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Biofuels and the Neglected Societal Dimension of Sustainability in EU Decision-Making on Fuels from Renewable Sources

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The authors are affiliated with the Faculty of Governance and Global Affairs (FGGA), Leiden University (Bonenkamp and Kamphof) and the Delft University of Technology, Microelectronics Department (Middelburg and Wolffenbuttel), respectively. In this paper, they aim to bridge gaps between social and technical sciences in the study of biofuels.

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# Abstract

Biofuels, in the form of bioethanol and biodiesel, were the first viable option in the transition towards a large-scale renewable fuel economy with a reduced dependency on fossil fuels. Bioethanol has been successfully and remarkably smoothly introduced to the fuel infrastructure, owing to the fact that it: can be easily blended with petrol (in practice E10 and E85), can be used in conventional combustion engines and has 58% of the energy density of petrol (thus not dramatically impacting full-tank travel range). Similarly, biodiesel can be blended with regular diesel (B7 and B20). In contrast, the decision-making process on biofuels in the European Union (EU) has been particularly turbulent, including U-turns due to changing priorities and re-assessments of the environmental impacts (including side-effects). Energy security and socio-economic issues related to the agricultural sector have dominated the discussion, while the social dimension and continuity of intra-European mobility appear to have been pushed aside.

The two-stage research question addressed in this article is the following: 1) What political, institutional and technical factors enable or impede the scenario of mass-scale introduction of E85 and bioethanol flex-fuel automotive production in the EU and 2) how would the EU decision-making process be affected by the prospect of bioethanol leading the EU towards a methanol-based renewable fuel economy, through its potential to facilitate a seamless transition of the energy infrastructure while maintaining long-distance intra-European mobility?

The EU decision-making process concerning biofuels is analyzed. Subsequently, an assessment is made of the benefits of a non-disruptive change of the present fuel economy towards one based on energy from renewable sources, with an emphasis on the importance of the continuity offered by the use of liquid fuels. The possible role of bioethanol in realizing a methanol-based economy from renewable sources is investigated within this framework, both in terms of the fundamental technical concept and the potentially positive impact on the decision-making process in the EU.



***Keywords****: Biofuel, EU decision-making, methanol-based fuel economy, EU shared competence, non-disruptive infrastructural change, Intra-European mobility.*

# Contents

## 1. Introduction

The EU is facing unprecedented environmental, security and economic challenges. An important step towards seeking solutions came in 2015 when the European Commission and its President Jean-Claude Juncker announced ten priorities for the period between 2014 and 2019.[1] Two of these reflect the urgency to find a set of EU-wide solutions for the transportation sector.

Firstly, the priority of 'a resilient energy union with a forward-looking climate change policy' reaffirms the belief that energy and climate policy are two sides of the same coin. The need for the EU to 'reduce its dependence on fossil fuels and cut greenhouse gas emissions' is weighed against the aim of 'providing households and businesses with affordable energy'. Reducing dependence on fossil fuels, more than 50% of which is imported, would improve the security of the energy supply.[2] While '94% of transport relies on oil products, of which 90% are imported', the European transportation sector accounts for 25% of energy-related greenhouse gas emissions, 70% of which originate from road transport.[3]

Secondly, as stated in the Juncker priority of 'a new boost for jobs, growth and investment', investment will be targeted towards infrastructure, including transport, and that the priority will be given '(...) to removing the significant regulatory and non-regulatory barriers which remain across key infrastructure sectors including (...) transport'. In other words, the current infrastructure differences between member states remain an impediment to intra-European mobility, which calls for innovation in the transportation sector.

The decision-making process on energy infrastructure and transportation in the EU is significantly complicated by the fact that these policy domains are a shared-competence and therefore subject to the co-decision-making procedure. This applies to biofuels, which were initially introduced with inherent benefits over traditional fossil fuels, such as greater energy security, a reduced impact on the environment and socio-economic advantages for the agricultural sector. The term 'biofuels' is generally used to classify renewable fuels which originate from biomass or organic waste. The two

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[1] European Commission, 2015. Ten priorities for Europe: A new start for Europe: an EU agenda for jobs, growth, fairness and democratic change. /ec.europa.eu/commission/publications/president-junckers-political-guidelines_en [accessed December 29, 2017]

[2] Energy production and imports, 2017. Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_production_and_imports#Energy_security [Accessed December 29, 2017].

[3] European Commission, 2016. A European Strategy for Low-Emission Mobility. COM (2016) 501 final, p. 2. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52016DC0501. [Accessed December 29, 2017].

main components are biodiesel, from vegetable oil (e.g. soybean or rapeseed) and bioethanol, which can be produced from biomass from such as plants, agricultural and forestry debris and a large portion of waste streams (Su et al., 2015). The main commercial sources are sugar cane and maize. Bioethanol can be easily blended with petrol (i.e. E10 and E85, which refer to petrol mixed with 10% and up to 85% of bioethanol by volume, respectively) for use in conventional petrol engines, while biodiesel can be blended with regular diesel fuel (similarly, B7 and B20) for use in diesel engines. As the political discussion focuses on bioethanol, we limit our analysis to the decision-making aspects of biofuels and specifically on bioethanol.

Globally, about 60 % of the bioethanol produced is derived from feedstock from sugar crops and is referred to as 'first-generation biofuel' (Demirbas, 2009). From 2000 to 2015 global ethanol production for fuel use increased from 17.1 to 84.4 million cubic meters.[4] The first bioethanol producing country was Brazil, which was also the first to introduce flex-fuel vehicles to the market in 2003 and flex-fuel motorcycles in 2009, encompassing 24% of the total motorcycle fleet in 2015.[5] Presently, more than 80 percent of vehicles operated in Brazil use bioethanol-blended fuels and by 2020 flex-fuel vehicles are expected to comprise 86% of the entire light-duty vehicle fleet (Demirbas, 2009; H.M. and Nuñez, H.M., 2016). In Europe, Sweden has the largest flex-fuel fleet in the European Union, with about 200,000 flex-fuel vehicles out of a total fleet of 300,000 alternative-fuel based passenger cars.[6]

In countries all over the world bioethanol production is promoted by means of *public* measures, such as tax exemptions, subsidies, blending mandates or other (financial) incentives. Leading bioethanol countries maintain large government programs to support the production and export of biofuels, while sometimes also incentivizing citizens/automotive industries to buy/sell biofuel blends. Brazil was previously the only country where ethanol production was profitable and competed with that of petrol (Sorda et al., 2010). In Brazil bioethanol is produced from sugar cane, which is considered 'the most sustainable option currently in the market' (Afionis and Stringer, 2012). The United States, however, has been the largest producer of bioethanol from 2006 onwards. A typical feature of US bioethanol production relates to security issues with energy independence and the promotion of

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[4] Energy Information Administration (EIA) 2018, http://www.eia.gov/totalenergy/data/annual/index.php. [Accessed February 10, 2018]

[5] Brazilian Transportation Fleet, 2017. Retrieved from http://sugarcane.org/the-brazilian-experience/brazilian-transportation-fleet. [Accessed June 16, 2017].

[6] Advanced Motor Fuels in Sweden, 2015. Retrieved from http://iea amf.org/content/publications/country_reports/Sweden. [Accessed June 16, 2017].

American (agricultural) industries as additional reasons for bioethanol policy decisions (Grossman, 2013). China also provides incentives for a biofuel-based infrastructure, with large bio-energy and bio-policy programs supported by the government (Su et al., 2015). However, the current relatively low oil price has led to increased scrutiny of policies promoting biofuels.[7]

The most significant drawback is the need for (agricultural) land for biofuel production, which inevitably leads to the debate over food and energy security. Consequently, the controversies surrounding biofuels have shifted focus towards alternative energy solutions, such as all-electric vehicles and a hydrogen-based fuel economy, and away from the fundamental benefits of biofuels. Yet biofuels have the potential to function as the interlocking mechanism between state-of-the-art and a renewable energy-based infrastructure of the future, because of compatibility with existing infrastructure built for fuels that are liquid at ambient conditions. However, this implies that only one aspect of Juncker's priorities is addressed (i.e. 'making energy more sustainable'), while two equally important aspects (i.e. 'making energy more secure and more affordable') appear to be overlooked. While the European 'alternative fuels strategy' supports a comprehensive mix of fuels for ensuring 'technological neutrality' and diversification of the energy supply, it is questionable whether biofuels have been adequately considered.[8] Therefore, placing more emphasis on the inter-European mobility argument may act as a catalyst in the decision-making process.

This article is a combined politico-institutional and technical study intending to reveal the political, legal, institutional and technical aspects that are enabling or impeding efforts towards realizing a scenario of bioethanol production and consumption in the EU automotive sector. The objectives of this article are to: 1) analyze decision-making processes in the EU in relation to biofuels, 2) point out that continuity of intra-European mobility is a critical societal aspect of sustainability, and 3) re-establish the legitimacy of bioethanol (E85) in the EU as an enabler of a transition towards a fuel economy based on methanol from renewable sources, without a complete overhaul of the fuel distribution network and vehicle design sector.

[7] International Energy Agency, 2015. Renewable Energy: Medium-Term Market Report. https://www.iea.org/Textbase/npsum/MTrenew [accessed November 27, 2017].
[8] European Commission, 2013. Communication 'Clean Power for Transport: A European alternative fuels strategy', COM (2013) 17 final, 24 January 2013, Brussels. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52013PC0017. [Accessed November 27, 2017].

## 2. The Discussion on Fuel from Renewable Sources and the Role on Biofuels Therein

The discussion on bioethanol has a long history. Initially it was favorably regarded as a renewable fuel. The negative side effects of the bioethanol-based energy scenario, such as competition with food production and impact on bio-diversity, have been widely debated and have resulted in negative public opinion of the concept. This change has had a significant impact on the decision-making on biofuels in the European Union (EU) and is briefly reviewed below.

An essential factor of EU decision-making on energy infrastructure choices is that any EU-wide agreement must follow the co-decision-making procedure. This policy domain is a shared-competence, as mentioned in Article 126 of the Treaty on the Functioning of the European Union and requires agreement of both the EC and member states.[9] As will be established below, although this procedure significantly complicates decision-making, it also provides a framework for assessing to what extent the continuity of trans-European mobility potentially influences EU decision making.

The environmental dimension of biofuels is characterized by a two-fold debate: there are those who believe that biofuels are part of the solution (i.e. reducing $CO_2$ emissions), while others consider it to be part of the problem (Searchinger and Heimlich, 2008; Fargione and Hill, 2008). While proponents of biofuels have economic arguments in mind why biofuels should be adopted, opponents outline ecological challenges that biofuel cultivation can entail. However, arguments that that are derived from the social dimension are scarce and typically limited to country-specific circumstances. For instance, while Norway predominantly relies on electrical and hydropower, Sweden has historically been much more leaning towards use of bio-waste for biofuel purposes (Ydersbond, 2014).

Ever since 2008, when the EU became more reluctant to promote conventional (i.e. first-generation) bioethanol EU-wide for environmental reasons, farmers and civil society groups have met this development with unease and protest. The general agricultural position as expressed by an influential interest group for European farmers, COPA-COGECA, that bioethanol gives '[...] prospects of new economic opportunities'[10] is opposed by environmental civil society groups, which have emphasized the dangers of continuing crop-based (first-generation) bioethanol production in the EU and have

[9] Consolidated Version of the Treaty on the Functioning of the European Union, 26 October 2012. (2012/C 326/47). http://eur-lex.europa.eu/legal- content/EN/TXT/PDF/?uri=CELEX:12012E/TXT&from=EN [accessed March 15, 2017]
[10] Copa Cogeca's position on the EU's biofuels Policy. Copa Cogeca, 2013. https://copa-cogeca.eu/Main.aspx?page=Papers&lang=en&id=20122. [Accessed August 30, 2017]

urged (through major initiatives) the EU to cease bioethanol production activities altogether.[11] However, the discussion mainly centers on the environmental and economic dimensions of sustainable development, while the social dimension is often overlooked.

The change in the 'green credentials' of bioethanol after the negative side effects became widely known forced the EU to attempt to remove bioethanol as an option by phasing out first-generation biofuels. Unfortunately, this somewhat abrupt reversal of policy left little room for the careful consideration of second-generation bioethanol derived from bio-waste or third-generation bioethanol derived from algae (which uses barren or marginal land and water resources, such as salt water and waste water (Su et al., 2015)). Nevertheless, amongst the European public it was found that a large part of the respondents (72%) favored the idea of promoting biofuels. Still, a higher share of respondents (83%) supported the idea of promoting *sustainable* biofuels, showing that encouraging second-generation biofuels was considered more desirable.[12] This has caused a disruption in the biofuel energy market, which, from an economic point of view, has resulted in losers (first-generation bioethanol producers) and winners (environmental groups) at the same time.

The EU's position on bioethanol remains subject to criticism and is condemned by Members of the European Parliament and various lobbying organizations. Nevertheless, first-generation bioethanol production is to be gradually decreased until 2030, while at the same time second-generation bioethanol is to be promoted.[13] This indicates that the Commission does not seek to abandon the concept of bioethanol entirely.

The positioning of bioethanol fuel within the spectrum of recognized viable renewable fuel infrastructures requires an overview of the options. It should be noted that this paper is not intended as an overview of the issues and merits of any of the acknowledged fuel infrastructures nor is it a comparative study of any of these. Overviews and comparative studies on, for instance, hydrogen, are available in the literature (Crabtree et al., 2004; Chalk and Miller, 2006). Moreover, no claims will be made on the technical or economic superiority of biofuel. The sole purpose here is to position the

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[11] Biofuel Campaign: Please support the scientists' call to protest, 2014. Retrieved from https://www.rainforest-rescue.org/petitions/774/biofuel-please-support-the-scientists-call-to-protest [Accessed June 17, 2017].
[12] European Commission, 2010. Special Eurobarometer on Biotechnology. European Union. http://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_341_en.pdf. [Accessed June 23, 2017].
[13] European Commission, 2017. White Paper on the Future of Europe: reflections and scenarios for the EU27 by 2025. https://ec.europa.eu/commission/sites/beta-political/files/white_paper_on_the_future_of_europe_en.pdf. [accessed November 30, 2017].

bioethanol and methanol fuel economies as highly suitable candidates within a chain of transition infrastructures composed of several liquid fuel types ('the energy mix') to enable a non-disruptive energy transition. Consequently, the arguments provided cannot be considered as constituting a comprehensive comparative analysis of the different renewable fuel economies listed in Fig. 1.

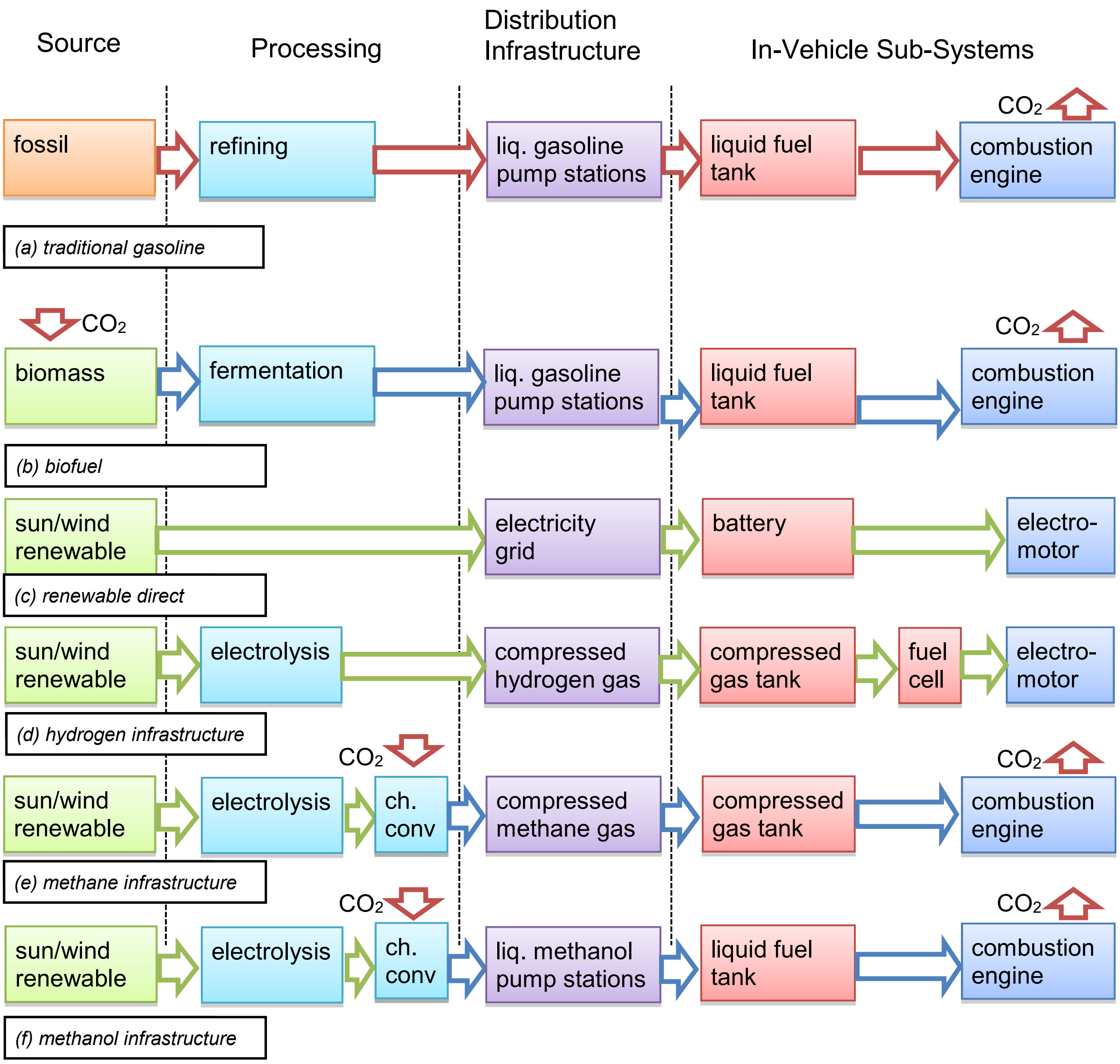


*Figure 1. Scenarios for energy infrastructure*

When analyzing an energy infrastructure system, it is useful to divide it into three parts: (a) generation and central processing, (b) fuel distribution and dispensing infrastructure and (c) in-vehicle sub-systems. Central processing can be a large-scale industrial operation which can be designed for high efficiency, for instance for electrolysis in a hydrogen scenario or chemical conversion in methane and methanol scenarios. However, it can also be the aggregate of many small-scale producers, such as privately-owned solar panels on the roofs connected to a smart grid in an all-electric scenario.

The public discussion is primarily on the generation of renewable energy and central processing. However, these are not the critical parts of the system. The impact of fuel storage, distribution and dispensing on infrastructure is often underestimated, for instance the compatibility requirements imposed to serve all vehicle types in circulation. The difficulty with the in-vehicle part of the system is that the vehicle is the actual mass-fabricated component of the system. Consequently, it is more difficult to achieve high efficiency in such a small system and to justify changes due to the costs associated with the large number of units involved.

State-of-the-art infrastructure is based mainly on liquid fuels in combination with traditional fossil fuels and biofuels (combination of Scenarios 1a and 1b). In Europe the standard biofuel obtainable at petrol stations has a low-ethanol content and is typically petrol mixed with 10% bioethanol by volume (referred to as E10 fuel).[14] High-ethanol content biofuel, with up to 85% bioethanol by volume (referred to as E85), is widely available in other countries, especially in the USA (Balat and Balat, 2009). In most cases conventional petrol combustion engines can burn E10 without problems, so the petrol station can simply be modified to dispense the low-ethanol blend without the customer even noticing the slight decrease in energy content per unit of volume. So-called flex-fuel vehicles are specially designed to run on fuel mixtures consisting of any ratio between petrol and ethanol, using a sensor system to notify the engine management system, which allows in principle any ratio to be used (Middelburg et al., 2017). This flexibility enables matching of bioethanol use to availability (for instance high ethanol content in agricultural areas in an attempt to maximize the local socio-economic benefits).

The negative turn in the discussion on bioethanol has brought the all-electric scenario (Fig. 1c) to the foreground, which has a pervasive public appeal due to the evident unmodified use of renewable energy. Disadvantages such as the use of rechargeable batteries and the associated environmental problems of mining and recycling are included in the margin of the debate and generally considered manageable. [15] The current electricity grid is not dimensioned to deliver an enormous amount of

[14] Blue One. (2017). Retrieved from https://www.blueone95.nl/ [Accessed December 29, 2017].
[15] Wade L. (2016, March 31). Tesla's electric cars aren't as green as you might think. Retrieved from http://www.wired.com/2016/03/teslas-electric-cars-might-not-green-think/ [Accessed April 8, 2016].

energy to enable e-mobility on a large-scale. [16] Moreover, the increased demand for electric power comes with an increased variability of supply due to more power being generated locally by windmills and rooftop solar panels. One proposed solution is the smart grid, which would alleviate the demands on the grid by, for instance, attempting to match supply and demand at the local level by employing communication systems and large-scale storage of off-peak generated power. The embedding of the enormous, diverse electric power network in the energy infrastructural legacy is one of the major causes delaying the availability of sufficient capacity to ensure e-mobility until 2050, as indicated in the Technology Roadmap of the International Energy Agency.[17]

Another operational challenge is the limited travel range between re-charging nodes, which has resulted in the use of the term 'range anxiety' to express the reluctance of would-be users to drive electric vehicles. Unsurprisingly, the expected increased use of battery-powered electric vehicles was found to depend mainly on the availability of charging nodes beyond home and the workplace (Neubauer and Wood, 2014). Especially when fast charging is factored, the load on the electricity grid can grow rapidly. When charging a 100kWh battery within a time span of 5 minutes, 1.2 MW of power is required during charging, which in practice will introduce peak loads on the grid. These issues are typically down-played by the public's confidence in future technological developments.[18] At the same time, however, there is widespread consensus within the EU that long-distance travel coupled with electrification presents serious challenges. A study by the European Commission reckons that '[...] Apart from rail, electrified transportation technologies still lag behind conventionally powered systems in terms of range, cost and appropriate refueling systems'. A new infrastructure is required which is composed of a network of charging points. These are in development in several European countries ("Charging Infrastructure[19] " and "Charging on the Go[20] "), but access to recharging systems remains an issue.

Complications due to the energy density of the fuel or the energy storage medium have prompted research into alternative options for renewable energy infrastructures as listed in Figs. 1d-f. In each

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[16] Vaughan, A. (2017). Electric cars will fuel huge demand for power, says National Grid. Retrieved from https://www.theguardian.com/business/2017/jul/13/electric-car-boom-power-demand-national-grid-hinkley-point-c [Accessed July 13, 2017].

[17] IEA, 2011. Retrieved from: https://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf. [Accessed December 29, 2017]

[18] The Economist, 2017. Accessed: 2017, August 12. Electrifying everything. Retrieved from https://www.economist.com/news/briefing/21726069-no-need-subsidies-higher-volumes-and-better-chemistry-are-causing-costs-plummet-after [Accessed August 16, 2017]

[19] Charging infrastructure. Retrieved from http://nederlandelektrisch.nl/charging-infrastructure

[20] Charging on the Go: Plug into the Largest and Smartest Charge Network in Europe. (2017). Retrieved from https://newmotion.com/en/charging-solutions/charging-on-the-go [Accessed August 23, 2017]

option, the input is electricity from renewable sources which is converted in hydrogen by electrolysis in the hydrogen-based fuel economy (Fig. 1d) and subsequently into methane (in Fig. 1e) or methanol (in Fig. 1f) by means of a catalytic reaction and binding of atmospheric $CO_2$. Although experimental implementations exist which demonstrate the concept of an internal combustion engine (ICE) running on hydrogen, these typically require major changes in engine technology. Components requiring a dedicated design are for example material selection, lubrication methods, cooling systems and the complete fuel system. A mature version of a hydrogen-based ICE would require more research on fundamental problems. The pressurized fuel tanks of a hydrogen-based car can be considered more complex than traditionally fueled cars. However, experimental implementations show tank pressures of 350 bar and beyond using materials such as carbon and aluminum (Verhelst and Wallner, 2009). It should be noted that compression when cooling fuels that have a gaseous composition at ambient conditions, for the purpose of achieving a practical energy density, leads to a loss in overall well-to-wheel efficiency. What is an essential factor for options (e) and (f) is that the traditional combustion engine is used, albeit modified to run on methane or methanol. The electromotor in Fig. 1d calls for a more structural re-design of the vehicle, but avoids in-vehicle $CO_2$ generation and pollutants altogether. Ignoring the carbon recycling makes the hydrogen-based fuel economy appear more effective in reducing $CO_2$ emission. The methane-based fuel economy relies on the Sabatier reaction, in which environmental $CO_2$ and hydrogen is converted into methane and water at a high temperature and pressure using a nickel catalyst. Low-temperature systems are being explored using iron and sunlight (Rao et al., 2017). Although methane is itself also a greenhouse gas[21] and requires pressurized tanks, in several European countries, natural-gas powered buses are used for public transportation.[22]

The overall concept of the hydrogen-, methane- or methanol-based fuel economy is that electricity originating from any source, preferably sustainable, can be converted into a high-energy density carrier. Furthermore, liquid methanol has the advantage of being compatible with current state-of-the-art automotive technology, and the distribution and dispensing networks. Within this concept the societal or political objections typically related to the ethanol-based fuel economy are not applicable and issues with the huge power strain on the electricity grid can be circumvented, since methanol production can be centralized.

[21] U.S. Environmental Protection Agency, Greenhouse Gas Emissions: Overview of Greenhouse Gases, 2017. Retrieved from www.epa.gov/ghgemissions/overview-greenhouse-gases. [Accessed November 13, 2017]

[22] Commission letter: transition from HTM busses (in Dutch), 2007. Retrieved from https://denhaag.raadsinformatie.nl/modules/13/overige_bestuurlijke_stukken/612 [Accessed November 13, 2017]

The liquid fuel infrastructure in Fig. 1 would not suffer from such operational constraints (Vancoillie and Verhelst, 2010). Both methanol and ethanol are liquid alcohols that can in principle be produced from hydrogen in a catalytic reaction. Although ethanol derived from electricity via hydrogen would be seamlessly compatible with a bioethanol infrastructure, production of methanol from hydrogen (here referred to as the methanol-based fuel economy) can be less difficult and more efficient. This methanol-based fuel economy concept has indeed already been promoted, leading George Olah receiving the Nobel Prize in Chemistry for his research in 1994. (Olah, 2005; Wesselbaum et al., 2012).

Besides their compatibility advantage, liquid fuels provide competitive operational characteristics. The most important of these is energy density, which (along with conversion efficiency) determines the travel distance between re-fueling when considering a storage capacity that is sufficiently proportional to the dimensions of the vehicle (see also Table 1).

| Fuel<br>Mode | Road/Passenger | | | Road/Freight | | | Air | Water | |
|---|---|---|---|---|---|---|---|---|---|
| Range | *Short* | *Medium* | *Long* | *Short* | *Medium* | *Long* | | *Inland* | *Sea* |
| *Electricity* | X | | | x | | | | | |
| *Biofuels* | X | X | X | x | X | X | x | x | x |
| *Hydrogen* | X | X | X | x | x | | | x | |

*Table 1: Travel range coverage for the main types of renewable fuel, adapted from European Commission, Alternative Fuel Strategy[23]. Note that bioethanol is typically applicable to road/passenger, while biodiesel is used in road/freight.*

There is no widespread consensus on the most suitable scenario for a fuel economy based on renewable energy. An important criterion is the overall utilization of the energy, as expressed in the well-to-wheel efficiency. Obviously, any conversion of energy, such as a catalytic reaction, takes place at a certain efficiency, which is a strength of the direct use of electrical energy in e-mobility that needs to be balanced against the limitations of energy density. Other criteria, such as the compatibility with the state-of-the-art in fuel storage and dispensing infrastructure, are often considered less relevant. Meanwhile, there is a growing sense of urgency. Awareness is growing that satisfying $CO_2$ targets will require a very challenging reduction in fossil fuels within a relatively short time period. Moreover, the negative impact of an abrupt and complete overhaul of the existing energy infrastructure is

[23] European Commission, 2013. Communication ‘Clean Power for Transport: A European alternative fuels strategy’, COM (2013) 17 final, 24 January 2013, Brussels. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52013PC0017. [Accessed November 14, 2017]

acknowledged. However, the benefit of an evolving fuel infrastructure consisting of the mixing of fuels, while some (fossil) components are phased out and others (renewables) are phased in, has not yet been widely realized. The merit of such a non-disruptive approach, and the role of biofuels therein, is the key argument in this study.

Biofuels require only minor changes to the operational characteristics of fossil-fuel vehicles, as is the case with methanol, while other fuel scenarios, such as battery-based and hydrogen-based, will require major changes in both energy infrastructure and vehicle design. Consequently, the daunting task of managing the transition towards greener energy infrastructure without socio-economic fallout will likely be easier if a smooth transition can be *a priori* ensured. The fact that bioethanol provides the perfect opportunity for the EU to transition smoothly from the first into a next renewable fuel infrastructure, because of its compatibility with the existing infrastructure based on liquid fuels (i.e. without major changes to the fuel distribution and dispensing systems and only minor adjustments to current engine technology), has received scant attention and should be considered in any discussion on the (electrical) transition of the fuel market. After all, shouldn't the European public have the right to continue travelling throughout the European continent without being interrupted by an energy transition? An interconnected European continent is in the interest of all Europeans and affects all dimensions of sustainability. This effect is barely acknowledged in the different scenarios presently being considered for a transportation system based on energy from renewable sources. Therefore, what is discussed in this work is an assessment of European policy initiatives specifically regarding the social dimension of sustainability within this compatibility framework, which is a new and highly relevant aspect to be explored.

This paper argues that the compatibility advantage of the already proven concept of bioethanol could be regarded as a first step in a chain of non-disruptive transitions towards a 'green' transportation infrastructure network based on liquid fuels. The liquid composition of methanol derived from renewable sources could be an interesting subsequent step. Such a sequence of steps may facilitate decision making and assist in reconciling the two Juncker priorities mentioned; the need to adopt an ambitious climate change policy with non-interrupted seamless inter-European mobility.

## 3. Methods

For our analysis we use the conceptual framework of the three dimensions of sustainability, which presumes that sustainability as a whole is composed of three dimensions: environmental, economic and social[24]. This framework has had widespread use in different assessments of sustainable development (Baumgartner and Rautner, 2017; Strezov, Evans and Evans, 2016; Cavagnaro and Curiel, 2012) and can also be applied to describe the EU's policy considerations regarding biofuels. Firstly, the development of biofuels must cause as little harm to the environment as possible, ensuring long-term environmental preservation in Europe for generations to come (Sobrino and Monroy, 2009). Secondly, there is an important economic dimension to the development of sustainable biofuel rules and policies. Biofuels need to provide a sufficient economic incentive for businesses, consumers and other stakeholders, to consolidate continuous economic growth. Thirdly, social factors and the concrete, long-term needs of the European population, such as household energy security and employment, need to be considered when biofuel production or usage policies are developed. Above all, as this research reveals, biofuels can and should be implemented as a non-disruptive transition fuel to bolster intra-European mobility in the current energy transition taking place. It is important to note that different disciplines take different views on the three dimensions of sustainability, especially the social dimension. For instance, a politician might take into consideration organization and governance aspects, whereas an anthropologist may refer to general health and wellbeing and an ecologist will strictly maintain an environmental perspective (Magee, Scerri, James, 2012). In this analysis, sustainability is regarded from the perspective of the non-disruptiveness and long-distance travel aspects of bioethanol from a *politico-technical* perspective. This multi-disciplinary approach inevitably and profoundly affects the way the results of this research on biofuels are presented, which is a combination of qualitative methodology, as is customary in political science, and an analytical study, as is customary in technical sciences.

Findings from the literature and analytical technical work were combined, followed by two rounds of interviews, including a total of thirteen semi-structured interviews, conducted with European stakeholders in the renewable energy field. The first round formed the basis for analyzing the state-of-the-art in EU politics and decision-making on the issue. The second round was used to gain more insight into the opinions of these experts and/or stakeholders. Participants were questioned about

[24] Report of the United Nations Environment Assembly of the United Nations Environment Programme, United Nations, 2014. https://shop.un.org/series/report-united-nations-environment-assembly-united-nations-environment-programme [Accessed February 13, 2017]

transportation infrastructure the merit of the transitioning from an ethanol- towards a methanol-based infrastructure network, as compared to the current 'preferred option' of relying on electrical- or hydrogen-based infrastructure for the transition, and the role that the non-disruptive aspect could play in the debate and decision-making on biofuels.

As the objective of this paper is to combine political, institutional and technical perspectives, this research is based on a combination of a review (literature, policy documents, case-law, legislation) of technical research on the petrol/ethanol/water composition of biofuels as well as thirteen semi-structured interviews with (mainly) EU and Member State officials at the policy adviser level, (assistants of) Members of Parliament and multiple societal stakeholders in the car industry, agricultural industry, etc., as well as Civil Society Organizations.[25] The study focuses on the period from the introduction of the Renewable Energy Directive and Fuel Quality Directive (2009), which almost coincided with the entry into force of the Lisbon Treaty. The findings in this paper are based on multiple sources of information, which are brought together through triangulation. The interviews were semi-structured and lasted approximately 60 minutes. Some interviews were conducted by phone. The interviewees received the general semi-structured questions at the latest 12 hours before the interviews. Not only do interviews help to identify empirical patterns, but they also provide input for theorizing any relationship and analyzing the political decision-making process involved with technical decisions. The weaknesses of interview data are mitigated by using the interviews in conjunction with other forms of evidence (Lynch in Mosley, 2013: 31-44).

# 4. The EU debate on renewable fuel and biofuel specifically

## 4.1. Analysis of the dynamics of the debate

Although the EU is not a significant bioethanol producer, the issue is high on the political agenda. The EU is a global leader in environmental policy (Kelemen, 2010) and has delivered an important contribution to the UN's 2030 Agenda for Sustainable Development (Afionis, 2011). Its environmental legislation addresses areas from reducing greenhouse gas emissions, to recycling, to waste management (Afionis and Stringer, 2012). The discussion and decision-making in the EU is nonetheless complicated by a number of legal and political factors: Firstly, in almost all policy areas related to biofuels (primarily transport, energy, environment, and agriculture) the EU and Member States *share*

[25] Interviews were carried out between 19/07/2016 and 17/05/2017. Please see the Annex for more information on the anonymised interviews.

*competences*, with trade as a notable example of an exclusive EU competence while tax policies, land-use policies and the energy mix remain competences primarily in the hands of Member States. The mixed competences force the EU and Member State actors to coordinate their actions, both within the EU as well as in external forums. As a result, many interests need to be balanced. For example, France has a large agricultural lobby and is historically oriented towards using (bio-)diesel. Germany, on the other hand, is a more petrol-oriented country with a large automotive industry. These country-specific interests need to be balanced in the politico-institutional context of E85 in the EU.

Secondly, the policy debate has led to some U-turns in EU policies. Many protests against rising food prices and critical scientific reports led in 2012 to an amendment dropping the initial 10 percent target of biofuels in transport from the 2009 Renewable Energy Directive to 7 percent *without* food-based biofuels[26]. In the more recent 'Strategy on Low-Emission Mobility' report, the Commission suggests phasing out all subsidies to these first-generation biofuels by 2020[27]. The transition towards advanced biofuels was adopted after difficult and long discussions on the Indirect Land-Use Change (ILUC). Therefore, while originally on the list of alternative fuels, blending biofuels with petrol seems only to be a *transitional* phase. Symptomatically, few funds promote biofuel-related research: DG CLIMA-managed NER-300 programs diminished and Horizon-2020 research funding on biofuels barely continued after 2015/2016. [28] The 'U-turns' in policies on alternative fuels have led the Member States to fragmented initiatives, with some countries focusing on hydrogen (e.g. Germany), others on electrification, and newer EU13 Member States focusing on traditional combustion engines instead of controversial food-based biofuels.

Thirdly, transport and agriculture are so-called 'non-ETS' sectors in the European Union: these sectors are not part of the EU Emissions Trading System and therefore are not regulated at the EU level. It is therefore the responsibility of Member States to define and implement national policies and measures

[26] European Academies Scientific Advisory Council, 2012. The current status of biofuels in the European Union, their environmental impacts and future prospects. EASAC policy report, 19, Dec. 2012. https://www.easac.eu/fileadmin/PDF_s/reports_statements/Easac_12_Biofuels_Complete.pdf. [Accessed November 27, 2017]

[27] European Commission International Cooperation and Development. The 2030 Agenda for Sustainable Development. https://ec.europa.eu/europeaid/policies/european-development-policy/2030-agenda-sustainable-development_en [accessed November 27, 2017]

[28] The Horizon 2020 program makes a total amount of 82.7 million Euros available in both 2014/2015 and 2015/2016 to promote research and innovation into 2nd generation biofuels. In addition to this, in the Horizon Work Programmes 2016-2017 again the development of next generation biofuel technologies was included, indicating a continuation of support for research into more advanced biofuels. See: HORIZON 2020 - Work Programme 2016 - 2017 'Secure, Clean and Efficient Energy'. http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-energy_en.pdf. [accessed November 27, 2018]

to limit emissions. The Effort Sharing Decision from the 2030 EU Energy and Climate Package nevertheless sets national annual binding targets for emissions not covered under the EU emission trading scheme (ETS). However, and specifically relevant for biofuels, emissions from land use, land use change and international shipping are not included. The 2014 directive on 'alternative fuel infrastructure' focuses more on the deployment of infrastructure[29]. Because of this 'Non-ETS' characteristic Member States could develop their own 'national policy frameworks' setting up the market development of alternative fuels and deployment of relevant infrastructure only within the remit of their own national borders. [30]

Fourthly, related to the above-mentioned factors, the Council versus Commission discussions on transport policies in general are traditional 'institutional turf battles' in which Member States are reluctant to transfer powers to the European Commission (Egenhofer, 2011). While the inclusion of transport in the ETS and national 'hard targets' is often coined as an idea, this has been pushed back by the Council and especially some Member States including Germany. Even since the 'Dieselgate' scandal, the Commission has yet to be placed in charge of 'tougher competences', as Consumer Affairs Commissioner Jourova puts it. [31] Interestingly, there is also 'intra-institutional' competition resulting in many DGs (and ministries) with different powers. Mostly, DG ENER takes the lead with policy initiatives, but competences and responsibilities are dispersed across DGs, with DG MOVE (transport) and especially DG AGRI (agriculture) noticeably absent[32]. The European Parliament is slightly less involved, given its lack of technical expertise, but MEPs raised a louder voice in the 'emotional' debates on biofuels in the late 2000s and early 2010s.

Partly because of the controversies surrounding biofuel, the electrification of transport methods using in-vehicle batteries for energy storage (Scenario C) is currently the most popular approach for combatting climate change. Yet the relatively low energy density of Li-ion batteries results in a penalty

[29] Directive 2014/94/EU of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, 22 October 2014, L307/1. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32014L0094 [Accessed November 27, 2017]

[30] An assessment of national policy frameworks is foreseen for November 2017. See European Commission (2017) Communication 'Europe on the Move: An agenda for a socially fair transition towards clean, competitive and connected mobility for all', COM (2017)283 final. Brussels, 31 May 2017, p. 17. https://ec.europa.eu/transport/sites/transport/files/com20170283-europe-on-the-move.pdf. [Accessed November 27, 2017]

[31] Teffer, P. (2017). Dieselgate: EU disappointed with VW's treatment of customers. Retrieved from https://euobserver.com/economic/136983 [Accessed February 21, 2017]

[32] European Commission, 2017. White Paper on the Future of Europe: reflections and scenarios for the EU27 by 2025. https://ec.europa.eu/commission/sites/beta-political/files/white_paper_on_the_future_of_europe_en.pdf [accessed November 30, 2017].

in terms of additional mass of the portable energy and, consequently, in a limited travel range. Hydrogen-based infrastructure is seriously being considered in EU Member States to overcome these limitations, (notably Germany through the H2 Mobility initiative (Garcia, 2017)).

## 4.2. The potential impact of the social dimension on the debate

Since the main question of this article explores the *politico-institutional and technical considerations* of biofuels within the EU, it is essential to note that the policy-making process is typically carried out by taking into account the three dimensions of sustainability, which is consequently used in this work as a theoretical lens. An important cornerstone of the UN's Sustainable Development Goals (SDGs) is the balancing of sustainability dimensions, which was evidently adopted by the Commission when integrating the UN's 2030 Agenda on Sustainable Development in its '10 priorities from 2015 to 2019'. In adopting the SDGs as a theme, the EU has committed itself to balancing these dimensions as well[33]. In relation to biofuels, for the EU a balance between economic, environmental and societal deliberations is typically pursued to equally satisfy European interest groups on opposite sides of the spectrum. The current policies on biofuels in the EU have a predominantly environmental focus. Furthermore, growing unease among farmer groups resulting from the environmental attention biofuel receives has created an 'opposing camp' that attempts to safeguard economic interests. Altogether, this has shifted the debate to a predominantly environmental/economic one.

Shifting more explicit focus to the third 'social' dimension may lead to more effective decision-making at the EU-level, as it requires a critical evaluation of the options for an energy infrastructure from renewable sources with an emphasis on the economic dimension. Namely, due to overt attention placed on the environmental and economic aspects of biofuel, (continuity of) intra-European mobility may have been sidelined as an argument.

It is important to note that, although a disruptive technology is often considered beneficial and can spurs economic growth, this condition is unlikely to apply to the abrupt renewal of energy infrastructure for several reasons.

[33] European Commission, 22 January 2016. Communication on the next steps for a sustainable European future, COM(2016) 739 final. https://ec.europa.eu/europeaid/sites/devco/files/communication-next-steps-sustainable-europe-20161122_en.pdf [Accessed June 8, 2017]

Firstly, any viable change needs to include a transition phase in which the conventional and new infrastructure would co-exist. The EU general agreement on the choice of energy infrastructure would be needed to ensure trans-European mobility, which would be subject to the co-decision-making procedure and shared-competences. However, the transport systems in EU Member States differ substantially. While some Member States may be open to the idea of increasing the infrastructure network needed for electrical driving, the existing domestic energy infrastructure in other Member States would cause these countries to be more reluctant, thus impeding the high-impact transition process throughout Europe. For example, in 2015 in the Netherlands there were 145 EV charging points per 100,000 city inhabitants, while in Romania this number was merely 2 [34].

Secondly, the transportation infrastructure based on energy from renewable sources other than bioethanol may increase the cost of mobility. The mere fact that petrol and bioethanol are both liquid fuels implies that the available infrastructure of fuel storage and dispensing can be maintained. Although re-balancing the costs of fossil fuel versus other renewable fuels in the transportation sector can be achieved through (fiscal) stimulus measures (Steenberghen and Lopez, 2008), any significant increase in hardware requirements for vehicles (implementing battery packs or fuel cells) would be an impediment that is difficult to avoid. Fuel storage, distribution and dispensing infrastructures have barely been considered in the assessment of the different fuel economies. A liquid-fuel based infrastructure network has significant advantages in terms of storage, handling, energy density and compatibility with the state-of-the-art and, consequently, offers the best promise for a non-disruptive transition towards renewable energy.

Therefore, when considering the social dimension of sustainability, or more specifically the compatibility with existing infrastructures, automotive manufacturing technology and long-haul transportation security, the methanol-based fuel economy, as a direct extension of bioethanol, should be seriously considered as an option.

## 4.3. Validation by interviews

The overt economic/environmental focus on biofuels is consistent with the information gathered from stakeholders interviewed for this article, as presented below. The preoccupation on the environmental and economic dimensions is confirmed during interviews, along with the notion that

[34] Electric vehicle charging points, 2015. Retrieved from https://ec.europa.eu/transport/facts-fundings/scoreboard/compare/energy-union-innovation/ev-charging-points_en [Accessed November 30, 2017]

this shortcoming should be addressed, as social enablers do in fact exist, are relevant to the discussion and should consequently be included in the debate. The politico-institutional situation of biofuels in the EU that was described by the interviewees is mostly similar to the state-of-the-art in biofuels, and as mentioned presents a predominantly economic/environmental perspective. These results are briefly summarized. Thereafter, newly found results shed light on biofuels differently, while introducing social and technical determinants.

(a) *The economic dimension*

The main stakeholders that are interested in the economic situation of biofuels are the agricultural sector and the automotive sector, specifically passenger transport. Accordingly, stakeholders from these groups were interviewed.

For the agricultural sector an increase in biofuel blends is generally considered desirable and a means to maintain higher levels of employment in this sector.[35] For the European agricultural branch the '[...] mandatory blending' schemes in the Member States have been interesting, as these maintain or even expand the agricultural production levels of those agricultural groups which focus on biocrop production. Crop production designated for the creation of biofuels is only meaningful when first-generation biofuels, such as wheat and corn, are not opposed by EU policy and legislation. Accordingly, the current phasing out of first-generation biofuels is '[...] misleading the European population' and will be '[...] more difficult than it seems', according to agricultural interest groups. As the agricultural lobby considers second-generation biofuels impossible to be efficiently produced and therefore barely viable, they stress that '[...] there is no legal basis to speak of advanced and non-advanced biofuels'. Altogether, the findings, therefore, comply with the position of COPA-COGECA, that bioethanol gives '[...] prospects of new economic opportunities'[36]

The automotive sector depends on the economics of bioethanol as well. Decisions on, for instance, the introduction of flex-fuel cars needed for operation on high bioethanol blends are conditional to expected demand. Although transforming an engine for flex-fuel operation purposes is cheaper than the fabrication of an electrical engine, '[...] the demand for electrically chargeable vehicles, especially for passenger cars, is forecast to emerge as a more viable option for consumers around 2020 as a

[35] Interviews conducted on 07/09/2016 and 03/03/2017.
[36] Copa Cogeca's position on the EU's biofuels Policy. Copa Cogeca, 2013. https://copa-cogeca.eu/Main.aspx?page=Papers&lang=en&id=20122. [Accessed August 30, 2017]

result of EU and national policies aiming to boost their penetration' [37]. Nonetheless, even if '[...] the conventional combustion engine is currently being phased out', E85 may serve as an alternative during the transition to an all-electric infrastructure for passenger cars in Europe [38]. However, higher blends (E85) are not supported by proper European infrastructure networks, and therefore at the time the energy transition reaches an advanced stage the possibility of switching back to conventional fuel will intentionally no longer be available. The technological potential could also be assessed in other heavy polluting transport sectors beyond the scope of this study, such as aviation, shipping and heavy-weight freight[39].

Hence, from an economic point of view, there are mixed thoughts on whether it is useful for car producers to focus on high-concentration bioethanol blends. The automotive sector's cautious viewpoint on biofuels is widely known in the state-of-the-art (on how the automotive industries considers renewable options for the future). The electric car sales hit a record in 2016 with over 750,000 units sold worldwide [40]. Although this comprised less than 1% of the global sales of new cars, the trend is closely monitored by the automotive industry.

(b) *The environmental dimension*

The group of stakeholders looking mostly at the environment in the discussion on bioethanol is found in NGOs and citizens organizations, such as the European Environmental Bureau and the Corporate Europe Observatory ("European Environmental Bureau" and "Corporate Europe"). For NGOs, two priorities seem stand out: 1) '[...] biofuels need to be more [environmentally] sustainable and 2) '[...] the expansion of high-carbon unconventional fuels needs to be prevented'.[41] Producers ought to primarily focus on *how* ethanol is produced. For environmental groups this places the emphasis of the debate on looking at substances and their environmental impact, such as '[...] biomass/firewood/field/forests', before looking at the economic benefits that biofuels provide. Although it is true that biofuels leave a smaller footprint when used in a combustion engine, it is

[37] USDA Foreign Agricultural Service, 2016. EU Biofuels Annual 2016. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_6-29-2016.pdf [accessed August 30, 2017]

[38] Fuel vision (in Dutch). (2014). Retrieved from https://www.energieakkoordser.nl/~/media/files/energieakkoord/nieuwsberichten/2014/brandstofvisie/duurzame-brandstofvisie-met-lef-2e-druk.ashx [Accessed November 30, 2017]

[39] Biomassa 2030: Strategische visie voor de inzet van biomassa op weg naar 2030, 2015. Retrieved from https://www.rijksoverheid.nl/documenten/rapporten/2015/12/01/biomassa-2030 [Accessed November 30, 2017]

[40] Global EV Outlook, 2017. Retrieved from https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf [Accessed November 30, 2017]

[41] Interview conducted on 19/07/2016.

believed by environmental groups that '[...] ILUC is very important'. This puts them on the opposite side of biofuel farmer interest groups, whose livelihoods are dependent on land and crop cultivation.

The information from environmental stakeholders matches closely with that found in the literature and documents that have already been published on the topic. The most notable are the two influential studies from 2008, introducing for the first time the ILUC issue (Searchinger and Heimlich, 2008; Fargione and Hill, 2008). Since their publication, much more research has reaffirmed the environmentalists' position on biofuels, depicting (at least first-generation biofuels) them as environmentally unfriendly and not sustainable when produced on a large scale.

(c) *The social dimension*

An assessment was made of the benefits of a non-disruptive change from the present fuel economy towards one based on energy from renewable sources. Emphasis was given to the potential role of bioethanol in realizing a methanol-based economy, both as a technical concept and in terms of the positive impact it can have on the decision-making process in the European Union.

European societies need to be well-connected, which requires harmonized infrastructure so that no difficulties exist in crossing borders between member states. Part of this infrastructure is the ability to refuel with a compatible fuel at a gas station in any member state or to find electricity charging points throughout the EU. Unsurprisingly, farmers producing crops for ethanol have argued in favor of an improved E85 infrastructure to increase intra-European mobility without drivers having to resort to petrol after border crossing in order to create a viable market. For the automotive industry, E85 would be desirable if there were sufficient demand and a market for flex-fuel vehicles. This constitutes the classic 'chicken and the egg' dilemma.

The desire for energy independence is particularly noticeable in Poland, while the impact on employment is mainly an issue in the agricultural sector. These are not included in detail in this study.

(d) *Technical determinants*

The technical aspects result from issues raised in the interviews, but are addressed using analytical approaches and the literature. For example, one interviewee raised the point that the EU is in fact technologically advanced enough to start producing second- and third-generation bioethanol, indicating from a technical perspective that biofuels 'can be a go' in the future. Additionally, another interviewee outlined the technical uncertainties of the batteries, range and life cycle of electric vehicles. Fuel needs to be distributed and dispensed to make it available to the customer. Traditionally, fuel has been based on a liquid medium. In a hydrogen and methane-based infrastructure network, the fuel is a compressed gas, while the methanol- and ethanol-based fuel infrastructure network remains based on a liquid.

The energy content of fossil fuels and several fuels that are generally considered viable alternatives differ hugely. Conventional petrol has a convenient energy density of 34 MJ/L (or specific energy of 46 MJ/kg), which for a typical fuel-economic car with a 50 liter fuel tank results in an average range between refuelings of about 750 km (Golnik, 2003; Tietge and Mock, 2016). A state-of-the-art electrical car design requires 545 kg of Li-ion battery capacity for 85 kWh, because of the low specific energy of about 0.4 MJ/kg (Advanced Vehicle, 2016). As a result, a fully charged battery contains about 305 MJ of energy, which results a typical travel range of about 420 km between rechargings.[42] The lower specific energy results in a high impact of the battery on the mass of the vehicle and a more limited range (‘the payload’). Although sufficient for local travel, the use of the all-electric car for long-haul transport is debatable. Bioethanol has a specific energy of 26 MJ/kg, which implies that the energy density of E85 is 35% lower than that of conventional petrol.

Despite this somewhat lower value, no disruptive changes would be required at the gas station when shifting from the fossil fuel infrastructure to the bioethanol-based one, which is indeed the reason for the seamless integration of biofuel in the existing infrastructure and, consequently, large-scale implementation. The energy density of methanol is 23.8% lower compared to bioethanol, which is a smaller step compared to the transition from fossil fuel to bioethanol. Research has indicated the viability of the methanol-ethanol-petrol blend is flex-fuel vehicles to enable a gradual partial replacement of ethanol in E85 with methanol (Sileghem et al., 2014). Integration in the infrastructure can be expected to be equally smooth. Therefore, a biofuel-based energy infrastructure (scenario in Fig. 1b) can be considered an intermediate step towards a methanol-based infrastructure (scenario in

[42] Advanced Vehicle, 2016. Retrieved from https://avt.inl.gov/sites/default/files/pdf/fsev/fact4500tesla2014.pdf. [Accessed November 30, 2017]

Fig. 1f), with the essential advantage of avoiding disruptions. In contrast, electric mobility is a *disruptive* trend, as it requires an overhaul of the energy distribution infrastructure and the traditional combustion engine to be replaced with an electric motor.

A non-technical complication of the methanol-based fuel economy is public acceptance. One issue is $CO_2$-recycling (uptake at the large-scale centralized chemical plant where the catalytic reaction is to take place and release in each combustion engine). Another is the overt focus on 'well-to-wheel' efficiency, and indeed it should be mentioned that the scenario of methane and methanol production from sustainable electricity via hydrogen does typically reduce conversion efficiency and, consequently, reduces the effective use of the generated renewable energy. However, this 'well-to-wheel' efficiency is just one of the criteria that should be applied to determine which alternative fuel should be examined. The concept of fuel produced by sustainable electricity in the methanol fuel economy does in principle not lead to a net carbon generation, as the $CO_2$ uptake and release are inherently balanced. The self-ignition temperature is higher than that of petrol, and methanol is biodegradable in water. However, toxicity is an issue (as are most fuels) and methanol has a low boiling temperature of 65 $^{o}$C.

It is interesting to note that China's Ministry of Transport, managing freight transportation and passenger transportation, has launched various schemes in several Chinese regions (including Shanghai) for vehicles running on methanol (M85 and M100) (Chen et al., 2014). China's National Energy Agency's (NEA) 2015 *Initiative on clean and efficient utilization of coals* has indicated the government's desire to proceed with developments in the chemical coal industry, albeit at a moderate pace (Hao et al., 2017).

## 5. Discussion

The two-stage research question put forward in this article was: 1) *What political, institutional and technical factors enable or impede the scenario of mass-scale introduction of E85 and bioethanol flex-fuel automotive production in the EU and 2) how would the EU decision-making process be affected by the prospect of bioethanol leading the EU towards a methanol-based renewable fuel economy, through its potential to facilitate a seamless transition of the energy infrastructure while maintaining long-distance intra-European mobility?*

The issue of 'alternative' transportation fuels such as electricity, hydrogen and biofuels is receiving increasing attention in the European Union. Alternative fuels can make a useful contribution to reducing emissions in the transport sector by means of lower greenhouse gas emissions and reduced effects on air quality in comparison with the current oil and gas-based fuels.[43] EU strategies support a 'comprehensive mix' of fuels, ensuring 'technological neutrality' and diversification of the energy supply.[44] Bioethanol (E85) could be considered technically as a 'non-disruptive' change based on traditional combustion engines and blending with other fuels in flex-fuel vehicles.[45] This could in the long-term lead to fuel infrastructure based on only renewable energy sources. This is predominantly an economic argument that strengthens the social sustainability of biofuels. However, in practice the electricity and (to a lesser extent) hydrogen options seem much more popular than advanced biofuels in the EU, despite especially the limitation of battery-based cars to 'longer' range distances.[46]

Considering the fuel infrastructure also, intra-European travel at this moment cannot be successful when considering electric options alone. Moreover, there is only scant attention in the literature devoted to the decision-making processes and institutional background within the European Union, as most research on fuels is technical or economic. This is problematic, as policies on alternative fuels are still mainly driven by governments, and manufacturers are dependent on policy makers to decrease uncertainty through appropriate policy measures, legislation and standards (Su et al., 2015; Steenberghen, 2012). The EU and Member State incremental decision-making process could tell a great deal about the policy formulation on bioethanol in practice.

The mixed competences on alternative fuels in the EU make it difficult to come to coherent policy formulation, specifically concerning bioethanol. The EU and Member States share competences on policy areas such as climate change (environment), transport, agriculture and energy. Also, autonomous Member State competences such as taxation and land-use policies are deemed important. Moreover, within the primary shared competence of energy, the 'energy mix' is within the

[43] The four alternative fuels that are often suggested as main options for passenger cars (and light duty vehicles for medium distances) are electricity, hydrogen, compressed natural gas (CNG) with biomethane and advanced biofuels. See e.g. European Commission, 2011. Report of the European Expert Group on Future Transport Fuels: Future Transport Fuels. https://ec.europa.eu/transport/sites/transport/files/themes/urban/cts/doc/2011-01-25-future-transport-fuels-report.pdf [accessed November 30, 2017).
[44] European Commission, 2013. Communication 'Clean Power for Transport: A European alternative fuels strategy. COM (2013) 17 final. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52013PC0017. [Accessed November 30, 2017]
[45] European Commission, 2016. A European Strategy for Low-Emission Mobility. COM (2016) 501 final. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016DC0501&from=en. [Accessed June 8, 2017]
[46] European Commission, 2011. Report of the European Expert Group on Future Transport Fuels: Future Transport Fuels. https://ec.europa.eu/transport/sites/transport/files/themes/urban/cts/doc/2011-01-25-future-transport-fuels-report.pdf [accessed November 30, 2017)

responsibility of individual Member States, which negatively affects EU cooperation on alternative fuels. The directives on, for instance, fuel quality, alternative fuel infrastructure and renewable energy could therefore provide guidance. However, the last several years have seen many U-turns in EU and Member State policies, which has been detrimental to the mass-scale introduction of flex-fuel vehicles. There is considerable debate whether biofuels currently have to compete with food security and various academic publications have addressed this issue, for instance (Renzaho et al., 2017).

The interviews make clear that E85 is mostly seen as a 'transition fuel' in between the current petrol/diesel market towards alternative fuels like electricity and hydrogen. However, taking into account the emotional state of the debate, many EU Member States seem not even willing to consider, let alone actively support, the mass-scale introduction of bioethanol in this transitional phase. It is not the price or the engine modifications needed for flex-fuel vehicles that are hindering the mass-scale introduction of E85 and flex-fuel vehicles, but instead a general 'hold up' in the car, fuel and agriculture industries waiting on infrastructure, legal and political certainty and support measures by governments. As a result of the 'U-turns' in policies on alternative fuels, the Member States have only developed fragmented initiatives.

None of the stakeholders or EU/MS officials working with biofuels really sees the scenario of the large-scale introduction of E85. Some of the stakeholders speak of a classical 'chicken and egg situation' in which stakeholders hold each other hostage on this topic before conceding. Indeed, this study points to the difficulty of waiting for proven technical solutions first but instead focusing primarily on the decision-making procedures in the EU.

The technical impediments for the E85 intra-European bioethanol infrastructure mentioned do not apply to the low-concentration E10 blend, simply because of the fact that the vast majority of conventional combustion engines can be operated without any modification. This resulted in a state-of-the-art solution in which the use of E10 was introduced without any noticeable disruption, making widespread distribution throughout the EU possible. This penetration by stealth is an advantage, but by this very nature has also resulted in little awareness.

Free movement of goods, people, services and capital across borders is key to the EU internal market and is not served by the kind of disruptive innovation on which business R&D thrives. Therefore, we have explicitly applied this aspect as a key issue when considering the societal dimension, as reflected in the points on intra-European mobility. In general, the seamless transition between compatible fuels avoids disruption, which is highly desirable and consequently adds value to the chain departing from all-fossil fuel (Scenario a in Fig. 1), via the biofuel scenario (Scenario b) to a methanol-based infrastructure (Scenario f).


*Figure 2. Evolution towards the methanol-operated vehicle with electromotor.*

A disadvantage of the methanol-based fuel scenario, as illustrated in Fig. 1f, is the reliance on the combustion engine, which is liable to emit other pollutants, such as: hydrocarbons due to unburned fuel, CO due to partially oxidized/burnt fuel and oxides of nitrogen (NOx). Three-way catalytic converters (TWC) are used to effectively reduce the emission of these components in the exhaust gas before exiting through the tailpipe to meet increasingly stringent emissions standards. Nevertheless, one may be tempted to consider the electromotor as a solution for all problems at once, despite the benefits of compatibility mentioned in this paper. However, it should be emphasized that the merits of the methanol-based fuel economy are primarily found in the fuel storage, distribution and dispensing infrastructure and high energy density. The engine in the vehicle is of secondary relevance, as the combustion engine can (gradually) be replaced by an electromotor plus a fuel cell, as shown in Fig. 2.

## 6. Conclusions

The results from this combined technical and non-technical study may pave the way for future research on scenarios for alternative fuels in which decision-making procedures are discussed in conjunction with the technical enablers of new fuel economies. Therefore, there could be significant merit in taking a closer look at the technical potential of these advanced biofuels in combination with the decision-making procedures, preferably taking into account (and comparing) the situation in other regional blocs as well as the multilateral context.

The fuel policies seem to be one of the traditional battles in which there is Member State reluctance to transfer powers to the European Commission. Future research could build on this study and scrutinize the influence of mixed competences, the Court's case-law and other legally defined powers over the political decision-making process of alternative fuel policies. More political and legal research on this topic could point to the 'institutional' constraints that currently hinder the introduction of a genuine 'single market' on alternative fuels. One of the contributing factors might also be the current absence of multilateral cooperation on this topic, which as a result keeps the EU and its Member State decision-makers within their own ambition cycle and heavily influenced by domestic stakeholders.


*Figure 3. Potential Design of a user panel: a fuel station in the 2030-ies based on different fuel scenarios (designed and drawn by Thierry Wolffenbuttel).*

The key issue discussed here is the aspect of non-disruptive transition. Referring to this specific aspect, it can be concluded that the transition to methanol via bioethanol has significant merit, but this does not imply a disqualification of alternatives. In light of the above, it is highly likely for the different fuel infrastructures in Fig. 1 to co-exist for a significant period of time, as shown in Fig. 3, which is in line with the state-of-the-art in which diesel, (E10 and sometimes E85) petrol and LPG are presently the selectable options at petrol stations. From a technical perspective it can be concluded that the proposed gradual introduction of biofuel blends, be that methanol or ethanol, with existing petrols, due to the continuity of the liquid phase-based infrastructure are unlikely to result in major technical challenges. The energy density of biofuels does not significantly compromise travel range. Developments in catalytic methanol production from green electricity do strengthen the business case of methanol as a viable renewable fuel.

The technical/non-technical approach taken in this paper is expected to be also applicable to studying the decision-making processes of other 'ethically loaded' topics in the EU, such as GMOs or nuclear waste.

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# Annex 1

**Interviews - Overview**

| 2016 | 2017 |
|---|---|
| 9 interviews | 6 interviews |
| +- 60 minutes per interview | +- 60 minutes per interview |
| Belgium (3x), the Netherlands (6x) | Belgium (2x), the Netherlands (4x) |

| 2016 | 2017 |
|---|---|
| Public sector (3x Dutch government, 1x European Institution) | Public sector (3x European Institution) |
| Stakeholder (cleaner transport) | Stakeholder (2x automotive industry) |
| Stakeholder (agriculture) | Stakeholder (methanol industry) |
| Stakeholder (ethanol producers | |
| Stakeholder (car industry) | |

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