in the renewable energies directive, indirect land use changes are still discussed controversially.

6. Conclusions

The results in this paper show that neither biofuel nor electric mobility is the silver bullet for sustainable road transportation. Modern Euro-6 vehicles have achieved a very low level in pollutant emissions and - with biofuels - allow for considerable GHG reductions without requiring costly batteries and an additional charging infrastructure. The production of biofuels, however, leads to higher life-cycle eutrophication and also acidification than the other options. Furthermore, issues such as competing land uses and land use change have to be considered, especially with increasing biofuel shares in the future.
On the other hand, electric vehicles offer the possibility for the use of many other renewable energy sources, which so far could not be used in road transport. This not only reduces political dependencies, but also offers the possibility to reduce GHG emissions associated with vehicle use to almost zero. Furthermore, much less land area is required for the generation of renewable electricity (e.g. wind or solar power) compared to biomass cultivation. The driving range of electric vehicles, however, is still limited and costs of batteries are still high. Furthermore, renewable energy systems should only be credited to electric vehicles, if they are truly additional to the systems which are built based on the already existing legislation.
The GHG balance of electric vehicles with such additional renewable electricity is better than for most biofuel options, even if additional impacts from battery production are taken into account. Furthermore, renewable electric mobility has low impacts in other categories such as eutrophication.
Considering that the development and production of electric vehicles is only in its initial stage, a further reduction of production impacts due to improvements in energy density and durability of batteries and their large scale production should be considered. Modern Euro-6 passenger cars in contrast, already represent a very well developed technological standard.
But also these vehicles will become more fuel efficient in the future, among other factors due to the introduction and further tightening of CO_2 emissions standards by the European Union. Electric vehicles will have to further improve to keep up with efficiency improvements of conventional vehicles. Such improvements are of importance, since vehicles with conventional combustion engines can be assumed to continue dominating the vehicle fleet in the next 10 to 20 years.
Future efforts should thus also be directed towards more energy efficient vehicles. This also applies if renewable energy is used, because renewable energy still is a limited good and should not be lightly wasted - be it in vehicles with combustion or with electric engines.

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