Potential and benefits of carbon abatement by ethanol use in Hungary

Prepared for Pannonia Ethanol Zrt.

Authors

Gábor BALÁS
Gábor BARTUS, PhD
Gábor KISS
Ágnes SZABÓ-MORVAI

Budapest, September 2014

HÉTFA Research Institute
„Knowledge You Can Use"
Hungary – 1051 Budapest, Október 6. Street 19. IV/2.
Contact: info@hetfa.hu
Phone: +36 30/730-6668
Fax: +36 1/700-2257
www.hetfa.hu

Executive Summary

While from 2000 to 2010 **greenhouse gas** (GHG) **emissions from the transport sector** stagnated in EU-27, they **increased by about 25% in Hungary,** and the transport sector accounted for 18% of total GHG emissions measured in Hungary in 2011. Based on the target set in the 2009/28/EC directive (RED) on the promotion of using energy from renewable sources, **the share of energy from renewable sources in the transport sector has to reach 10% in Hungary by 2020.** As it is shown in this study **this is not possible without the use of ethanol.**

Although several studies were prepared on the **carbon abatement cost of ethanol use**, the results **are very sensitive to country specific factors, thus this study focused** on carbon emissions from transport and the cost of using ethanol for carbon abatement **in Hungary**.

Our main conclusion is that despite the European-wide turbulent discussion on the CO_2 mitigation potential of bioethanol use in transport, **bioethanol has a significant positive GHG emission reduction effect, and even with a conservative estimation the CO_2 mitigation cost of bioethanol based on Hungarian corn is cheaper than the other alternatives for the mitigation of GHG emissions in the transport sector**.

Therefore it is a beneficial policy goal in Hungary to set a higher mandatory target for ethanol blending in gasoline, which is equivalent to a general use of E10. It is worth noting that our conclusion on ethanol use – and boosting ethanol use – is in line with relevant current Hungarian policies, strategies and plans, such as the New Széchenyi Plan or the National Energy Strategy.

How important is ethanol in the reduction of CO_2 emission of transport sector of Hungary? Our estimations predicted high CO_2 emissions for 2015 in all transport scenarios: 3155 thousand tons without and 2963 thousand tons with the introduction of the E10 blend. These are both scenarios that include a certain amount of ethanol blending; **CO_2 emissions are estimated to be 11.4% less in 2015 in the E10 scenario as opposed to a reference E0 scenario**. The reduction resulting from using E5 is half as large (189 thousand tons, 5.6%). **E10 could abate 382 thousand tons of CO_2 emissions per annum,** which is **equivalent of 3% of total transport GHG emissions** in 2011.

This reduction has a moderate cost even with a conservative estimation. Our calculation shows that **the CO_2 mitigation cost for society of bioethanol based on Hungarian corn and included engine energy efficiency effect is less than zero (-2 €/t CO_2eq instead of 84 €/CO_2eq without energy efficiency effect),** thus ethanol usage can be **a reasonable and viable choice** for further CO_2 reduction in the transport sector. This mitigation cost is fair and advantageous considering the following:

- the **social cost** of one ton of CO_2 emission, proposed by various economic analyses, varies between 16 and 676 Euros; and the European Commission has also used a carbon cost of 70–170 €/t CO_2eq based on the marginal abatement costs from sector targets,

- **other alternatives** for the mitigation of GHG emissions in the transport sector **have a higher costs:** battery electric and fuel cell vehicles have a technologies with significant, two to ten times higher costs.

Carbon Abatement Cost of Hungarian Ethanol					
€/t CO_{2e}	Hungarian estimation			Reference values	
	Based on EU prices and without engine energy efficiency effect	Based on Hungarian prices and without engine energy efficiency effect	Based on Hungarian prices and included engine energy efficiency effect*	European Commission's reference value on carbon abatement cost	GHG abatement cost by electric vehicles
without iLUC	123	84	-2	70–170	210-895 (current) 140-280 (in 2020)
with iLUC	162	111	-3**		

Note: * with 1.8% efficiency improvement based on Geringer et al [2014], with Hungarian market prices.
** Due to methodological reasons it is of no relevance how much negative the figure is. Any value in the negative territory is worth to invest for.

As the chart above shows, **efficiency gain is a crucial issue.** Based on the best available science we modeled a significant engine energy efficiency improvement and added to the business-as-usual methodology of carbon abatement cost estimation. Provided the additional 1.8% engine efficiency increase by the use of E10 blend, an impressive -2 €/t CO_2eq abatement cost is achieved in our calculations. Moreover it is a not country-specific factor, thus with 1.8% efficiency gain of E10 blend a zero close abatement cost is probably also achievable in other European countries. **It would be useful to have more research emphasis on the effect of ethanol on engines' energy efficiency.**

These estimates for Hungary are very conservative for two reasons.

First, beyond CO_2 abatement, **using ethanol has other socially beneficial effects**, like

- reducing energy import dependency,
- improving air quality (CO and hydrocarbons emissions), and
- positive employment and income effects

With respect to this last consideration, our previous analyses (see HÉTFA [2012]), suggest that the impact of E10 in Hungary would be in the thousands of jobs and hundreds of millions of Euros. Although these effects are not calculated in this study, they would also **contribute to the social benefit of increased use of ethanol**.

Second, the CO_2 abatement cost is very sensitive to prices and technological change. **If the price of conventional fossil fuels grows further – as it is expected -, the future social cost-benefit ratio of GHG abatement by ethanol will be more favorable.** Similarly the technology improvements in ethanol plants (as it is a relatively young industry), the increase of feedstock yields and the greening of farming (reduced tillage, using perennial crops, sustainable intensification, etc.) are the strongest effects that result in a further decrease of carbon mitigation costs by ethanol.

Table of contents

Introduction

Context

Although several studies were prepared on carbon abatement cost of ethanol use, the results are very sensitive to country specific factors, such as local production of fuel and ethanol, alternative use of agriculture land, characteristics of the set of cars in the country and local habits in car use or country-specific potentials for alternative measures of carbon abatement.

This study will focus on carbon emissions from transport and the cost of using ethanol for carbon abatement in Hungary.

Based on various assessments between 2005 and 2011 in different EU countries significant GHG savings have occurred: 4% to 15% (as the percentage of the total emissions) when shifting from conventional gasoline to E10, from 12% to 96% with E85, and from 46% to 90% with E100 [Li Borrion – McManus – Hammond, 2012].

The market of biofuels is regulatory-driven. The European Union promotes ethanol (and other types of biofuel) use through mandatory targets. First, the 2003/30/EC Directive set a non-binding target of 2% substitution of conventional transport fuels by biofuels by 2005 and a further 5.75% substitution by 2010. Under the 2009 EC Renewable Energy Directive (RED), **10% of all transport energy must come from renewable sources by 2020**. The EU target was officially aimed at reducing greenhouse gas (GHG) emissions from transport fuel. (Regarding regulations in other continents see Sorda – Banse – Kemfert [2010]).

Because of different measures of Hungarian Government a higher share of renewables is expected in the total final net consumption in the transport sector. The projected change in the composition of renewables includes a higher share of bioethanol (see Table 1).

Table 1 Projected composition of renewables in the total renewable final net energy consumption in the transport sector

	2010	2020
Bioethanol/bio-ETBE	22.7%	35.3%
Biodiesel	73.3%	59.3%
Hydrogen from renewables	0.0%	0.0%
Renewable electric power	4.0%	4.5%
Other (biogas in public transport)	0.0%	0.9%

Source: REKK [2014]

Questions and focus

The Study is based on a benchmark analysis of existing international and Hungarian studies supplemented with expert interviews and the analysis of statistical data, focusing on the question **what the marginal abatement cost of increasing ethanol use in transport sector is under the current transport habits, car composition and price.**

The Study consists of two parts: a static analysis of existing circumstances and the examination of three short- or mid-term future scenarios: (0) E0 as a baseline, (i) E5 remains a blending standard (business-as-usual scenario), and (ii) expanding ethanol use with E10.

The Study calculates not only the direct effect of ethanol use, but takes indirect land use change (iLUC) into account as well. Effects of long-run changes in agricultural practices are excluded from our calculation, but the relevant research results are summarized in the literature overview (in order to indicate the possible further changes in the efficiency of ethanol use in GHG emissions reduction).

To sum up, the focus of the estimation:

- general overview of emission trends and current carbon abatement costs across various sectors in Hungary,
- calculating marginal abatement cost of measure in the present and short- or mid-term,
- taking into account both direct and social (external) costs and benefits,
- focusing on transport sector
- scenarios in calculation: (i) business-as-usual, i.e. 5% ethanol use in fuel, (ii) 5% increase of ethanol blending to gasoline as opposed to current level in transport sector, and (iii) E0 as a theoretical baseline for calculation of GHG abatement by ethanol use.
- factors taken into account (and used in sensitivity analyses) in the model:
    - fuel and ethanol price,
    - iLUC, and
    - fuel efficiency data.

General introduction to the carbon abatement economy and the methodology of the analysis

Price of carbon emissions

The social optimal price of one ton of CO_2 emission, proposed by various economic analyses, varies between 16 and 676 Euros. The European Commission has also used a carbon cost of 70–170 €/t CO_2eq based on the marginal abatement costs from sector specific targets in the first decade of 2000's.

Table 2 Unweighted estimates of the Social Cost of Carbon (measured in 1995 dollars per metric tonne of carbon (USD$/tC))

	All	**Pure rate of time preference (Discount rate)**		
		0%	**1%**	**3%**
Mean	105	232	85	18
Standard Deviation	243	434	142	20
Mode	13	–	–	–
33rd percentile	16	58	24	8
Median	29	85	46	14
67th percentile	67	170	69	21
90th percentile	243	500	145	40
95th percentile	360	590	268	45
99th percentile	1500	–	–	–
Number of estimates (N)	232	38	50	66

Source: Tol [2009]

The market (EU-ETS) price of one ton of CO_2 emission was 12.60 Euros in Europe in 2010 and dropped to 6 Euros in 2014. In the last decade the highest price was approximately 20 Euros in 2008. It is clear, that the regulation of the European Union was not able to realize the Social Benefits of GHG mitigation in the market prices. The governments of Europe were not able to cope with the problem of the huge external social cost. Therefore it is important to judge the efficiency or rationale of a given GHG abatement alternative not only based on market prices, but rather in the light of Social Cost of Carbon.

Methodology

There are three main GHG methodologies (RED, RTFO and PAS2050) that may potentially be applied to biofuel production. Each has a different approach to measure GHG emissions from biofuel production, and each provides a different result, causing difficulties for policy makers [Whittaker – McManus – Hammond, 2011]. Based on this study we will follow the rules of RED methodology, which is constructed to support the implementation of EU Directive on Renewable Energy (2009/28/EC).

Our Study is based on a benchmark analysis of existing international and Hungarian studies supplemented with expert interviews and statistical data analyses. The estimation consists of the following phases:

- setting up a simple model of carbon abatement,
- collecting general parameter estimates in the literature,
- testing the logic and assumptions of the model and adjusting the parameters to Hungary using expert survey,
- calibrating the missing parameters of the model, using data analyses on statistical data sets and filling the gaps from expert survey,
- estimation of results and sensitivity analyses of key parameters.

The estimation is based on the following assumptions and suffers from the following limitations. In this static model

- international transit transport effects are not taken into account,
- habits in transportation are stable in time (length of travel and means of transport),
- there is no long run adaptation effects, thus
  - GDP is fixed,
  - investment cost and amortization (sets of vehicle) do not change, and
  - demand for transport is stable with measures.

While this Study provides robust answer to the question, its numbers can be more or less indicative, as it heavily depends on the quality and comparability of available benchmark information. However we have tried to offer more precise country specific data and information through a few short interviews of experts.

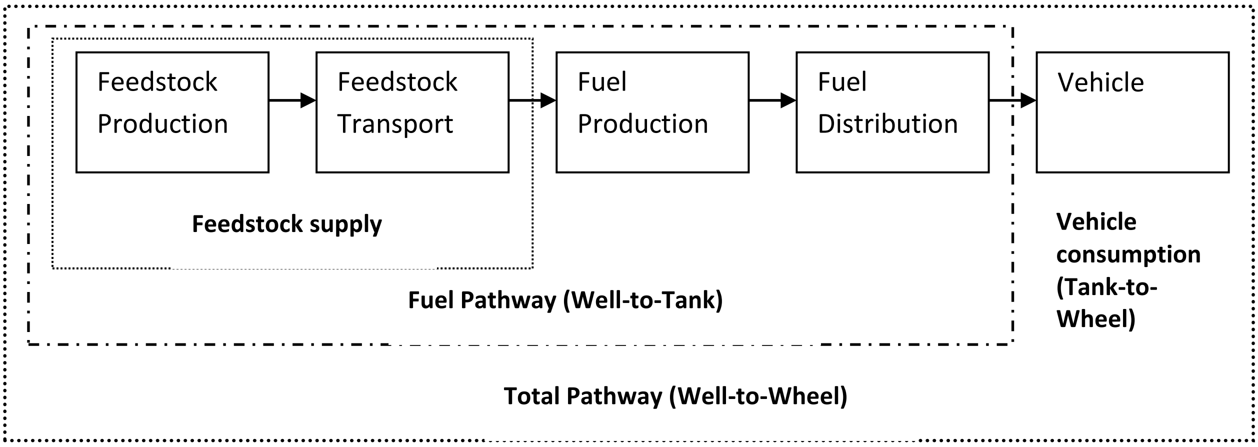


Fig. 1 **The structure of the standardization transport model (STM)**
Source: El-Houjeiri – Field [2012]

As seen in Figure 1 a standardization transport model (STM) chain can be established. The five parts of the chain are summed up into two linked energy stages:

- Well-to-Tank chain, which aggregates the production and distribution of fuels, and

- Tank-to-Wheel chain, which includes the vehicle operations.

The aim of our Study is to collect the cost and GHG emissions data for each block through three scenarios:

Scenario #0 (reference or E0): transport fuel use without ethanol (100% gasoline)

Scenario #1 (business-as-usual or E5): blended fuel with 5% ethanol content

Scenario #2 (one-step-forward or E10): blended fuel with 10% ethanol content

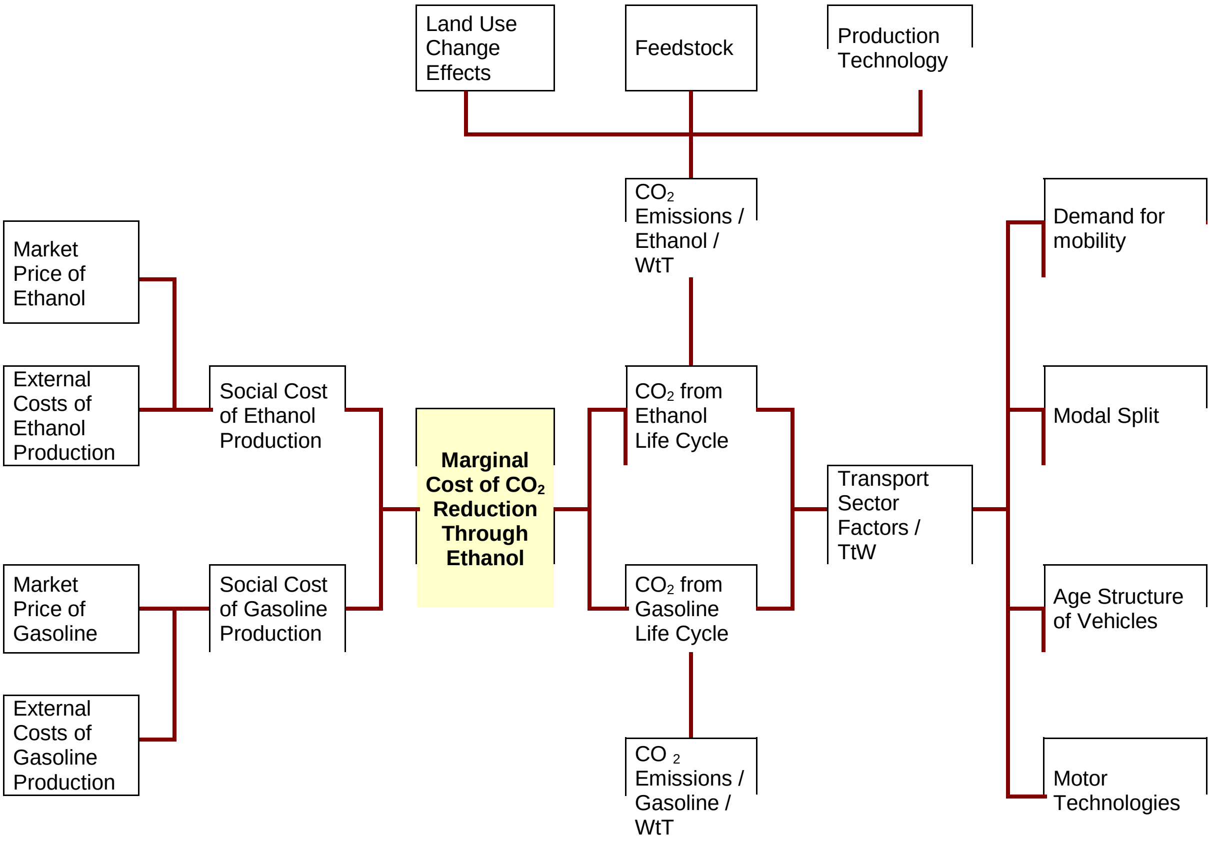


Fig. 2 The structure of calculation method

After some interview of experts, finally we decided to summarize the effects of Modal Split, Age Structure of Vehicles and Motor Technologies into one factor of Gasoline Demand. The reason of this change in calculation method was the lack of data regarding the above-mentioned factors, but we were able to collect different projections for the future gasoline consumption pathway.

A detailed overview of the life cycle of ethanol as a transport fuel was given by von Blottnitz – Curran [2007] and Mizsey – Racz [2010]. For a detailed overview of life cycle analysis for GHG emissions, see Reijnders – Huijbregts [2007].

Well to tank:
Introduction of the ethanol industry in general and in Hungary

Summary of previous studies

Trends of ethanol production in Europe

In 2008 from the total world production of biofuels bioethanol represented 75%. In contrast, in Europe biodiesel accounted for 79%. [Gnansounou, 2010] There is a clearly potential to increase ethanol use. An EU overview is given by Cansino – Pablo-Romero – Román – Yniguez [2012].

The ethanol production concentrated in 2008 in US and Brazil; these two countries produced 58 billion litres from the 65 billion litres total production. The EU27 counted only 2.7 billion litres. In 2013 the ethanol production has grown further: 51 billion litres in US, 23.5 billion litres in Brazil and 6.7 billion litres in the EU. [ePURE, 2014]

The production in Hungary were 30 million litres in 2007, 150 million litres in 2008 (*source: European Bioethanol Fuel Association*), 174 million litres in 2011 (*source: US Energy Information Administration*), and about 350-400 million litres in 2013 (*source: Pannonia Ethanol*).

There is an impressive dynamics in the field of ethanol production, which reflects the results of innovation of production technologies, of more competitive prices of ethanol and a good potential in carbon abatement.

Environmental impacts of ethanol production

In the last years the environmental effects of biofuels use were intensely criticized by various researchers and stakeholders. The criticisms were overviewed by Levidow [2013].

Despite all the political debates, **most of the scientific studies has shown a positive effect of bioethanol on GHG reduction. There is an emerging scientific consensus on the significant benefits of bioethanol.**

An early study was published on life cycle analysis of bioethanol use is by Larson [2006]. In recent years a lot of case studies were published for various countries. **The results highlighted the importance of regional factors of ethanol production and use.**

In the next few paragraph we will illustrate, that there is no one size fits all solution in biofuel production. Some of the articles are outdated, and the data used refer to other countries, therefore the quantitative results are not relevant for the current Hungarian situation. However the literature overview is important, as

- the different studies characterize various factors which are important in the evaluation of GHG mitigation costs in Hungary,
- the findings provide alternatives for further possible reductions of life-cycle emissions of ethanol production through agricultural technology improvement.

It is important to note, that not all findings are relevant for Hungary because of different climate, different technology and management culture of feedstock production, etc.

The GHG reduction potential, first of all, **depends on the climate and the type of feedstock**. For example, tropical sugarcane has an advantage in measures of avoided carbon emission, see Figure 3.

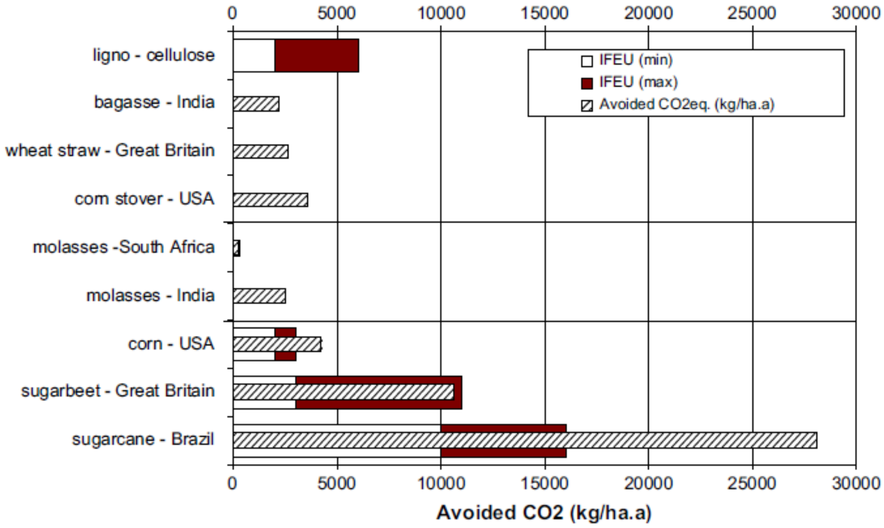


Fig. 3 **GHG reduction potential varies by climate and feedstock**
Source: von Blottnitz – Curran [2007]

In a case study for the United Kingdom Acquaye et al. [2012] characterize the **different GHG saving potential by the type of biomass** used for ethanol production. An analysis in Spain [Lechón et al, 2009] also stressed the importance of feedstock: the source of the cereal and vegetable oil influences the efficacy of the biofuels. El-Houjeiri – Field [2012] shows that the type of biomass feedstock for bioethanol production have a significant effect on the land use. Martinsen – Funk – Linssen [2010] also examined the different area requirements by various feedstock types for energy biomass.

Concerning the uncertainty in bioethanol GHG emissions calculation, results of Malca – Freire [2012] show that the most significant uncertainties arise in the cultivation stage (See Table 3).

Table 3 Uncertainty in ethanol GHG emissions

Type of input	Contribution to the variance
Soil carbon emissions	68,3%
Soil N_2O emissions	21,1%
GHG from N fertilizer production	2,4%
GHG from soy meal production	2,2%
Wheat yield	2,1%
N fertilizer app rate	1,8%
Other	2,1%

In line with these results, a French case study [Gabrielle et al., 2014] highlighted that **the N_2O emissions from energy crops are lower than expected.** In the most of cases a methodology based on fixed emission factors are used, while it is a most reasonable way to calculate based on regional factors. The ecosystem modeling by Gabrielle et al lead to 50-70% lower estimates for N_2O emissions of first-generation biofuels. Emissions of N_2O from soils are difficult to assess because they vary widely across time and space, depending on environmental conditions and agronomic characteristics such as crop management and fertilizer use efficiency. **The estimated values based on IPCC 2006 guidelines are significantly higher than CERES-EGC agro-ecosystem model used by French researchers**.

The total (more than GHG based) environmental impacts depend on mostly the management practices of farming [Fazio and Monti, 2011]. The cradle-to-farm gate impacts, i.e. including the upstream processes, may account for up to 95% of total environmental impacts. Therefore, increasing the sustainability of crop management through using agronomic inputs in a most effective way (i.e. sustainable intensification), or using crop residues complementarily can be expected to significantly improve the overall sustainability of biofuel chains. Perennial crops resulted in higher environmental benefits than annual crops: considerable amount of GHG emissions, up to 5 Mg/ha of fossil carbon, could be avoided with the cultivation of perennial crops.[1]

Further case studies were made in China [Tao – Yu – Wu, 2011], in the United Kingdom [Li Borrion – McManus – Hammond, 2012], in Denmark [Moller – Slento – Frederiksen, 2014] and in Brandenburg, Germany [de Vries – van de Ven – van Ittersum, 2014], also **stress the importance of country specific factors in agriculture for life-cycle analyses**.

Effects of direct land use change (LUC) were examined by Malca – Freire [2012] as well. Bioethanol use can cause different GHG emissions depending on what type of land use is to be converted to wheat or corn cultivation.

---

[1] According to industry interviews it is also true, that at the same time, as seed companies recognize that their customers may seek higher amounts of carbon sequestration, gains are being made in the carbon performance of annual crops to narrow this gap in climate performance.

Soil organic carbon is a key indicator of soil quality and degradation, as it directly affects soil properties such as productivity, nutrient recycling and general soil physical properties. Declining (oxidation) of soil organic carbon occurs after tillage operations; for example up to 15 kg of carbon is lost per hectare during mouldboard ploughing. **Residue incorporation and reduced tillage can lead to a build-up of soil organic carbon over time**. [Whittaker et al., 2014] Xue – Pang – Landis [2014] showed the importance of the different agricultural cultivation methods (the use of synthetic fertilizers versus manure), while Reijnders – Huijbregts [2007] also stressed the importance of agricultural practices in GHG emission.

Results by Fazio-Monti [2011] are in line with this data, cultivation practices account for 35-80% of total CO_2 emissions in case of annual crops, and 61-95% in case of perennial crops.

General conclusions from Mizsey – Racz [2010] were that automotive bioethanol production with first generation technologies has a modest efficiency, and there are better results if **co-products are fully utilized**. An evaluation of lingo-cellulosic ethanol production by Singh et al. [2010] underlined the importance of key factors such as feedstock type and use of residues/by-products.

So it is possible to characterize the significant factors of GHG emissions from ethanol production, in line with the different research papers.

The emissions of the current production or the alternatives for further improvement of carbon footprint depend on:

- **the feedstock type,**
- **fertilizers use and utilization rate of manure,**
- **agricultural technics and cultivation methods, like tillage, residue incorporation.**

The conclusion is, that is not possible to use life cycle analysis data of an analysis in one country without a specific evaluation to the other one. The relevant inputs for Hungary will be estimated in the next sub-chapter.

Our findings

Well-to-Tank Carbon Emissions

The calculations of the well-to-tank stage are based on BioGrace model[2], which is in line with EU RED. For a kind of validation of BioGrace model, we also used the evaluation theory of Mizsey – Racz [2010] and the underlying GHG calculation model, the EBAMM[3].

There are five main points of the ethanol production which may differ in Hungary from the benchmark data. These are: land use change factor, fertilizers and herbicides application rate, tillage, farm machinery usage and crop yield. These are the points in the process, which are adjusted in order to tailor the calculation to Hungary.

Land use change

The most important upper limit of the produced amount of first-generation bioethanol is the capacity of cropland areas of Hungary. GHG reduction turns negative if other than cropland is used for bioethanol feedstock production. Since the share of croplands is very high, namely 46.5% in Hungary (the half of the country's land is cropland), E10 blending target is easy to reach.

In order to calculate the land use change as a result of increasing the blending rate of ethanol, we assume that until the whole amount of ethanol presently produced in Hungary is used up, there is no need to increase the domestic production of ethanol. Even in case of 10% blending rate, the annual consumption of ethanol in Hungary (118.7 million litres) would be approximately third or quarter of the ethanol production (350-400 million litres). The current production did not induce an increase in land area devoted to corn production and the corn input needed is fulfilled by the Hungarian farmers. **As a result, we claim that the direct land use change is zero for the ethanol production, even in case of higher blending rates.**

However, it may be that the decreased corn export induces **indirect land use change** (iLUC) elsewhere. First, this is very hard to quantify exactly. In the scientific publications and in the policy papers the value of iLUC effect is too general (a global or continental average values) which might be far from the actual value in case of a given ethanol product. Second, the increase of ethanol production may use feedstock other than that otherwise exported. This is the case of Hungary, because of the dramatic fall of the numbers of domestic pigs, the main consumer of corn production.

As the definition of iLUC stated: 'When biofuels are produced on existing agricultural land, the demand for food and feed crops remains, and may lead to someone producing more food and feed somewhere else. This can imply land use change (by changing e.g. forest into agricultural

---

[2] http://www.biograce.net/content/ghgcalculationtools/recognisedtool/

[3] http://rael.berkeley.edu/sites/default/files/EBAMM/

land), which implies that a substantial amount of CO_2 emissions are released into the atmosphere.'

In the case of corn the feed issue is more important. (The corn based food is marginal: 90% of corn for feed, 7% for industry and 3% for food is the composition of corn usage in Hungary [*2002 data, agr.unideb.hu]*.) In Hungary the demand for feed is declining because of the shrinking animal population. In 2002 there were more than 5 million domestic pigs in the country, in 2013 less than 3 million.

And the food demand also decreased generally (not only for corn) in Hungary, see Central Statistical Office data: *http://www.ksh.hu/docs/hun/xstadat/xstadat_hosszu/elm14.html*

This is why **an important assumption of the iLUC definition is not fulfilled in this case of current Hungarian corn production**. Therefore we will calculate simultaneously two carbon emission data, one with iLUC effect, and one without iLUC.

For the option with iLUC we use the value of 12 gCO_{2e}/MJ, an average score of recent papers. (For example: IFPRI [2014] stated 13 gCO_{2e}/MJ, while Kloverpris – Mueller [2013] 11 gCO_{2e}/MJ.)

Fertilizer application rate

According to the data of the Research Institute of Agricultural Economics, of the overall 1454 thousand tons of fertilizer bought by domestic farmers the nitrogen content was 23.8% (346 thousand tons) in 2013. (see AKI [2013]) This number indicates the fertilizer usage habits of Hungarian farmers. On average, they use simple nitrogen fertilizers and only in a small fraction are complex fertilizers used. These habits are slowly changing (89 kg/ha in 2012 and 94 kg/ha in 2013) and robust from year to year, thus it is enough to use one year's data.

The amount of fertilizers used in a year is more volatile, thus we used the average of 9 years data for the calculation. The Central Statistical Office[4] published the annual county-level fertilizer application data, which was 469 kg/ha on average in Tolna and Baranya counties in the years 2003-2012. From these figures it can be calculated that the nitrogen application in these counties was approximately 94kg/ha.

According to EC statistics published in 2010 phosphorus application rate was 1.8 kg/ha, potassium application rate was 4.8 kg/ha in Hungary in 2006-2008. This is a much smaller amount compared to US and EU application rates. In the year of 2012 – according to Central Statistical Office 'KSH' [2013] – the use of phosphorus and potassium both were higher with 19 kg/ha and 22 kg/ha. These data illustrate a heavy volatility of the Hungarian fertilizers use, however these changes do not have a significant effects on the carbon abatement cost.

---

[4] http://statinfo.ksh.hu/Statinfo/haDetails.jsp?query=kshquery&lang=hu

Tillage

The greenhouse gas emission rate of corn production is reduced in case of no-tillage and minimum tillage farming compared to conventional farming technology. The source of the reduction is two-fold. First off, when tilled by machinery, the soil organic matter is broken down and the carbon is released to the air in the form of carbon-dioxide. Second, the farming machinery itself emits carbon-dioxide while using up gasoline. In the calculations, the second factor is taken into account. The KSH (2012) summary includes information about the share of farming techniques in Hungary. According to that, minimum tillage is used on 11.2% of the farming lands and no-tillage farming is prevalent on 1.2% of the farming area. (See Fig. 4)

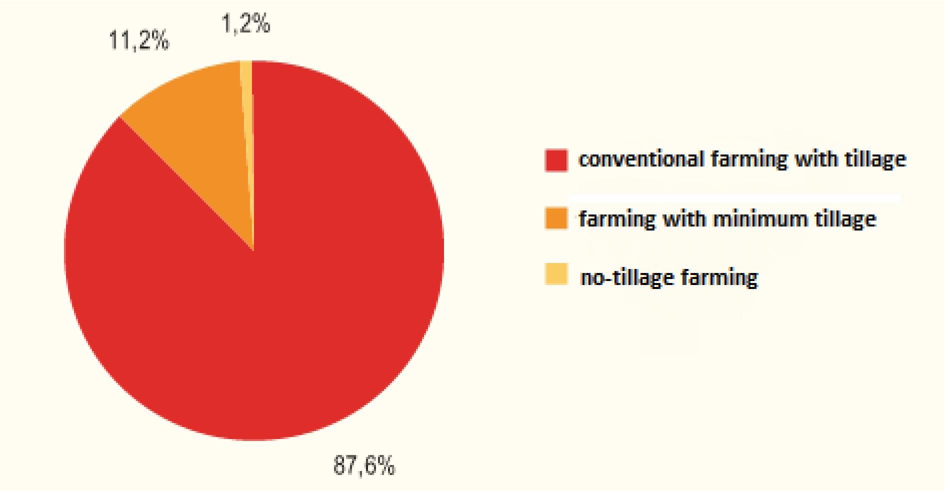


Fig. 4 **Share of farming techniques in Hungary**

Source: KSH [2012]

Farm machinery usage

Apart from no-tillage and minimum tillage techniques, the amount of farm machinery used to produce one kg corn differs by country. The diesel consumption is given in Table 4 below, the usage of Raba and MTZ are assumed which are typically used by Hungarian farmers.

In practice, some parts of the process may be omitted (for instance subsoil cultivation and medium disk harrowing), thus the diesel consumption may reduce to 104 liter/hectare. According to the experiments of Karcag Research Institute of the University of Debrecen CAS (see Forgács et al. [2006]) diesel usage of minimum tillage technique is 67% of the traditional farming technique and in case of no-tillage farming it is 25% of that. As a result, on average 97.3 liter/hectare diesel consumption is realistic in Hungarian average.

Table 4 **Fuel consumption in Hungarian farms**

Work phase	**Prime mover**	**Attachment**	**Diesel oil consumption (Liter/ha)**
Semi-deep subsoil cultivator	Rába tractor	subsoil cultivator	15
Plowing	Rába tractor	plow	45
Heavy disk harrowing	Rába tractor	heavy disk harrow	18
Medium disk harrowing	Rába tractor	medium disk harrow	14
Sowing	MTZ tractor	IH 6200 sowing machine	5
Fertilizer transportation	MTZ tractor	trailer	3
Fertilizing	MTZ tractor	spreader	4
Fertilizer transportation	MTZ tractor	trailer	3
Top-dressing	MTZ tractor	sprinkler	4
Chemical weed control	MTZ tractor	sprayer	3
Harvesting	TX62 combine harvester	-	18
Crop transportation	MTZ tractor	trailer	5
Total**			**137**

Source: Debrecen University, Crop Farming Technology Plan

Crop yield

The average corn crop yield is fairly volatile in Hungary. In the years 2003-2012 it was 5989 tons/ha.

Results

The agricultural phase of bioethanol production in Hungary is summarized in the following way. We have used the BioGrace model as a basis of our calculation. We used current Hungarian data which we have already described above, and gained a Hungary-specific benchmark.

BioGrace model is based on methodology of carbon calculation for UNFCCC, and strictly follow the methodology as given in Directives of 2009/28/EC and 2009/30/EC. In the BioGrace we have to calculate with crop yield, the used amount of four types of fertilizers (nitrogen, phosphorus, potassium and calcium), pesticide use, the diesel consumption of farm machinery, and the N_2O emissions from soil (which is a function of nitrogen fertilizer and manure use).

Table 5 GHG emissions in the feedstock (corn) production in Hungary based on BioGrace calculation model

	Agricultural phase sub-phases	Calculated CO_2 emission	Adjustment to Hungarian data	Adjusted value	Data source
		(kg CO_2e/ha)			
1	Nitrogen fertilizer	552.8	N Application rate (kg/ha)	94	AKI (2013)
2	Phosphorus fertilizer	12.7	P_2O_5 application rate (kg/ha)	19	Central Statistical Office, Hungary (2013)
3	Potassium fertilizer	19.2	K_2O application rate (kg/ha)	22	Central Statistical Office, Hungary (2013)
4	Lime	0	Marginal use, not measured in statistics in Hungary		
5	Herbicide	18.7	Herbicide application rate (kg/ha)	1.68	Central Statistical Office, Hungary (2011)
6	Field N_2O	580.2	N application as above, no manure used		
7	Diesel	304.5	Diesel (MJ/ha)	3474.8	Forgács et al. (2006) & Debrecen University
	Total Agricultural Phase	**1488.0**			
		(g CO_2e/ kg of corn)			
	Total Agricultural Phase	**248.45**	Crop yield (kg/ha)	5 989	Central Statistical Office, Hungary

The result of the BioGrace-calculation is that **in the agricultural phase of bioethanol production in Hungary the GHG emission is 248.45 g CO_2eq/kg of corn**. This includes CO_2, CH_4 and N_2O emissions as well. For the detailed calculation see Table 5.

It is important to note, that using findings by Gabrielle et al. [2014] about the overestimation of field N_2O emission by IPCC methodology the emission value is changing to 200 g CO_2e/kg of corn. (In this case we made a calculation with 50% overestimation factor – which is in the lower end of the scale of results by Gabrielle et al.)

We have used the EBAMM as well, where as a control method we applied as reference values the classical version (Shapouri-McAloon [2004]) of the calculations.

In the EC statistics (2010) is another calculation available for Hungary, which demonstrated a lower GHG emission rate, which is in part due to the narrower system boundaries, omitting for instance the manufacturing of farm machinery. Nevertheless, the details of the calculation and the model coefficients are not presented in EC 2010 statistics, thus it is not possible to detect the exact source of the difference.

In those cases, where the data of the EU statistics based on Hungarian Governmental data collection and those of current Hungarian scientific or research papers were different, we have chosen the latter ones.

In Table 6, the phases and inputs of corn production are listed and the relevant GHG emissions are calculated. The lines are explained here in detail using West and Marland [2002]. The fertilizers used for corn production, such as nitrogen (N), phosphorus (P), and potassium (K) and agricultural lime ($CaCO_3$) (Rows 1-4) generate CO_2 emissions because of the energy needed for their production (e.g. mineral extraction, fuel used for mining limestone, fertilizer manufacture, packaging), transportation and application. Pesticides (Rows 5-6) induce GHG emissions through their feedstock and the energy used for production. The CO_2 emissions of the farm machinery (Rows 9-13 and 15) are a consequence of the fuel used by farm machines and the energy consumed in manufacture, transportation, and repair of the machines. The irrigation (Row 14) also consumes energy, which increases CO_2 emission of the farming process.

The result of the EBAMM-calculation is that **in the agricultural phase of bioethanol production in Hungary the GHG emission is 269.3 g CO_2eq/kg of corn**. This model has given a 8.4% higher emission value than the BioGrace model. Because the model boundaries of the EBAMM calculation method are wider, the result is in line with the BioGrace-based calculation. For the detailed calculation see Table 6.

Table 6 GHG emissions in the feedstock (corn) production in Hungary calculated with EBAMM

		CO_2 emission data		Adjustments		
	Agricultural phase sub-phases	Reference (Shapouri-McAloon)	Calculation for Hungary (HÉTFA)	Adjustment to Hungarian data	Adjusted value	Data source
1	**Nitrogen fertilizer emissions + Field emissions (kg CO_2e/ha)**	1638	**1 029**	**N Application rate (kg/ha)**	**94**	**AKI [2013] & CSO**
2	**Phosphorus (kg CO_2e/ha)**	102	**13**	**P_2O_5 application rate (kg/ha)**	**19**	**Central Statistical Office, Hungary [2013]**
3	**Potassium (kg CO_2e/ha)**	70	**19**	**K_2O application rate (kg/ha)**	**22**	**Central Statistical Office, Hungary [2013]**
4	Lime (kg CO_2e/ha)	9	**0**	**Marginal use, not measured in statistics**		
5	**Herbicide (kg CO_2e/ha)**	69	**42**	**Herbicide application rate (kg/ha)**	**1.68**	**Central Statistical Office, Hungary [2011]**
6	Insecticide (kg CO_2e/ha)	5	5			
7	Seed (kg CO_2e/ha)	-	-			
8	**Transport emissions (kg CO_2e/ha)**	15	**0**	**Transport emissions calculated separately later, gasoline use is very rare in Hungary**		
9	**Gasoline (kg CO_2e/ha)**	114	**0**			
10	**Diesel (kg CO_2e/ha)**	248	**317**	**Diesel (MJ/ha)**	**3474.8**	**Forgács et al. [2006] & Debrecen University**
11	Nat Gas (kg CO_2e/ha)	46	46	No alteration between Hungarian data and benchmark value or no available data for Hungary		
12	LPG (kg CO_2e/ha)	61	61			
13	Electricity (kg CO_2e/ha)	56	56			
14	Energy used in irrigation (kg CO_2e/ha)	4	4			
15	Labor transportation (kg CO_2e/ha)	-	-			
15	Farm machinery (kg CO_2e/ha)	21	21			
16	CO2 from land use change (kg CO_2e/ha)	-	-			
	Total Agricultural Phase (kg CO_2e/ha)	2462	**1613**			
	Total Agricultural Phase (g CO_2e/kg of corn)	281.5	**269.3**	**Crop yield (kg/ha)**	**5 989**	**Central Statistical Office, Hungary**

The non-adjusted GHG values are equal to the values in the benchmark article Shapouri - McAloon [2004].
The adjusted values are highlighted with bold.

Summarizing the previous calculations and taking into account the emissions of the other phases of production, the CO_2 emissions of the bioethanol production (agricultural phase + transport of feedstock + ethanol production phase) are the following (Table 7).

Table 7 **Calculated GHG emissions values**

	g CO_2e/kg of corn	**%**	**source**
Corn production	248.4	52	our calculation (BioGrace)
Land use change	0	0	our estimation
Corn transport	5.5	1	data from producers
Ethanol production	225.6	47	data from producers
TOTAL	479.5		

Corn-based bioethanol is able to reach a greater GHG saving potential in Hungary than the European average because of the **very low – practically zero at the moment – land-use change effect (which is the consequence of the abundant cropland quantity)** and one of the lowest nitrogenous fertilizer use in Europe (Hungary: 94 kg/ha – European countries: from 30 to 147 kg/ha), **but the efficiency of feedstock supply is relatively low** for the time being. In the long term there is a potential to improve crop yields with a modest increase in fertilizer use. But with more effective machinery use and with greening the agriculture – which is an important policy goal of the EU – the GHG emissions per tons of feedstock values also could be lower in the future.

General introduction into transport industry

Summary of previous studies

Emissions from different car technologies

One of the most important paradoxes of the European and Hungarian climate policy, that under the provisions of the international climate change agreements, the EU has agreed to an absolute cap on GHG emissions; while, at the same time increased consumption of transport fuels has resulted in a trend of increasing GHG emissions from this source [Ryan – Convery – Ferreira, 2006]. Since 1990, the transport sector's CO_2 emissions worldwide have increased by 36% by 2007 since 1990, and transport GHG emissions accounted for close to 27% of total emissions [IEA World energy outlook 2009]. See also: [Ajanovic – Haas, 2010]

The transport sector in the EU accounts for more than 30% of the total energy consumption, of which 98% is based on fossil fuels [Cansino etal, 2012]. All Member States have objectives for renewable energy participation as a percentage of final energy consumption in the transport sector.

Findings of an analysis in Germany [Martinsen – Funk – Linssen, 2010] showed that if the biomass share of the final energy in the transport sector increases to 10% by 2030, the CO_2 emissions will drop by nearly 9%.

A result of Gnansounou – Dauriat – Villegas – Panichelli [2009] based on a Swiss case study is that the net GHG emissions are 0.237 kg CO_2eq/km of gasoline and from 0.055 to 0.120 kg CO_2eq/km for ethanol/gasoline blends.

Based on Austrian data and analysis by Ajanovic – Haas [2014] the life cycle GHG emissions of gasoline reference to bioethanol were the following:

Table 8 Life cycle GHG emissions reduction potential of bioethanol

Energy carrier	Year	WTT	TTW	WTW
		g CO_2 eq / kWh		
Gasoline (reference to bioethanol)	2010	61	299	360

For a comparative assessment of road transport technologies, see Streimikiene – Balezentis – Balezentiené [2013]. Main approaches for reducing GHG emissions from road transport:

- **improving fuel economy by enhancing efficiency of motor technologies** and reducing car weight – new passenger cars have been put on trajectory towards emissions of 95 gCO_2/km by 2020 (almost a 50% cut compared to 1990),
- improving fuel economy by using hybrid electric vehicle (HEV),

- implementing low carbon fuel such as bioethanol (or biodiesel or CNG or LPG),
- substitution of a portion of petroleum by electricity used to power the vehicle by using plug-in hybrid vehicle (PHEV) or battery-electric vehicle (BEV) or fuel cell-electric vehicle (FCV),
- improvement of road infrastructure, better traffic management, smart transportation behavior or eco driving practices.

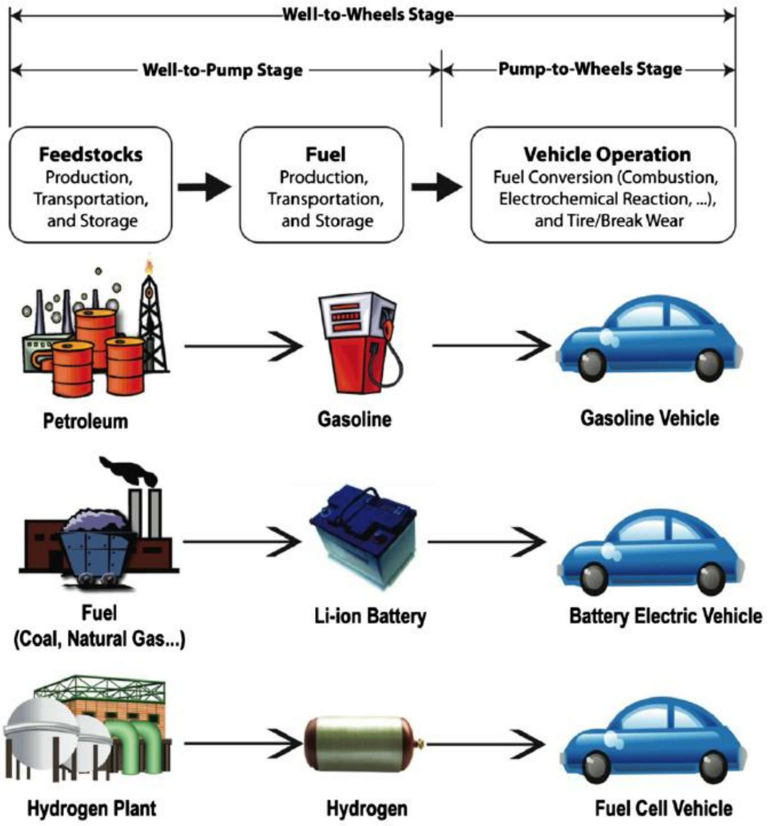
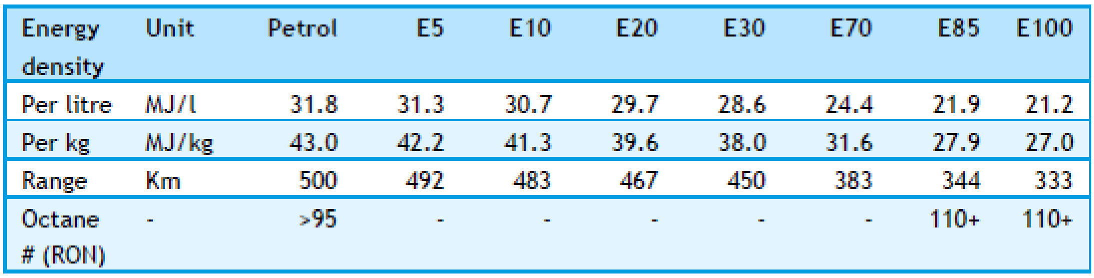


Fig. 5 **Vehicle/fuel systems**
Source: Hwang [2013]

Hwang [2013] discussed the GHG reduction potentials of various pathways for fuel cell vehicle applications. FCVs fuelled with the hydrogen from corn-ethanol reforming offer a low GHG emission but suffer from significant energy consumption.

The basic data relating to the energy content, energy density and GHG emissions we summarized in the next three tables.

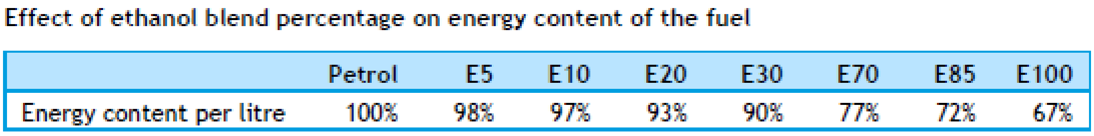
Table 9 **Energy related data for petrol and ethanol fuels and blends**



Energy density	Unit	Petrol	E5	E10	E20	E30	E70	E85	E100
Per litre	MJ/l	31.8	31.3	30.7	29.7	28.6	24.4	21.9	21.2
Per kg	MJ/kg	43.0	42.2	41.3	39.6	38.0	31.6	27.9	27.0
Range	Km	500	492	483	467	450	383	344	333
Octane # (RON)	-	>95	-	-	-	-	-	110+	110+

Source: Table 55, Kampman et al. [2013]

Table 10 **Energy related data for petrol and ethanol fuels and blends**



Effect of ethanol blend percentage on energy content of the fuel

	Petrol	E5	E10	E20	E30	E70	E85	E100
Energy content per litre	100%	98%	97%	93%	90%	77%	72%	67%

Source: Kampman et al. [2013]

Table 11 **CO_2 emissions of different fuels**

	kg CO_2eq/litre
Petrol (E0)	2.57
E5	2.46
E85	0.81

Source: Table 2, Särnholm – Gode [2007]

For WTW emissions calculations for different types of fuel, pathway and conversion (car motor technologies), see Bishop et al. [2012].

The engine efficiency effect of ethanol blends

Turner et al. [2011] described the **efficiency effect** as follows:

> “The benefits of adding ethanol into gasoline are reduced engine-out emissions and increased efficiency, and the impact changes with the blend ratio following a certain pattern. These benefits are attributed to the fact that the addition of ethanol modifies the evaporation properties of the fuel blend which increases the vapour pressure for low blends and reduces the heavy fractions for high blends. This is furthermore coupled with the presence of oxygen within the ethanol fuel molecule and the contribution of its faster

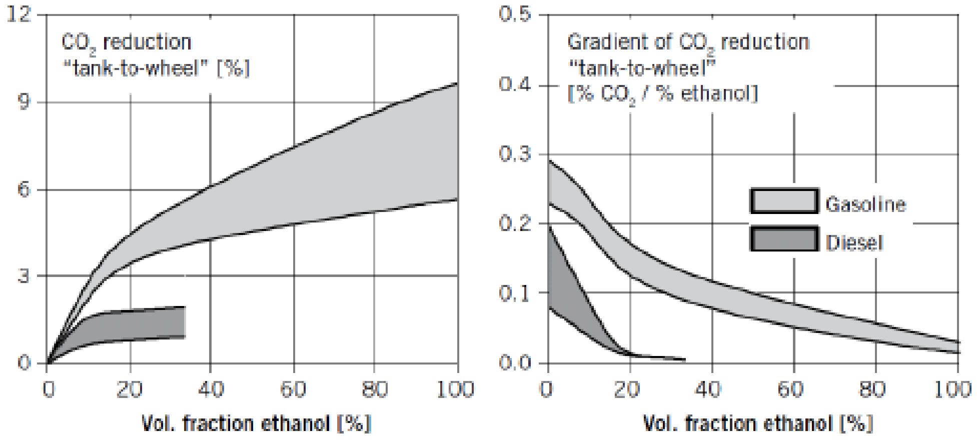
> flame speed, leading to enhanced combustion initiation and stability and improved engine efficiency.”

The highest efficiency gain (1.8% for E5 blend) was published by Eydogan et al. [2010]. However the circumstances of the investigation were specific:

> „In this study, the effects of ethanol–gasoline (E5, E10) and methanol–gasoline (M5, M10) fuel blends on the performance and combustion characteristics of a spark ignition (SI) engine were investigated. In the experiments, a vehicle having a four-cylinder, four-stroke, multi-point injection system SI engine was used. The tests were performed on a chassis dynamometer while running the vehicle at two different vehicle speeds (80km/h and 100km/h), and four different wheel powers (5, 10, 15, and 20kW).”

The range of possible engine energy efficiency effect of ethanol use we illustrate with the Figure 6 and 7.

Simulated effect of CO_2 reduction with engines optimised for ethanol blend: gasoline and diesel, both direct injection and turbo charged



❼ Reduction of CO_2 emission with adapted gasoline and Diesel engines in the NEDC

Fig. 6 The energy efficiency effect by ethanol blend use
Source: Figure 12, Kampman et al. [2013]

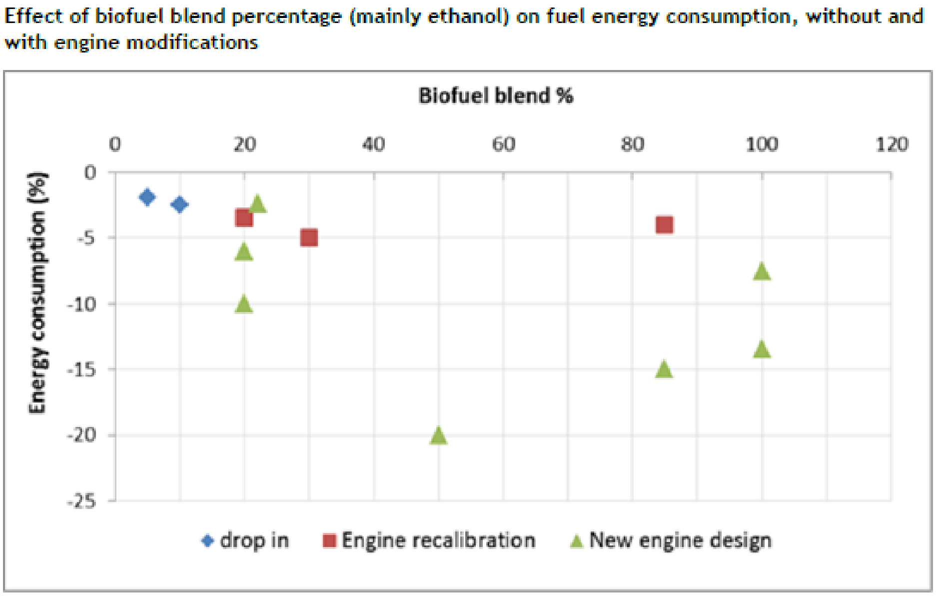


Fig. 7 **Energy consumption as a function of ethanol blending**
Source: Figure 13, Kampman et al. [2013]

Although the energy density of ethanol is lower than that of gasoline it has been proven that with increasing ethanol content the efficiency of the engine increases due to the higher octane number. According to Kampman et al [2013], E10 is 2.5% more efficient than pure gasoline, and E20 – if engines are re-designed – can be 20% more efficient.

Summing up, **the efficiency improvement due to the higher octane number in case of the feasible E10 blending in Hungary results in 1-2.5% CO_2 emission decrease** compared to pure gasoline cars. **This is a conservative evaluation, and further researches needed to investigate the real effect of engine efficiency improvement by ethanol on GHG emissions reduction**.

Taking into consideration that the emission of cars is only a part of the entire CO_2 emission life-cycle, and that the above results were established in laboratory environments which are usually not achievable in real traffic, more research is needed to calculate the GHG reduction effect in practice. However, the first results of these two independent meta-analyses (Geringer et al [2014] and Kampman et al [2013]) support the use of these evidences in our calculation. **In the Study the engine efficiency effect is included in the model with further 1-5% GHG emission decrease by ethanol (E10 blend) related to gasoline as a conservative calculation.** We also provide a calculation with the most impressive engine efficiency research data in the literature (Eydogan et al. [2010]), which is valid for E5 blend and the measured efficiency gain is 1.8%.

Our findings

The transport sector accounted for 18% of total GHG emissions measured in Hungary in 2011, and 19% including aviation emissions, measured in tons of carbon-dioxide equivalent. Transport emissions (including CH_4 and N_2O) increased significantly in the period of 1985-2011, from 7929.91 to 12561.43 kt CO_2 equivalents (including aviation), with two breaks in the upward trend. Transportation activity and consequently emissions declined for some years in the period of transition (from 1990 to about 1995), and later as a result of the recent recession from 2009. [REKK, 2014]

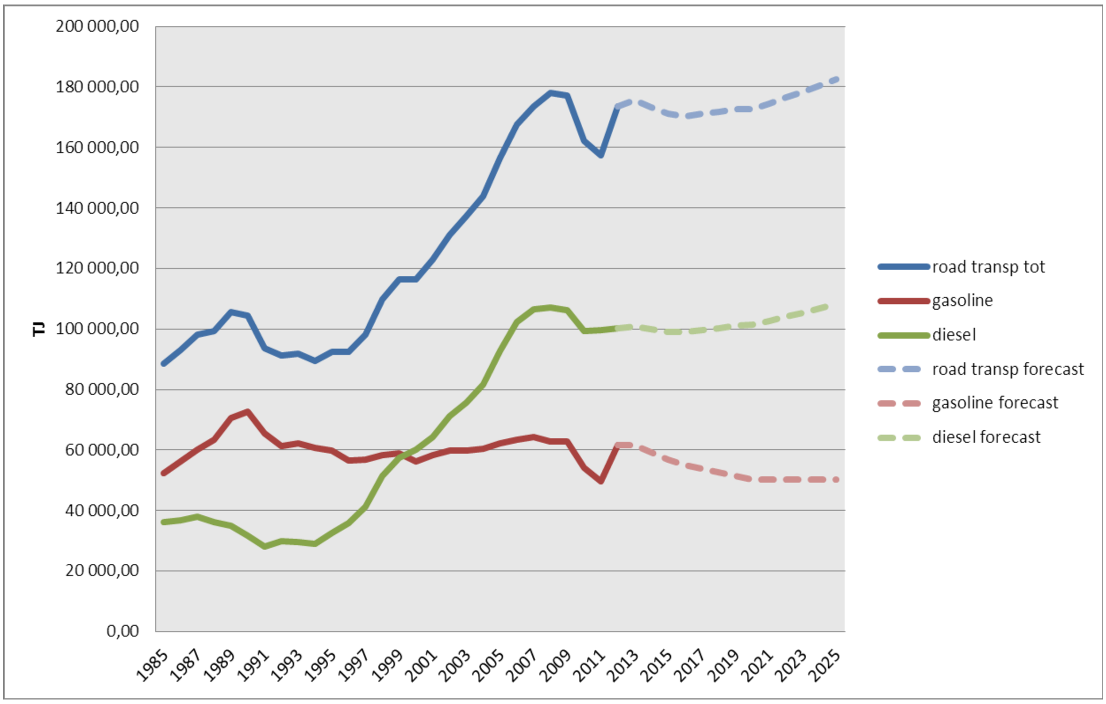


Fig. 8 **Forecast of diesel, gasoline and total energy consumption of road transport in Hungary**
Source: REKK [2014]

The currently negotiated National Transport Strategy (NKS [2013]) calculates a projected reduction in car use by different planned measures. So the Government expects a 1.1 millions km reduction by 2020 in personal car traffic.

Emission forecast

The estimation procedures in this chapter are based on figures of total gasoline demand in Hungary, assuming that the same amount of gasoline used in different cars produces similar levels of CO_2. This eliminates the problem of obtaining detailed data on passenger kilometers by different types of cars (age, engine etc.). If the travelling behavior of the owners of different car types does not change radically in the forecasted period, more aggregate data may provide reasonable estimates. We estimated the CO_2 reduction resulting from the introduction of E5 and E10 in Hungary in two ways. In the **first approach**, we used quarterly data from the third quarter of 2009 on. During these estimations we used the international daily stock market prices of gasoline and ethanol provided by Pannonia Ethanol.[5] Since gasoline consumption was available on a quarterly basis in the time span 2009q3-2014q1 on the website of the Hungarian Petroleum Association (HPA), we calculated quarterly averages of the daily price data as well. We also obtained quarterly GDP data from the Hungarian Central Statistical Office (HCSO), but including that as a control variable was not statistically significant in our model. Seasonally adjusted growth rates obtained from the OECD were significant, but quarterly forecasts were not available, so we could not use them either. This, on the other hand, did not worsen the fit of this model to a significant extent. Since it is reasonable to assume that international gasoline prices and Hungarian GDP growth do not affect each other (at least in the lack of very large shocks to the former), which we also confirmed by regression analysis, dropping GDP growth from the model did not bias our estimates. We used Brent crude oil spot price data and its quarterly forecast up to 2015q4 from the US Energy Information Administration for forecasting gasoline prices. Thus, the time horizon of our forecasts was limited by the availability of this Brent oil price forecast. Besides price data, quarterly dummies and a deterministic trend was included in the regression model.

In the next step, we converted gasoline demand in Hungary from liters to mega joules (MJ), and also converted the forecasted gasoline price from USD/tons to HUF/MJ, using data from Kampman et al [2013] and the exchange rate time series from the Hungarian National Bank. For future exchange rates, we used the yearly forecasts of OECD for every quarter.[6] We assumed that E5 was the standard fuel in this period, so we used the corresponding benchmarks from the literature to convert the measures. Then we estimated a simple OLS model including the obtained historical MJ prices, seasonal dummy variables and a deterministic trend. This model fit the actual values rather well, so we used it for forecasting demand for gasoline energy. Since we used international prices, it was reasonable to assume that they are not simultaneously influenced by Hungarian demand (Hungary being a small economy). Using the benchmark data 83.8 gCO_2e/MJ, we then calculated the CO_2 emission resulting from the forecasted gasoline demand.

In the other two scenarios, we supposed that E0 or E10 would be generally introduced in the first quarter of 2015. Since the ethanol price time series proved to be a random walk based on the Augmented Dickey-Fuller test, we used the latest price as the forecast of future ethanol prices. Based on the forecasted gasoline and ethanol prices and the energy content/liter benchmark from Kampman etal [2013] (see above), we obtained a different forecast of gasoline energy demand. In these scenarios, the different price and energy content of ethanol alters the price of one MJ, which we incorporated into the forecasted energy price in accordance with the 90% to 10% and 95% to 5% ratios of blending, respectively (in liters). Since the blending makes gasoline and one MJ of energy more expensive according to this calculation, but also changes

---

[5] Prices of Premium Unleaded Gasoline FOB NEW (USD) and Platts Ethanol Rotterdam (EUR)

[6] http://www.oecd.org/eco/outlook/economicoutlookannextables.htm

the energy content of one liter of fuel, this forecast shows smaller values regarding energy consumption, but larger demand for liters of fuel for 2015 than the ones in the scenario without blending. Our assumption was that the CO_2 emission from ethanol is 0 (as the feedstock absorbs the whole emitted amount), so we accounted only for the emission produced by gasoline (i.e. 90% of the E10 fuel and 95% of E5). Comparing the three scenarios, **ethanol blending is calculated to result in a decrease of CO_2 emission by 199502 tons altogether in 2015 due to the introduction of E10, which is about 6.6 percent of the CO_2 emission from gasoline consumption in the E0 scenario**. In the case of the E5 scenario, this decrease would be 96985 tons, which corresponds to 3.4%. It must be noted again, that this approach does not take into account the possible effects of GDP growth on the demand, which could occur both through increase in the passenger kilometers by those who own a car, and also through an increase in the number of car owners. However, the fit of the model is exceptionally good.

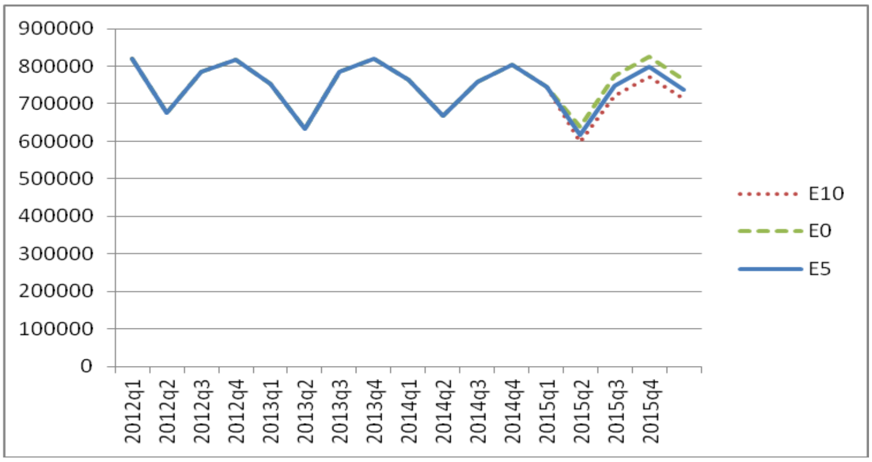


Fig. 9 Change in CO_2 emission from gasoline use, OLS estimation, quarterly data

In **the other approach** we used yearly data: average retail gasoline prices obtained from the HCSO, yearly consumption from HPA, GDP data from OECD and the forecast of GDP growth from the Convergence Programme of Hungary. In order to approximate retail ethanol prices, we used similar calculations as GKI[7], i.e. added a 52.5% retail margin and excise taxes and VAT. In this approach, we based our price forecast on the Brent oil prices mentioned above and on the HUF/USD exchange rate. A major difference from the previous approach was that E0 was used as a baseline scenario during the calculation of energy demand.[8] In this analysis we used measures for the changes in the variables instead of the absolute levels.[9] In the final model used for the forecast we included only two explanatory variables – FT/MJ energy price (coming from gasoline, like above) and real GDP -, since others (such as consumer price index and population) had

---

[7] http://www.gkienergia.hu/content/heti-uzemanyagarak-dizel-ara-csokkenhet-benzin-dragulhat-mindez-el-maradhat

[8] I.e. in this case we multiplied yearly energy demand in liters by the energy content of one liter of E0, while we used the energy content of one liter of E5 for the quarterly data.

[9] Since we found that most of them follow random walk processes, findings from a time series regression including the level variables would be a so-called spurious regression, since we established that the two series are not cointegrated.

statistically insignificant effect on energy consumption. We started with ordinary least squares estimation, but since in this case Hungarian retail prices were used, there is a chance that this model is biased due to the simultaneity of the determination of prices, demand and supply. Therefore we tested the robustness of the OLS estimates by applying other estimation techniques.

We estimated a system of equations (two-stage least squares, 2SLS) using the change in the yearly average of the US Brent crude oil price as an instrument for the Ft/MJ price of gasoline and the change in real GDP. This resulted in somewhat different coefficient estimates, although we could not reject the possibility that there is no simultaneity and price determine demand, but prices are not affected by demand and supply conditions.[10] Further robustness checks based on these instrumental variables (three-stage least squares -3SLS - and generalized method of moments - GMM) resulted in the same coefficients as the 2SLS estimation. Besides the OLS estimates, we report the GMM estimation results here since this method works with the least assumptions. We preferred the latter model when forecasting demand and emissions; other regression outputs can be found in the Appendix A.

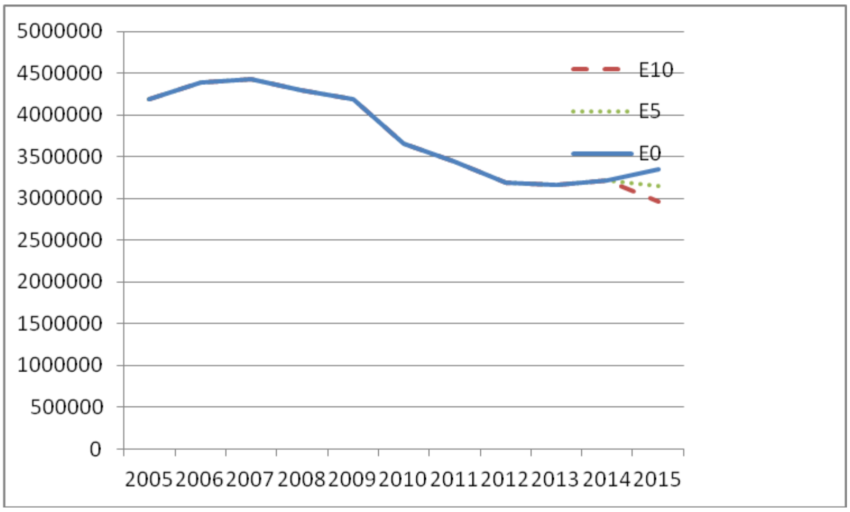


Fig. 10 Change in CO_2 emission from gasoline use, GMM estimation, annual data

Based on the forecasts of the OLS estimation and the benchmark values mentioned above, the predicted CO_2 emission stemming from gasoline consumption without the ethanol blend for 2015 is 3256 thousand tons. **This is 316 thousand tons higher than the emission that we calculated in case the E10 blending would occur** (a 9.7% decrease compared to the E0 scenario), and 126 thousand tons higher than in the case of E5. **The GMM estimation** (which we consider more robust) predicted higher CO_2 emissions for 2015 in all scenarios: 3345 **thousand without and** 2963 **thousand with the introduction of the E10 blend**. **The latter means that CO_2 emissions are estimated to be 11.4 percent less in 2015 comparing the E10 scenario to the**

---

[10] The test we used for this is an asymptotic one, but we only has a very small sample.

reference (E0) scenario. The decrease resulting from the use of E5 is would be half as large (189 thousand tons, 5.6%). The estimated decrease (like in the model based on quarterly data) is due to the effects of two factors: one is the increase in the price of a unit of energy from gasoline; the other is the decrease of the gasoline content in the fuel. As can be seen in the table, the OLS specification predicts an increase in gasoline demand (but a decrease in energy demand), while the GMM model shows decrease in this respect as well. It must be noted that these models fit the actual data much less than the one used for quarterly data: the R^2s are significantly smaller and the forecast errors are much larger.

The Table 12 shows the calculations for the CO_2 emissions in the three scenarios (E0, E5 and E10) according to specifications. Apart from the differences in the length of periods and the estimation techniques we applied, there are further reasons for the difference in the results. First, the energy content of one liter of fuel we applied during the calculations of energy demand and fuel energy prices corresponded to E5 for the quarterly and E0 for the annual data. This was necessitated by the different time frames used for estimation (2009q2 to 2014q1 and 1996 to 2014). It is also important to mention that the models using annual data assume that the joint behavior of price, GDP and demand did not change over one and a half decades. The model for quarterly data describes the short-term behavior of price and demand, and the time series starts in 2009, the period of the economic crisis, during which the relationship between price and demand may have changed (although there is no evidence for this, according to the regressions run on annual data).

Table 12 Forecast of gasoline demand and CO_2 emissions for 2015

Periods and method	Quarterly, OLS			Annual, OLS			**Annual, GMM**		
Scenario	E0	E5	E10	E0	E5	E10	**E0**	**E5**	**E10**
Gasoline demand, million liters	1126.95	1145.77	1168.99	1221.98	1223.85	1225.88	1255.18	1246.63	1235.53
CO_2 emissions, tons	3003155	2900638	2803653	3256369	3098280	2940108	3344866	3155957	2963248
Difference (compared to E0)		-96985	-199502		-158089	-316261		**-188909**	**-381617**
Percentage difference		3.4%	6.6%		4.2%	9.7%		**5.6%**	**11.4%**

The models for quarterly and annual gasoline prices are shown in a detailed way in Appendix A.

Estimation of marginal abatement cost of increasing ethanol blending

Summary of previous studies

Cost of ethanol fuels versus gasoline

The cost difference (overcost) between biofuels and conventional fuels was a relatively high in 2010 in Europe (according to Sanz et al. [2014]), but this gap has shrunk because of higher oil prices and dynamically developing ethanol production technologies.

Table 13 Overcost of biofuels in 2010 [Sanz et al, 2014] and in Q2/2014 [our calculation]

€/toe	*Overcost in 2010*	*Overcost in Q2/2014*
Biodiesel	169	Not calculated
Bioethanol	**407**	**259**
Biodiesel 2G	817	Not calculated
Bioethanol 2G	1405	Not calculated

There are significant differences between the marginal cost of bioethanol-based GHG mitigation alternatives depending on geographic region. According to data from 2008-2010 the global GHG abatement costs by ethanol was lower - because of the cheap Brazil sugarcane ethanol option - (see for example Figure V2.1 in McKinsey Report [2010]), than the European alternatives, which have a higher marginal abatement costs (see Exhibit 20, 21 and 22 for Czech Republic, also from McKinsey [2008]). We will show later, that the cost advantage of the tropical ethanol production has narrowed by now.

Biofuels use has external benefits also beyond the benefits from GHG reduction. The empirical investigation in the United States for the time period of 1982-2010 by Guerrero-Lemus et al. [2012] shows that **biofuels played an important role in reducing volatility and systematic risk in the fuel mix**. Therefore, the complementarity between fossil energies, biofuels, and electricity, seems to be a relevant factor for the energy policy in the transport sector in order to reduce dependence, increase diversification and lower emissions.

On the impact of energy prices on the volatility of ethanol prices, see Zafeiriou – Arabatzis – Tampakis – Soutsas [2014]. Beyond CO_2 abatement the use of ethanol has other positive effects, like **alleviating price volatility of transport fuel**. The trends presented by Guerrero-Lemus et al. [2012] and Zafeiriou – Arabatzis – Tampakis – Soutsas [2014] are based on data from 1982 to 2010 are similar in the last four years, there is **a continuous alleviating effect** on the price volatility of transport fuel.

The prices in Hungary for the time period 2009-2014 also suggest that the volatility reduction effect still exists (see Appendix B).

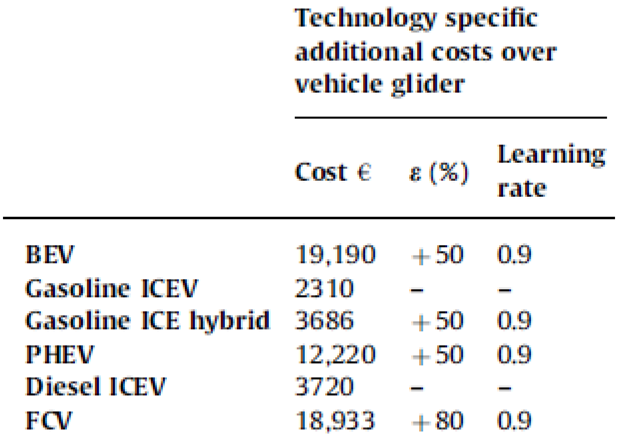
Cost of ethanol fuels versus electric vehicles

To switch from conventional fuels in vehicles there are alternatives to bioethanol use. As we summarized earlier in this study (see Fig. 5) battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), and fuel cell vehicles (FCV) are all relevant to reducing carbon emissions. According to last five years' scientific publications, with electric technologies higher CO_2 abatement could be reached, though at a high price.

The result that biofuels have a clear cost-benefit ratio advantage over electric technologies stems from the following factors:

- alternative engines (BEV, PHEV, FCV) have a significantly higher initial costs. Vehicle glider costs are the same, but there are a different power-train specific costs;

Table 14 **Initial costs – including uncertainty margins (ε) and estimated learning rates – for different types of vehicle technologies**

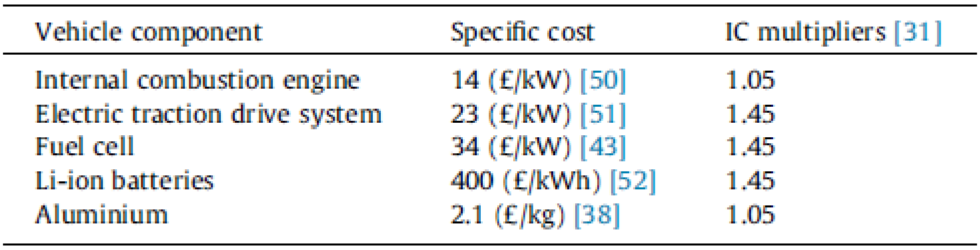


	Technology specific additional costs over vehicle glider		
	Cost €	ε (%)	Learning rate
BEV	19,190	+50	0.9
Gasoline ICEV	2310	–	–
Gasoline ICE hybrid	3686	+50	0.9
PHEV	12,220	+50	0.9
Diesel ICEV	3720	–	–
FCV	18,933	+80	0.9

ICEV: internal combustion engine vehicle

Source: Pasaoglu – Honselaar – Thiel [2012]

Table 15 **Vehicle powertrain components, costs and indirect cost (IC) multipliers**



Vehicle component	Specific cost	IC multipliers [31]
Internal combustion engine	14 (£/kW) [50]	1.05
Electric traction drive system	23 (£/kW) [51]	1.45
Fuel cell	34 (£/kW) [43]	1.45
Li-ion batteries	400 (£/kWh) [52]	1.45
Aluminium	2.1 (£/kg) [38]	1.05

Source: Bishop et al [2014]

- use of alternative engines needs a significant development of refuelling infrastructure. For example “the development of an initial hydrogen refuelling infrastructure is very costly, requires significant planning efforts and involves a first mover risk” [Pasaoglu – Honselaar – Thiel, 2012, p. 411].

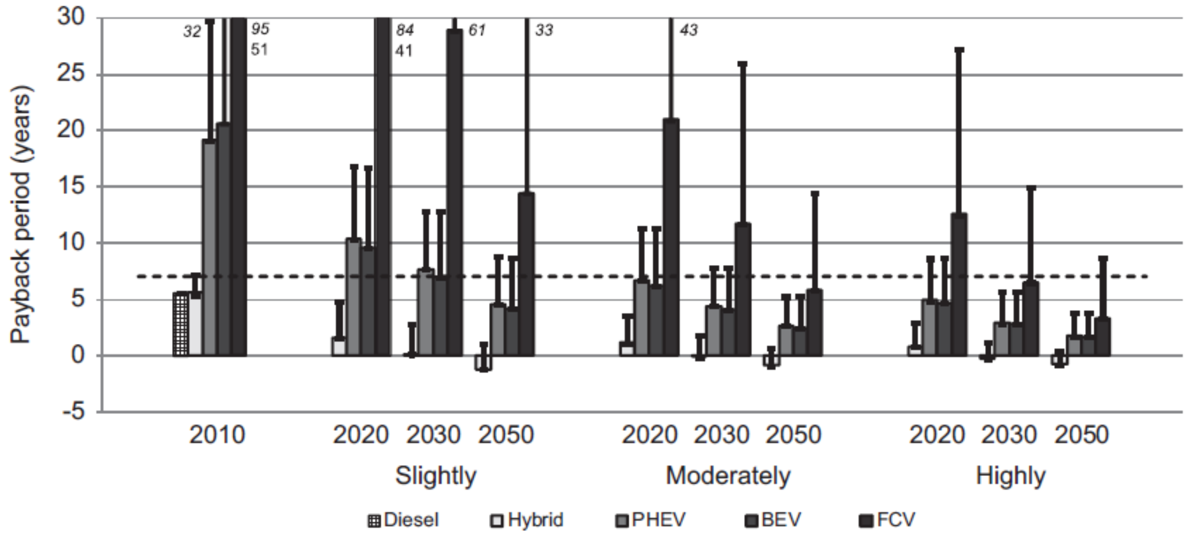


Fig. 11 Payback period (in years) by different engine technologies under various oil price/carbon abatement policy scenarios

Source: Pasaoglu – Honselaar – Thiel [2012]

According to Bishop et al [2014] the marginal vehicle cost to avoid GHG emissions are the following:

- advanced gasoline or diesel engines: from -790 to 1400 GBP,
- HEV from 45 to 7000 GBP,
- Fuel cell HEV from 2600 to 6500 GBP,
- PHEV from 12000 to 22000 GBP, and
- Fuel cell PHEV from 14000 to 21000 GBP.

It is important to underline that ethanol blending is one of the most efficient ways to reduce GHG emissions of car use in the near future, too. The Table 16 is summarized cost estimation values for Lithuania in 2020.

Table 16 Estimates of emissions and costs of road transport technologies in 2020 (based on Lithuanian data)

Car technology	GHG life cycle emissions (g/km)	Estimated fuel cost in 2020 (EUR/l)	Total private costs (EURcnt/km)
Petrol	125-500	1.5	19.2-22.2
Bioethanol	80-350	1.2	16.8-19.2
HEV	100-400	1.5	17.5-18.8
BEV	125-300	1.5	18.0-19.1
CNG	120-420	0.5	12.5-13.8

Based on Table 1 and Table 2 of Streimikiene – Balezentis – Balezentiené [2013]

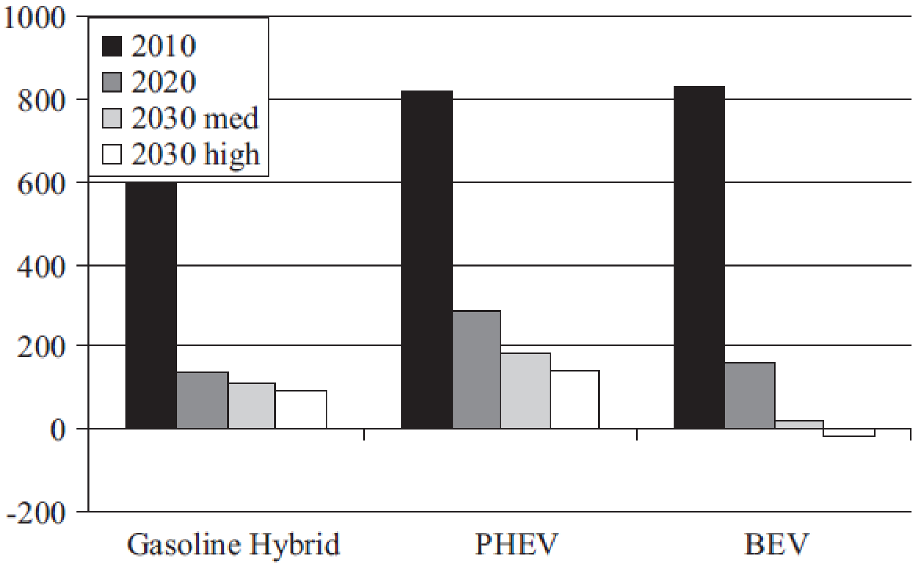


Fig. 12 Additional marginal cost of carbon abatement across alternative vehicle types relative to advanced gasoline engine vehicle

Source: Thiel – Perujo - Mercier [2010]

The carbon mitigation costs appearing in various publications (Bishop – Martin – Boies [2014], der Zwaan – Keppo – Johnsson [2013], Pasaoglu – Honselaar – Thiel [2012], Prud'homme – Koning [2012] and Thiel – Perujo – Mercier [2010]) **vary widely: from 10 to 895 €/t CO_2e (current, calculated) and 140-280 €/t CO_2e (in 2020, estimated)**.

It is clear, that the ethanol use in gasoline engine vehicles has a significant cost advantage over the new electric car technologies, like hybrid or plug-in hybrid electric vehicles (HEV/PHEV), battery electric vehicles (BEV), or fuel cell vehicles (FCV).

Our findings

First we used the average price of Premium Unleaded Gasoline in the first half of 2014 and Platts Ethanol FOB Rotterdam average price of 2014. The energy content and GHG emission data for gasoline were taken from the literature. The GHG emission of corn based ethanol is calculated based on the RED methodology, but some coefficients were changed regarding specific Hungarian data based on statistical data and expert interviews. The results are shown in Table 17.

We calculated a GHG emission from feedstock production 248.4 g CO_2eq/kg of corn. This resulted a total emission of 479.5 g CO_2eq/kg of corn. (See Table 7.)

Table 17 Marginal cost of GHG reduction based on bioethanol use in transport based on European commodity market prices and excluding engine efficiency effect of ethanol

		GASOLINE	ETHANOL
Market price, EU, average Q2/2014	USD/t; EUR/m3	1 003.023	487.125
Gasoline price conversion USD-EUR	EUR/t	742.237	
Gasoline price conversion EUR/t-EUR/m3	EUR/m3	534.188	
Market price, average Q2/2014	EUR/dm3	0.534	0.487
Energy content	MJ/dm3	31.800	21.200
Adjusted price, EU, average Q2/2014	€cent/MJ	1.679	2.297
CO_2 emission per 1kg corn – farming only	g(eq)/kg		248.4
CO_2 emission per 1kg corn – total production	g(eq)/kg		479.5
Life cycle CO_2 emission	g(eq)/MJ	83.800	33.678
CO_2 reduction relative to gasoline	g(eq)/MJ		50.122
Price difference, rel. to gasoline	€cent/MJ		0.618
Carbon mitigation cost	€cent/kg(eq)		12.328
Carbon mitigation cost	**€/t(eq)**		**123.28**

Indirect land use change factor was also added, in this case (we used a 12 g CO_2e/MJ value for iLUC) the GHG savings were only 38.122 g CO_2e/MJ instead of 50.122. The carbon mitigation cost were increased to 162 €/t CO_2e.

Thereafter we examined the GHG mitigation cost **based on current** (Q2-2014) **Hungarian market prices** (without taxes) **of gasoline and ethanol**. It is clear, that it is more realistic to investigate the GHG abatement cost for Hungary based on Hungarian real data than average European prices. We calculated the gasoline commodity price from gasoline consumer prices (published by Central Statistical Office of Hungary) and the composition of the consumer price based on MOL data (published by portfolio.hu[11]). 39% is the share of production cost in the consumer price in Hungary, the tax content is 51%, and the trading margin covers 10%. In the second quarter of 2014 the average consumer price was 415.67 HUF/litre, hence a commodity market price of 162.11 HUF/litre is calculated. At the exchange rate of 310 HUF/€ the Hungarian gasoline market

---

[11] http://www.portfolio.hu/vallalatok/csak_a_gazolaj_ara_emelkedik.4.202152.html

price is 0.523 €/litre. The price of ethanol is 0.438 €/litre based on Hungarian producers' data. The result for **carbon abatement cost is 84 €/ t CO_2e**. (See Table 18.)

Table 18 **Marginal cost of GHG reduction based on bioethanol use in transport based on Hungarian market prices and excluding engine efficiency effect of ethanol**

		GASOLINE	ETHANOL
Production cost, HU, average Q2/2014	EUR/dm3	**0.523**	**0.438**
Energy content	MJ/dm3	31.800	21.200
Adjusted price, HU, average Q2/2014	€cent/MJ	1.645	2.066
CO_2 emission per 1kg corn – farming	g(eq)/kg		248.4
CO_2 emission per 1kg corn – total production	g(eq)/kg		479.5
Life cycle CO_2 emission	g(eq)/MJ	83.80	33.678
CO_2 reduction relative to gasoline	g(eq)/MJ		50.122
Price difference, relative to gasoline	€cent/MJ		0.421
Carbon mitigation cost	€cent/kg(eq)		8.407
Carbon mitigation cost	**€/t(eq)**		**84.07**

Taking the iLUC factor into account, the calculation resulted a mitigation cost of 111 €/t CO_2e.

As a second modification shown in Table 19 **we have to take into account the engine energy efficiency effect of ethanol use**. The literatures (Kampman et al. [2013] and Geringer et al. [2014] as meta-analyses) have examined that the use of ethanol enhances the engine efficiency. It results in a further GHG reduction and a significantly lower carbon abatement cost. (We investigate the theoretically highest effect later. See Table 20.)

Table 19 **Marginal cost of GHG reduction by using bioethanol in transport based on European commodity market prices or Hungarian production costs and including the engine efficiency effect (EEE) of ethanol**

without iLUC

EEE	cost of carbon mitigation	
	EU prices	*HU prices*
%	€/t CO_2eq	
1,4	**40**	**12**
1,6	**32**	**5**
1,8	**24**	**-2**
2,0	**16**	**-9**

with iLUC

EEE	cost of carbon mitigation	
	EU prices	*HU costs*
%	€/t CO_2eq	
1,4	**49**	**15**
1,6	**38**	**6**
1,8	**28**	**-3**
2,0	**19**	**-10**

Remarks:
Due to methodological reasons, any value in the negative territory is worth to invest for. Not relevant how much negative. (-2 v -3). This is the reason why including iLUC makes cost of carbon mitigation even more negative over 1,8% efficiency.
For detailed method description see Appendix C.

For the investigation of the impact of engine efficiency effect (EEE) of the E10 blend on the carbon mitigation cost a calculation model - shown in a detailed way in Appendix C - was constructed. We used the technical data of Geringer et al. [2014] with a 1.8% efficiency gain (for E10) as a mean value.

The EEE has a significant effect on carbon abatement cost. Our calculation shows that **the CO_2 mitigation cost of bioethanol (E10 blend) based on Hungarian corn, domestic prices and taken into account the engine efficiency effect with 1.8% increase is -2 €/t CO_2eq. With European average prices the abatement cost is 24 €/t CO_2eq.**

The theoretical maximum of the energy efficiency effect regarding current peer-reviewed literature

In some recent articles even more impressive results were published about the engine energy efficiency improvement. For example Eydogan et al. [2010] has recognised 1.8% engine energy efficiency improvement in case of the E5 blend in laboratory. In Table 20 we illustrate how significant effect that would have if the car industry could be able to bring such engine efficiency improvement into practice, to the streets.

So, if the experimental results demonstrated by Eydogan et al. [2010] could be measured in reality, the GHG abatement cost of ethanol use would be estimated to be dramatically lower, around -50 €/t CO_2e .

Table 20 Marginal cost of GHG reduction based on bioethanol use in transport based on Hungarian market price (without taxes) and including new scientific results on engine efficiency effect of ethanol – the theoretical maximum

Gasoline (E0)		
Density	kg/l	0,74
Energy Content	MJ/kg	43,0
Energy Content	MJ/l	31,8
CO_2 emission	g/MJ	83,8
Gasoline Price	€cent/MJ	1,645

Ethanol		
Density	kg/l	0,79
Energy Content	MJ/kg	27,0
Energy Content	MJ/l	21,2
CO_2 emission	g/MJ	33,7
Ethanol Price	€cent/MJ	2,066

Gasoline/Ethanol **E5 BLEND**		
WITHOUT ENERGY EFFICIENCY EFFECT		
Blending Rate (V/V)		5%
Blend Energy Content	MJ/l	31,3
CO_2 emission	g/MJ	82,12
Emission reduction	g/MJ	1,68
Blend price	€cent/MJ	1,659
Price difference	€cent/MJ	0,014
CO_2 abatement cost	**€/t**	**84**

Gasoline/Ethanol **E5 BLEND**		
WITH ENERGY EFFICIENCY EFFECT		
Blending Rate (V/V)		5%
Blend Energy Content	MJ/l	31,3
Energy Efficiency Gain		**1,8%**
Adjusted Blend Energy Content	MJ/l	31,9
CO_2 emission	g/MJ	80,62
Emission reduction	g/MJ	3,18
Blend price	€cent/MJ	1,630
Price difference	€cent/MJ	-0,015
CO_2 abatement cost	**€/t**	**-50**

Source: Ethanol Europe, Eydogan et al. [2010] and HÉTFA calculation

The effect of scientific uncertainty in the field of nitrogen emission's estimation

Leaving the discussion about the range of engine energy efficiency effect, we are turning now to the results of Gabrielle et al. [2014] regarding the **overestimation of field nitrogen emissions**. The factor of overcalcualtion is about 50-70% according this study. We are modeling this effect with a value of overestimation of 50%.

Table 21 Marginal cost of GHG reduction based on bioethanol use in transport based on Hungarian production costs, excluding engine efficiency effect, and 50% reduction in the field nitrogen emission

		GASOLINE	ETHANOL
Production cost, HU, average Q2/2014	EUR/dm3	**0.523**	**0.438**
Energy content	MJ/dm3	31.800	21.200
Adjusted price, HU, average Q2/2014	€cent/MJ	1.645	2.066
CO_2 emission per 1kg corn – farming **with lower field emission value**	g(eq)/kg		**200.0**
CO_2 emission per 1kg corn – total production	g(eq)/kg		431.1
Life cycle CO_2 emission	g(eq)/MJ	83.80	**30..28**
CO_2 reduction relative to gasoline	g(eq)/MJ		53.52
Price difference, relative to gasoline	€cent/MJ		0.421
Carbon mitigation cost	€cent/kg(eq)		7.866
Carbon mitigation cost	**€/t(eq)**		**78.67**

Taken into account the nitrogen emission overestimation effect based on Gabrielle et al. [2014] the carbon abatement cost changed by 5 Euros from 84 to **79 €/t CO_2eq.**

Sensitivity analyses

Summary of previous studies

For sensitivity analysis regarding the influence of relative prices on welfare economic profitability, see Moller – Slento – Frederiksen [2014]. Sensitivity analysis regarding (i) prices of imported energy carriers, (ii) use of field crops, (iii) prices of biomass, (iv) extension of nuclear power lifetime and the use of clean coal technologies, and (v) CO_2 prices (penalties), see Martinsen – Funk – Linssen [2010].

Methodological problems

In the particular case of GHG balance, the magnitude of the discrepancy among the results of LCAs is tremendously high. See Gnansounou et al. [2009].

A comparison between the RED, RTFO and PAS2050 methodologies is given by Whittaker – McManus – Hammond [2011]. They found that is not possible to judge which methods is the best. In their model calculations the RTFO has given the lowest fuel chain emission values, and RED has resulted the highest ones. The differences are 27.3 $kgCO_2e/GJ$ for wheat grain to ethanol and 24.9 $kgCO_2e/GJ$ for wheat straw to ethanol. It **means the RED methodology, used in this study as well, is a conservative one**.

Our findings

The GHG mitigation cost by bioethanol is highly sensitive for the real (and currently uncertain) **impact on engine efficiency**. We showed earlier that this effect can change the abatement cost in the range from -50€ to 84€ (our mean value from calculations was 84€ without EEE and -2€ with EEE.) Further researches are needed to investigate the real value of the engine efficiency effect. **Not sufficient knowledge can cause a significant social loss because of a lower use of ethanol.**

We also examined various changes in input data as well. The results are summarized in Table 25.

The mitigation cost is very sensitive to the relative price changes of gasoline and ethanol as well. The car technology efficiency and the GHG intensity of feedstock production have a less effect on carbon abatement cost.

The ethanol industry would be benefited by the increase of gasoline prices or by the increase of efficiency of ethanol production from the point of view of carbon mitigation cost.

Table 24 **Results of sensitivity analysis**

Modified factor	**Variation**	**Mitigation cost €/t(CO_2eq)**	**Change (%)**
Mean value	No change	84	-------------
GHG coefficient for corn production	Up by 33%	98	+15
Gasoline price	Up by 10%	52	-39
Gasoline price	Up by 20%	19	-54
Ethanol price	Up by 10%	128	+51
Ethanol price	Down by 10%	44	-48
Ethanol energy efficiency gain	From 0 to 1.8%	-2	-102
More effective gasoline motors	Down by 10%	95	+12
Reduced carbon intensity of corn production	Down by 10%	80	-6
No tillage farming	Down by 25%	78	-8
N_2O emission uncertainty	Down by 50%	79	-6

References

Acquaye, A.A. – Sherwen, T. – Genovese, A. – Kuylenstierna, J. – Koh, S.C.L. – McQueen-Mason, S. [2012] Biofuels and their potential to aid the UK towards achieving emissions reductions policy target. *Renewable and Sustainable Energy Reviews* **16**, 5414-5422.

Ajanovic, A. – Haas, R. [2010] Economic challenges for the future relevance of biofuels in transport in EU countries. *Energy* **35**, 3340-3348.

Ajanovic, A. – Haas, R. [2014] CO_2-reduction potentials and costs of biomass-based alternative energy carriers in Austria. *Energy* **69**, 120-131.

AKI [2013] *Statisztikai Jelentések. Műtrágya értékesítés. 2013. I-IV. negyedév*. XXV. évfolyam, 1. szám (in Hungarian)

Bishop, J.D.K. – Axon, C.J. – Tran, M. – Bonilla, D. – Banister, D. [2012] Identifying the fuels and energy conversion technologies necessary to meet European passenger car emissions legislation to 2020. *Fuel* **99**, 88-105.

Bishop, J.D.K. – Martin, N.P.D. – Boies, A.M. [2014] Cost-effectiveness of alternative powertrains for reduced energy use and CO_2 emissions in passenger vehicles. *Applied Energy* **124**, 44-61.

von Blottnitz, H. – Curran, M.A. [2007] A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. *Journal of Cleaner Production* **15**, 607-619.

Cansino, J.M. – Pablo-Romero, M.d.P. – Román, R. – Yniguez, R. [2012] Promotion of biofuel consumption in the transport sector: An EU-27 perspective. *Renewable and Sustainable Energy Reviews* **16**, 6013-6021.

Cherubini, F. [2010] GHG balances of bioenergy systems – Overview of key steps in the production chain and methodological concerns. *Renewable Energy* **35**, 1565-1573.

El-Houjeiri, H.M. – Field, R.W. [2012] A standardized well-to-wheel model for the assessment of bioethanol and hydrogen from cellulosic biomass. *Energy Policy* **48**, 487-497.

Eyidogan, M. - Ozsezen, A.N. – Canakci, M. – Turkcan, A. [2010] Impact of alcohol–gasoline fuel blends on the performance and combustion characteristics of an SI engine. *Fuel* **89**, 2713–2720.

ePure [2014] *Renewable ethanol: driving jobs, growth and innovation throughout Europe - State of the industry report 2014*. European Renewable Ethanol, Brussels.

Forgács, L. – Zsembeli, J. – Tuba, G. [2006] *Tiszántúli réti talajok termőhely-specifikus művelési alternatíváinak kidolgozása*. DE ATC Karcagi Kutatóintézet, Mimeo, Karcag. (in Hungarian)

Fazio, S. – Monti, A. [2011] Life cycle assessment of different bioenergy production systems including perennial and annual crops. *Biomass and bioenergy* **35**, 4868-4878.

Foteinis, S. – Kouloumpis, V. – Tsoutsos, T. [2011] Life cycle analysis for bioethanol production from sugar beet crops in Greece. *Energy Policy* **39**, 4834-4841.

Gabrielle, B. – Gagnaire, N. – Massad, R.S. – Dufossé, K. – Bessou, C. [2014] Environmental assessment of biofuel pathway in Ile de France based on ecosystem modeling. *Bioresource Technology* **152**, 511-518.

Geringer, B. – Spreitzer, J. – Mayer, M. – Martin, C. [2014] *Meta-analysis for an E20/25 technical development study – Task 2: Meta-analysis of E20/25 trial reports and associated data*. Technische Universität Wien – Institute for Powertrains and Autmotive Technology, Vienna.

Giarola, S. – Shah, N. – Bezzo, F. [2012] A comprehensive approach to the design of ethanol supply chains including carbon trading effects. *Bioresource Technology* **107**, 175-185.

Giarola – Zamboni – Bezzo [2012] Environmentally conscious capacity planning and technology selection for bioethanol supply chains. *Renewable Energy* **43**, 61-72.

Gnansounou, E. – Dauriat, A. Villegas, J. – Panichelli, L. [2009] Life cycle assessment of biofuels: Energy and greenhouse gas balances. *Bioresource Technology* **100**, 4919-4930.

Gnansounou, E. [2010] Production and use of lignocellulosic bioethanol in Europe: Current situation and perspectives. *Bioresource Technology* **101**, 4842-4850.

Guerrero-Lemus, R. – Marrero, G.A. – Puch, L.A. [2012] Costs for conventional and renewable fuels and electricity in the worldwide transport sector: A mean-variance portfolio approach. *Energy* **44**, 178-188.

HÉTFA [2012] *Economic Impact Study on Pannonia Ethanol Dunaföldvár and Pannonia Ethanol Mohács Bioethanol Plants*. HÉTFA Center for Analysis, Budapest.

Hwang, J.J. [2013] Sustainability study of hydrogen pathways for fuel cell vehicle applications. *Renewable and Sustainable Energy Reviews* **19**, 220-229.

IEA [2009] *World energy outlook 2009*

IFPRI [2014] *Progress in estimates of iLUC with mirage model*. Joint Research Centre of the European Commission, Brussels.

Kalt, G. – Kranzl, L. [2011] Assessing the economic efficiency of bioenergy technologies in climate mitigation and fossil fuel replacement in Austria using a techno-economic approach. *Applied Energy* **88**, 3665-3684.

Kampman, B. – Verbeek, R. – van Grinsven, A. – van Mensch, P. – Croezen, H. – Patuleia, A. [2013] *Bringing biofuels on the market*. CE Delft, Delft.

Kloverpris, J.H. – Mueller, S. [2013] Baseline time accounting: Considering global land use dynamics when estimating the climate impact of indirect land use change caused by biofuels. *The International Journal of Life Cycle Assessment* **18**, 319-330.

KSH [2012] *Környezeti helyzetkép, 2011*. Központi Statisztikai Hivatal, Budapest. (in Hungarian)

KSH [2013] *Statisztikai tükör: Agrotechnikai adatok, 2012*. Központi Statisztikai Hivatal, Budapest, 2013. november 18. (in Hungarian)

Larson, E.D. [2006] A review of life-cycle analysis studies on liquid biofuel systems for the transport sector. *Energy for Sustainable Development* **10**(2), 109-126.

Lechón, Y. – Cabal, H. – de la Rúa, C. – Caldés, N. – Santamaría, M. – Sáez, R. [2009] Energy and greenhouse gas emission savings of biofuels in Spain's transport fuel. The adoption of the EU policy on biofuels. *Biomass and Bioenergy* **33**, 920-932.

Levidow, L. [2013] EU criteria for sustainable biofuels: Accounting for carbon, depoliticizing plunder. *Geoforum* **44**, 211-223.

Li Borrion, A. – McManus, M.C. – Hammond, G.P. [2012] Environmental life cycle assessment of bioethanol production from wheat straw. *Biomass and Bioenergy* **47**, 9-19.

Li Borrion, A. – McManus, M.C. – Hammond, G.P. [2012] Environmental life cycle assessment of lignocellulosic conversion to ethanol: A review. *Renewable and Sustainable Energy Reviews* **16**, 4638-4650.

Malça, J. – Freire, F. [2012] Addressing land use change and uncertainty in the life-cycle assessment of wheat-based bioethanol. *Energy* **45**, 519-527.

Martinsen, D. – Funk, C. – Linssen, J. [2010] Biomass for transportation fuels – A cost-effective option for the German energy supply? *Energy Policy* **38**, 128-140.

McKinsey [2008] *Costs and potentials of greenhouse gas abatement in the Czech Republic – Key findings*. McKinsey&Company, Prague.

McKinsey [2010] *Impact of the financial crisis on carbon economics - Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve*. McKinsey&Company.

Mizsey, P. – Racz, L. [2010] Cleaner production alternatives: Biomass utilization options. *Journal of Cleaner Production* **18**, 767-770.

Møller, F. – Slentø, E. – Frederiksen, P. [2014] Integrated well-to-wheel assessment of biofuels combining energy and emission LCA and welfare economic Cost Benefit Analysis. *Biomass and Bioenergy* **60**, 41-49.

NKS [2013] *Nemzeti Közlekedési Stratégia – Stratégiai Dokumentum*. Közlekedésfejlesztési Koordinációs Központ, Budapest. (in Hungarian)

Oliveira, M.E.D. – Vaughan, B.E. - Rykiel, Jr. E.J. [2005] Ethanol as Fuel: Energy, Carbon Dioxide Balances, and Ecological Footprint. *BioScience*, **55**(7), 593.

Pasaoglu, G. – Honselaar, M. – Thiel, C. [2012] Potential vehicle fleet CO_2 reduction and cost implications for various vehicle technology deployment scenarios in Europe. *Energy Policy* **40**, 404-421.

Patzek [2004] Thermodynamics of the Corn-Ethanol Biofuel Cycle. *Critical Reviews in Plant Sciences* **23**(6), 519-567.

Prud'homme, R. – Koning, M. [2012] Electric vehicles: A tentative economic and environmental evaluation. *Transport Policy* **23**, 60-69.

Reijnders, L. – Huijbregts, M.A.J. [2007] Life cycle greenhouse gas emissions, fossil fuel demand and solar energy conversion efficiency in European bioethanol production for automotive purposes. *Journal of Cleaner Production* **15**, 1806-1812.

REKK [2014] *Biennal Report 2013.* Regionális Energiagazdasági Kutatóközpont, Budapest.

Ryan, L. – Convery, F. – Ferreira, S. [2006] Stimulating the use of biofuels in the European Union: Implication for climate change policy. *Energy Policy* **34**, 3184-3194.

Sanz, M.T. – Cansino, J.M. – González-Limón, J.M. – Santamaría, M. – Yñiguez, R. [2014] Economic assessment of CO_2 emissions savings in Spain associated with the use of biofuels for the transport sector in 2010. *Utilities Policy* **29**, 25-32.

Särnholm, E. – Gode, J. [2007] *Abatement costs for carbon dioxide reductions in the transport sector*. Swedish Environmental Research Institute, Stockholm.

Shapouri - McAloon [2004] The 2001 Net Energy Balance of Corn-Ethanol. *Presented at the Corn Utilization and Technology Conference, June 7-9, 2004, Indianapolis, IN*

Singh, A. – Pant, D. – Korres, N.E. – Nizami, A.S. – Prasad, S. – Murphy, J.D. [2010] Key issues in life cycle assessment of ethanol production from lignocellulosic biomass: Challenges and perspectives. *Bioresource Technology* **101**, 5003-5012.

Sorda, G. – Banse, M. – Kemfert, C. [2010] An overview of biofuel policies across the world. *Energy Policy* **38**, 6977-6988.

Stichnothe, H. – Azapagic, A. [2009] Bioethanol from waste: Life cycle estimation of the greenhouse gas saving potential. *Resources, Conservation and Recycling* **53**, 624–630.

Streimikiene, D. – Balezentis, T. – Balezentiené, L. [2013] Comparative assessment of road transport technologies. *Renewable and Sustainable Energy Reviews* **20**, 611-618.

Tao, J. – Yu, S. – Wu, T. [2011] Review of China's bioethanol development and a case study of fuel supply, demand and distribution of bioethanol expansion by national application of E10. *Biomass and Bioenergy* **35**, 3810-3829.

Thiel, C. – Perujo, A. – Mercier, A. [2010] Cost and CO_2 aspects of future vehicle options in Europe under new energy policy scenarios. *Energy Policy* **38**, 7142-7151.

Thiel, C. – Schmidt, J. – Van Zyl, A. – Schmid, E. [2014] Cost and well-to-wheel implications of the vehicle fleet CO_2 emission regulation in the European Union. *Transport Research Part A* **63**, 25-42.

Tol, R.S.J. [2009] The Economic Effects of Climate Change. *Journal of Economic Perspectives* **23**(2), 29–51.

Turner, D. – Xu, H. – Cracknell, R.F. – Natarajan, V. – Chen, X. [2011] Combustion performance of bio-ethanol at various blend ratios in a gasoline direct injection engine. *Fuel* **90**(5), 1999-2006.

Xue, X. – Pang, Y. – Landis, A.E. [2014] Evaluating agricultural management practices to improve the environmental footprint of corn-derived ethanol. *Renewable Energy* **66**, 454-460.

de Vries, S.C. – van de Ven, G.W.J. – van Ittersum, M.K. [2014] First or second generation biofuel crops in Brandenburg, Germany? A model-based comparison of their production-ecological sustainability. *European Journal of Agronomy* **52**, 166-179.

West, T.O. – Marland, G. [2002] A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. *Agriculture, Ecosystems and Environment* **91**, 217-232.

Whittaker, C. – Li Borrion, A. – Newnes, L. – McManus, M.C. [2014] The renewable energy directive and cereal residues. *Applied Energy* **122**, 207-215.

Whittaker, C. – McManus, M.C. – Hammond, G.P. [2011] Greenhouse gas reporting for biofuels: A comparison between the RED, TRFO and PAS2050 methodologies. *Energy Policy* **39**, 5950-5960.

Zafeiriou, E. – Arabatzis, G. – Tampakis, S. – Soutsas, K. [2014] The impact of energy prices on the volatility of ethanol prices and the role of gasoline emissions. *Renewable and Sustainable Energy Reviews* **33**, 87-95.

Zamboni, A. – Murphy, R.J. – Woods, J. – Bezzo, F. – Shah, N. [2011] Biofuels carbon footprints: Whole-system optimization for GHG emissions reduction. *Bioresource Technology* **102**, 7457-7465.

van der Zwaan, B. – Keppo, I. – Johnsson, F. [2013] How to decarbonizes the transport sector? *Energy Policy* **61**, 562-573.

Appendices

Appendix A

Model for quarterly gasoline price

```
Dependent Variable: GASOLINEPRICE
Method: Least Squares
Date: 07/17/14   Time: 16:03
Sample (adjusted): 2009Q3 2014Q2
Included observations: 20 after adjustments
==========================================================================
        Variable          Coefficient    Std. Error    t-Statistic    Prob.
==========================================================================
           C               48.35976      42.78997      1.130166     0.2732
      BRENT_OIL_AR         8.472199      0.421511      20.09957     0.0000
==========================================================================
R-squared                  0.957345    Mean dependent var          897.6850
Adjusted R-squared         0.954976    S.D. dependent var          142.0428
S.E. of regression         30.14002    Akaike info criterion       9.744225
Sum squared resid          16351.58    Schwarz criterion           9.843798
Log likelihood            -95.44225    F-statistic                 403.9928
Durbin-Watson stat         1.619323    Prob(F-statistic)           0.000000
==========================================================================
```

Model for quarterly energy demand (from gasoline)

```
Dependent Variable: DEMAND_MJ
Method: Least Squares
Date: 07/18/14   Time: 13:08
Sample (adjusted): 2009Q3 2014Q1
Included observations: 19 after adjustments
==============================================================================
           Variable            Coefficient    Std. Error    t-Statistic    Prob.
==============================================================================
              C                 12138.23      532.9820      22.77417     0.0000
      GASOLINEPRICE_MJHUF      -605.1458      162.2739     -3.729164     0.0025
              Q2                1756.247      211.0301      8.322258     0.0000
              Q3                2409.836      199.2492      12.09458     0.0000
              Q4                1561.758      203.3387      7.680575     0.0000
            @TREND             -59.20974      25.32473     -2.338021     0.0360
==============================================================================
R-squared                       0.961794    Mean dependent var          10224.46
Adjusted R-squared              0.947099    S.D. dependent var          1356.890
S.E. of regression              312.0866    Akaike info criterion       14.57653
Sum squared resid               1266174.    Schwarz criterion           14.87477
Log likelihood                 -132.4770    F-statistic                 65.45211
Durbin-Watson stat              1.654552    Prob(F-statistic)           0.000000
==============================================================================
```

OLS estimation results for annual energy demand (from gasoline)

Dependent Variable: D_MJ_DEMAND
Method: Least Squares
Date: 07/16/14 Time: 17:38
Sample (adjusted): 1997 2013
Included observations: 17 after adjustments
Newey-West HAC Standard Errors & Covariance (lag truncation=2)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	128.2500	469.8531	0.272958	0.7889
D_FT_PER_MJ2	-2209.894	628.0947	-3.518408	0.0034
D_GDP_TOTAL2	1.601181	0.556566	2.876892	0.0122

R-squared	0.453295	Mean dependent var	-484.4064
Adjusted R-squared	0.375194	S.D. dependent var	2461.815
S.E. of regression	1945.933	Akaike info criterion	18.14366
Sum squared resid	53013192	Schwarz criterion	18.29069
Log likelihood	-151.2211	F-statistic	5.803973
Durbin-Watson stat	0.995159	Prob(F-statistic)	0.014597

GMM estimation results for annual energy demand (from gasoline)

Dependent Variable: D_MJ_DEMAND
Method: Generalized Method of Moments
Date: 07/17/14 Time: 14:48
Sample (adjusted): 1997 2013
Included observations: 17 after adjustments
Kernel: Bartlett, Bandwidth: Fixed (2), No prewhitening
Simultaneous weighting matrix & coefficient iteration
Convergence achieved after: 1 weight matrix, 2 total coef iterations
Instrument list: D_US_BRENT_OIL_PRICE D_GDP_TOTAL2

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	788.9292	831.2034	0.949141	0.3586
D_FT_PER_MJ_PRICE	-3581.586	1096.268	-3.267071	0.0056
D_GDP_TOTAL2	1.853584	0.805735	2.300489	0.0373

R-squared	0.312583	Mean dependent var	-484.4064
Adjusted R-squared	0.214381	S.D. dependent var	2461.815
S.E. of regression	2182.033	Sum squared resid	66657754
Durbin-Watson stat	0.916339	J-statistic	1.10E-31

3SLS estimates for yearly energy demand and gasoline price

```
System: UNTITLED
Estimation Method: Three-Stage Least Squares
Date: 07/17/14   Time: 14:45
Sample: 1997 2013
Included observations: 17
Total system (balanced) observations 34
Linear estimation after one-step weighting matrix
================================================================================
                        Coefficient     Std. Error     t-Statistic      Prob.
================================================================================
          C(1)             788.9292       797.0178        0.989851     0.3307
          C(2)            -3581.586       1157.633       -3.093887     0.0044
          C(3)             1.853584       0.836971        2.214632     0.0351
          C(4)             0.386666       0.121650        3.178516     0.0036
          C(5)            -9.76E-05       8.05E-05       -1.211475     0.2358
          C(6)             0.022663       0.009287        2.440226     0.0213
================================================================================
Determinant residual covariance          277407.1
================================================================================
Equation: D_MJ_DEMAND= C(1) + C(2)*D_FT_PER_MJ_PRICE+C(3)
    *D_GDP_TOTAL2
Instruments: D_US_BRENT_OIL_PRICE D_GDP_TOTAL2 C
Observations: 17
--------------------------------------------------------------------------------
R-squared                    0.312583   Mean dependent var           -484.4064
Adjusted R-squared           0.214381   S.D. dependent var            2461.814
S.E. of regression           2182.033   Sum squared resid             66657756
Durbin-Watson stat           0.916339
================================================================================
Equation: D_FT_PER_MJ_PRICE = C(4) + C(5)*D_MJ_DEMAND +
    C(6)*D_US_BRENT_OIL_PRICE
Instruments: D_US_BRENT_OIL_PRICE D_GDP_TOTAL2 C
Observations: 17
--------------------------------------------------------------------------------
R-squared                    0.499879   Mean dependent var            0.551239
Adjusted R-squared           0.428434   S.D. dependent var            0.682571
S.E. of regression           0.516037   Sum squared resid             3.728123
Durbin-Watson stat           1.250468
================================================================================
```

Appendix B

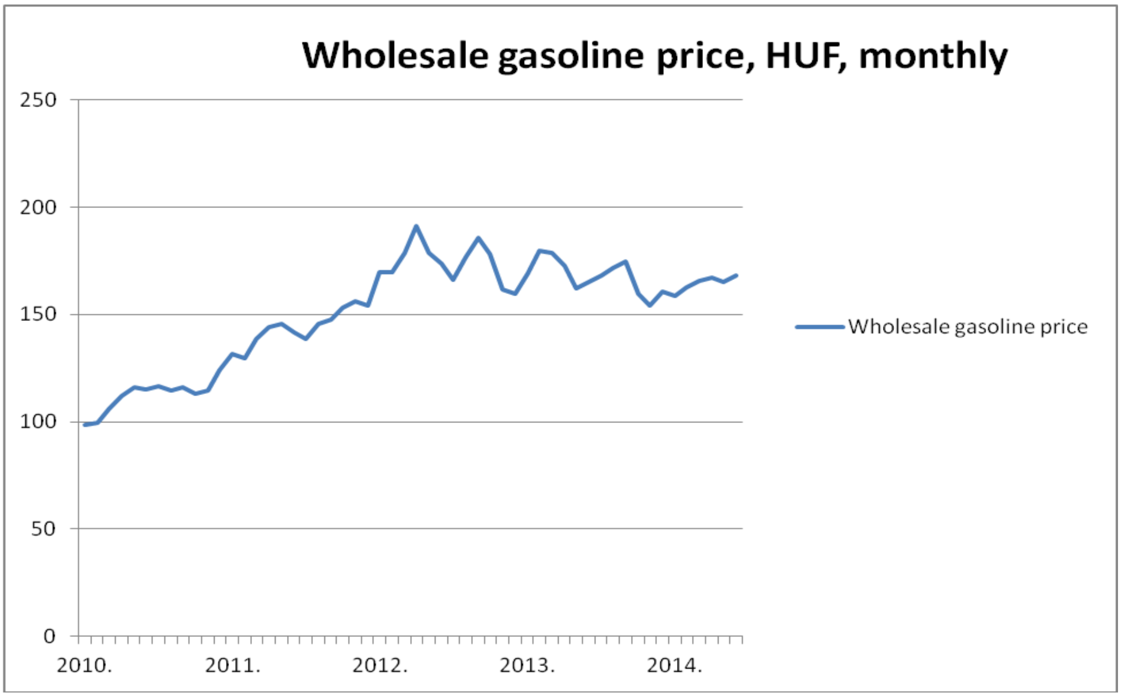


Fig. B.1 Prices of gasoline in Hungary in Hungarian Forints per liter from 2010 to 2014

Source: HÉTFA data collection

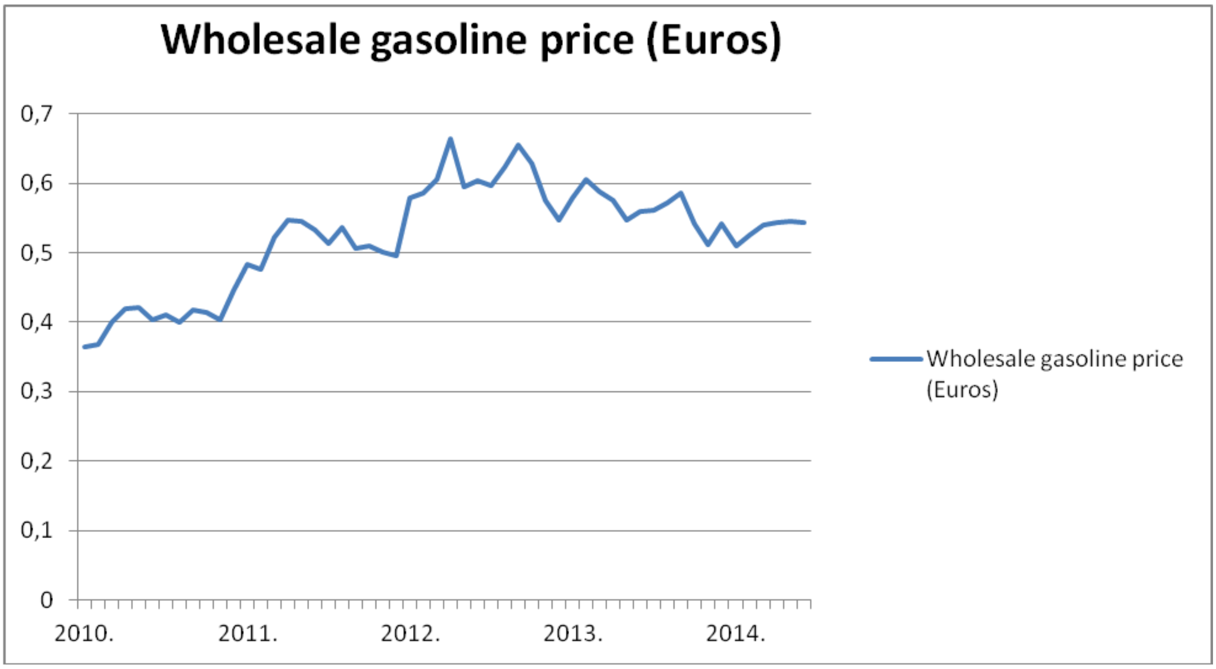


Fig. B.2 Prices of gasoline in Euros per liter from 2010 to 2014, using official exchange rates

Source: HÉTFA data collection

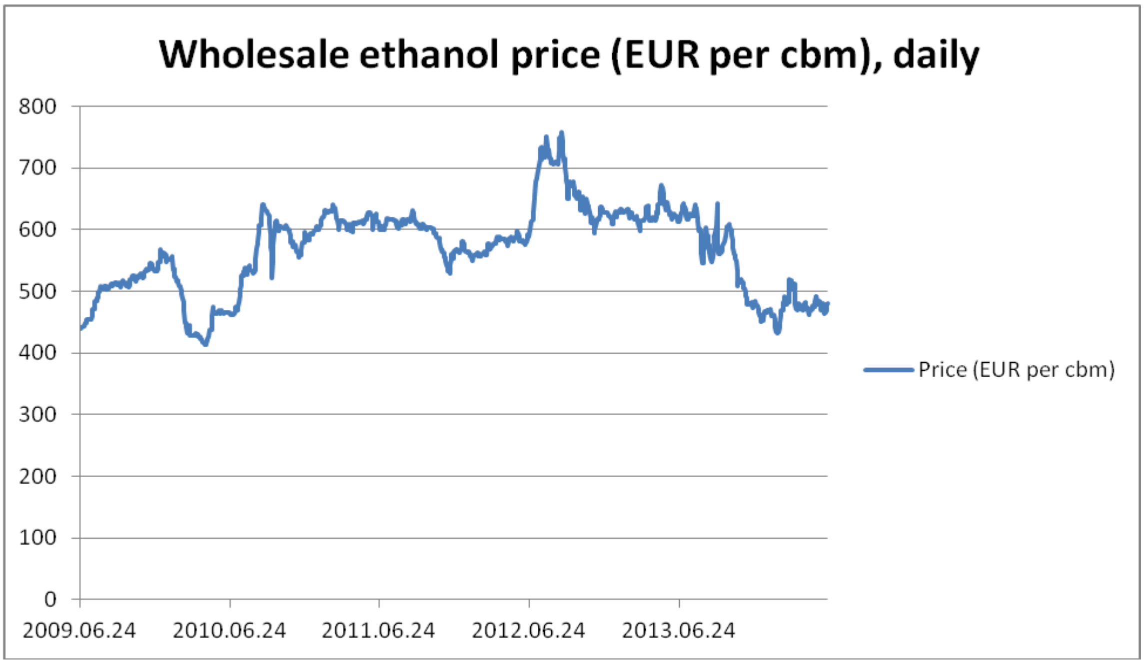


Fig. B.3 Prices of ethanol in European markets in Euros per m^3 from 2010 to 2014
Source: HÉTFA data collection

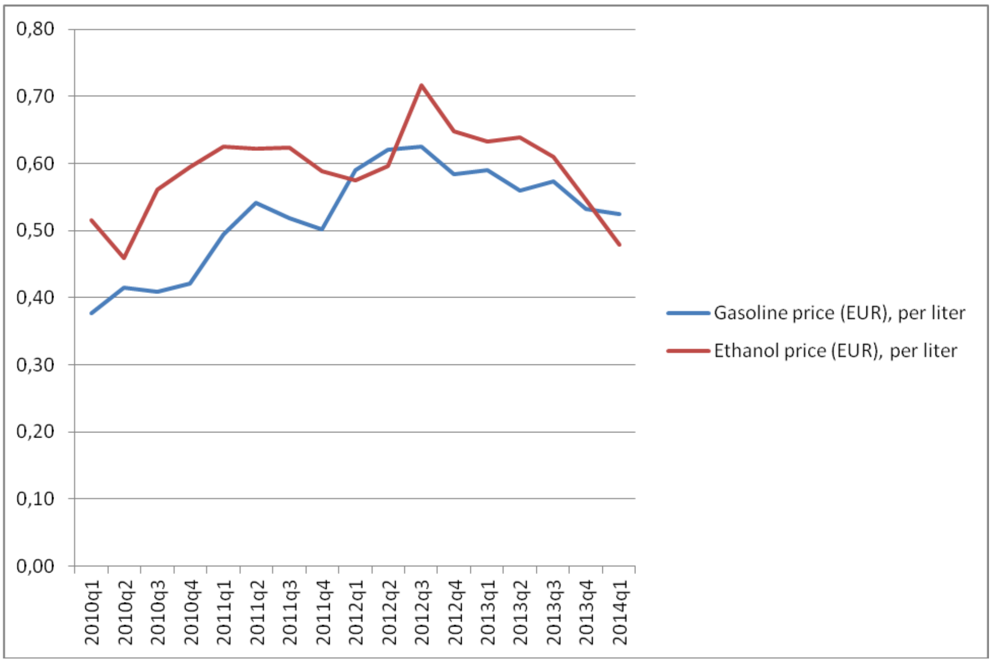


Fig. B.4 Hungarian production prices of ethanol versus prices of gasoline in Euros per litre from 2010 to 2014
Source: HÉTFA data collection and analysis

Appendix C

Energy efficiency effect of E10 blend

BASIC DATA		gasoline	ethanol
density	kg/litre	0,74	0,79
energy density	MJ/litre	31,8	21,2
energy density	MJ/kg	43,0	27,0
carbon emission	g(eq)/MJ	83,8	33,7
HU market price (Q2-2014)	€cent/MJ	1,645	2,066
EU market price (Q2-2014)	€cent/MJ	1,679	2,297

STEP 1
Suppose that we have a car with 5,13 litres/100km consumption of pure gasoline - it is representing the average fleet emissions were 136.6g CO2/km in 2012
In the first step carbon emission and cost of gasoline were calculated

		gasoline
consumption	l/km	0,0513
used energy	MJ/km	1,6304
carbon emission	g(eq)/km	136,626
cost of fuel	€cent/km	2,682

STEP 2
Change the fuel from gasoline to E10 blend
(E10 means here 10%(v/v) ethanol and 90%(v/v) gasoline)

Suppose that there an EEE exists with a value from 1.4% to 2.0%
Source: Figure 4-17 in page 33 of Geringer et al. (2014)
Similar value (around 2%) is given by Kampman et al. (2013), see Figure 12.

		the car	
energy use baseline	MJ/km	1,6304	Taken from Step 1
energy efficiency effect	%	1,8	Varies from 1.4 to 2.0
used energy with EEE	MJ/km	1,6010	

STEP3
Calculate the carbon emissions by E10 blend with calculated energy consumption of 1km travel

One unit of E10 blend contains:

		gasoline	ethanol	E10	rel.to gasoline
volume	litres	0,9	0,1		
energy	MJ	28,62	2,12	30,74	**96,7%**

This result is in line with Kampman et al (2013), where is 97%

Side track calculation: the consumption

		E10	rel.to gasoline
energy is needed	MJ/km	1,6010	
energy content	MJ/litre	30,74	
used fuel	litre/km	0,052083	
used fuel	l/100km	5,208	101,6%

- the consumption of our car is only marginally higher as in the case of using pure gasoline
- this is the result from two parallel effect:
ethanol has lower heating value but increases the efficiency
- this result is in line with Figure 4-2 of Geringer et al (2014)

Carbon emissions from using E10 blend:

		gasoline	ethanol	E10
energy content	MJ	28,62	2,12	30,74
energy use	MJ/km	1,491	0,110	1,601
carbon emissions	g(eq)/MJ	83,8	**33,7**	
emitted carbon	g(eq)/km	124,914	3,721	128,635

ethanol value: 33,7 without iLUC and
46,7 with iLUC
(iLUC=13g(eq)/MJ)

STEP 4
The carbon mitigation cost by E10

Production cost of E10 blend

		gasoline	ethanol	E10
energy content	MJ/km	1,491	0,110	
production cost	€cent/MJ	1,645	2,066	
cost of fuel	€cent/km	2,452	0,228	2,680

The carbon abatement cost is the following:

		gasoline	E10	difference
emitted carbon	g(eq)/km	136,626	128,635	7,991
cost of fuel	€cent/km	2,682	2,680	-0,002
abatement cost	€cent/g(eq)			-0,002
abatement cost	**€/t CO2(eq)**			**-2**

All simulations were shown in Table 19