2030 Transport Decarbonization in the EU

Report prepared for Pannonia Bio, by E3-Modelling

E3-Modelling | Athens, June 2021

Final Report

Preface

I would like to thank the team at E3-Modelling for conducting this excellent transport decarbonisation analysis on behalf of Pannonia Bio Zrt.

E3-Modelling and the PRIMES energy model are at the heart of European climate and energy policy analysis for transport, in particular the Impact Assessments of the Renewable Energy Directives and the 2030 climate packages. The European Commission relies on them for projections of energy demand, supply, prices and investment, and for transport emissions calculations for the Member States and Europe as a whole.

While one cannot observe up close the inner workings of an official EU Impact Assessment - the input data, assumptions, logic, review process, etc - it is possible to engage with the same experts and tools and conduct analogous policy-relevant assessments. The purpose of this initiative was to do just that, and to assess the main transport decarbonisation measures available to European policy makers in the 2030 timeframe, which are biofuels and electrification.

What emerges from the chapters herein, is that modifying cost, modelling assumptions to align with current industry evidence, and policy assumptions, alternative pathways can be found which also have substantial merit.

The consequences of these differences for policy making may potentially be substantial as legislators across the Union design implementing measures to achieve their desired mixes of renewables, in compliance with overarching EU directives.

I believe the findings of this study provide food for thought for policy stakeholders generally, and will be of particular value for Member State governments, EU institutions and the farm sector and supply chain that provides much of Europe’s renewable transport energy today.

Sincerely,

Ferenc HÓDOS, June 2021

Strategic Director at Pannonia Bio Zrt.

E3-Modelling

E3-Modelling is a private capital company, established as a knowledge-intensive consulting company spin-off inheriting staff, knowledge and software-modelling innovation of the laboratory E3MLab from the National Technical University of Athens (NTUA). The company specialises in the delivery of consulting services based on large-scale empirical modelling of the nexus economy-energy-environment. The experience of its staff dates back to 1990 and includes internationally renowned milestones, such as the design, implementation and continuous operation of the PRIMES and GEM-E3 models. Since 1990, the consultants of E3-Modelling prepare and publish every 2-3 years a European energy and transport outlook in close cooperation with the European Commission and have supported its major impact assessment studies via the construction of detailed policy scenarios.

Our modelling and consulting experience serve numerous studies for European governments, professional associations, and large-scale companies in the energy domain. The consultation expertise of our team focuses on the design and impact analysis of transition in the energy market and systems, both in the demand and supply of energy, and in the transport sector, towards green and climate-friendly structures and technologies. We assess the transitions from economic, policy and implementation perspectives with emphasis on the functioning of system and markets and the impact of policy instruments on behaviours and market outcomes.

Our energy team has particular expertise in regulatory and market design aspects for the electricity and gas sectors in Europe. Our macroeconomic team has well renowned research records in modelling economic growth, sectorial growth and employment at an international level based on the GEM-E3 model which is the most widely used macroeconomic general equilibrium model in Europe. Our transport team has contributed to EC impact assessments which are part of the 3rd Mobility Package, the introduction of regulatory targets on vehicle manufactures and the assessment of national transport policies for numerous national governments.

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Abbreviations

BEV	Battery Electric Vehicles
CEF	Connected Europe Facility
CNG	Compressed Natural Gas
CTP	Climate Target Plan
EV	Electric Vehicle
FQD	Fuel Quality Directive
GHG	Greenhouse Gas
HDV	Heavy Duty Vehicles
HVO	Hydrotreated Vegetable Oil
ICE	Internal Combustion Engines
iLUC	indirect Land Use Change
LCV	Light Commercial Vehicles
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
LUC	Land Use Change
PHEV	Plug-in Hybrid Electric Vehicles
RED	Renewable Energy Directive
TEN-T	Trans-European Transport Network
WLTP	Worldwide Harmonized Light Vehicles Test Procedure

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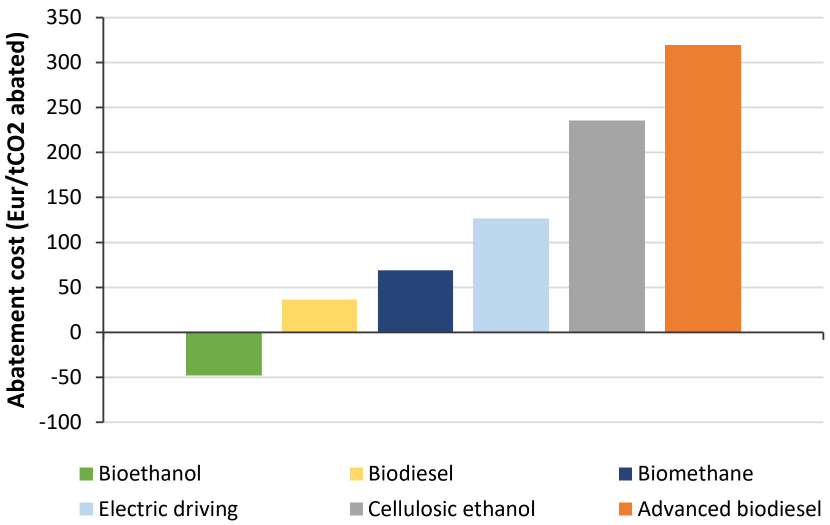
Executive Summary

The decarbonization of road transport is integral to Europe's effort to achieve its commitments for 55% GHG emission reduction by 2030 compared to 1990, under the EU Green Deal. The Impact Assessment underpinning the Climate Target Plan (CTP 2020IA) includes several policies in support of this goal such as the introduction of CO_2 standards for car and van manufacturers, a mandatory sub-target for advanced biofuels in the recast of the Renewable Energy Directive (RED II), the provisions of the Fuel Quality Directive (FQD) regarding the reduction of the GHG intensity of transport fuels, the redistribution of mitigation efforts through the Effort Sharing Regulation (ESR), and pricing measures that aim to shift travel demand towards more sustainable transport modes. In the CTP 2020IA, the transport sector is projected to achieve significant emission reduction primarily through the deployment of more efficient internal combustion engines, the uptake of electric vehicles and the use of biofuels.

Within this context, E3-Modelling carried out a model-based assessment to provide a policy relevant technical background on the barriers and drivers for the uptake of crop-based biofuels and in particular bioethanol in the EU transport sector by 2030. In doing so, E3-Modelling used the PRIMES-TREMOVE and the PRIMES Biomass supply models to assess a scenario context built on the policy setup and climate ambition scope of the scenarios of the CTP of the EC as published in September 2020. Pannonia Bio supported E3-Modelling to parameterize relevant scenarios related to: (a) updates in the characterization of bioethanol in terms of production costs and emissions, and in particular on techno-economic data of starch-based bioethanol production and (b) in addition, a scenario undertaking a projection which eliminates the crop cap of RED II. In this respect, two scenarios were designed and quantified: (a) the Counterfactual scenario considering the updates in techno-economic details and (b) the No Cap scenario considering, additionally to the Counterfactual scenario, the elimination of the crop-cap of RED II.

The present policy-relevant technical analysis demonstrates an improved cost profile of bioethanol, which shows that crop-based bioethanol can be a cost-effective measure to reduce road transport CO_2 emissions by 2030 (Figure ES 1). Crop-based bioethanol has negative abatement costs driven by the lower price of bioethanol compared to the higher pre-tax gasoline price.

Figure ES 1 Cost of CO_2 abatement for alternative fuels in the cars segment in 2030



The lower price of bioethanol is primarily driven by the higher uptake of starch-based ethanol after taking co-product credits into account. Starch-based bioethanol is projected to have the lowest production costs across all biofuels produced in 2030 (Table ES 1).

Table ES 1 Biofuel production costs in Eur/toe in 2030

Bioethanol	Eur/toe
Starch-based	565
Sugar-based	915
Cellulosic ethanol	1,545
Biodiesel	
Vegetable oil FAME	690
Vegetable oil HVO	1,100
UCO HVO	1,150
Advanced biodiesel	1,860
Biomethane	
Anaerobic digestion	670
Advanced gasification	870

The modelling confirms that eliminating the cap on crop-based fuels will have a positive effect on the penetration of bioethanol by 2030. The scenario analysis shows an additional 0.5 Mtoe of crop-based bioethanol consumption in road transport segments in 2030 compared to a scenario retaining the crop-based cap of RED II. Bioethanol is primarily consumed in the cars and vans segment; increased consumption of bioethanol was also found to take place in special car types such as E85 cars. Notably, eliminating the crop-based cap of RED II drives the additional uptake of 0.8 Mtoe of crop-based biodiesel, compared to the scenario that retains the crop-based cap in 2030.

The modelling identified additional major barriers to a wider uptake of bioethanol in road transport by 2030. The barriers relate mainly to the limits of the FQD, which do not allow a wider uptake of bioethanol in a blended form with gasoline, despite lifting the constraint on crop-based biofuels. Therefore, from the analysis, it is deduced that, in addition to the RED II cap on crop-based biofuels, the FQD limits represent the most important barrier. Lifting the FQD limits to E20 or E30 could result even to a doubling or tripling of bioethanol demand in a best-case scenario (if such limits were to be imposed as blending obligations in the whole EU).

In a context of more stringent CO_2 regulations on vehicle manufacturers, the sales of ICE-based vehicles will unavoidably decrease in order to allow manufacturers to comply in 2030. Zero emission cars will make significant inroads to the detriment of ICE cars and, therefore, a decreasing market trend for liquid fuels is expected. This limits the potential market for blended biofuels, as well. Both biofuels consumption and electromobility will contribute in reducing transport CO_2 emissions in 2030. The balance between the two can be greatly influenced by the cost evolution of BEVs this decade.

The key message of the analysis is that the existence of specific pieces of legislation (e.g. FQD, CO_2 standards and aspects of those) acts as a strong barrier (in addition to the crop-based cap of RED II) to a wider uptake of bioethanol in the EU. The model-based analysis shows that the policy-related barriers represent the most constraining factor on the uptake of bioethanol in the EU by 2030 and have the largest influence on the respective model results. These policy barriers were found to be far more important and influential than the modified assumptions and updates in the characterization of bioethanol in terms of production costs and emissions, and other techno-economic data that feed the model. The latter were found to influence more the uptake of bioethanol for use by E85 cars due to economic considerations.

1. Introduction

In 2019, the European Commission (EC) presented the EU Green Deal as its strategic plan to achieve climate neutrality by mid-century. While emissions from power generation and the end-use sectors of buildings and industry have been decreasing, emissions from transport are still higher relative to 1990. Road transport accounts for about three-quarters of the transport sector's energy use and Greenhouse Gas (GHG) emissions and about one-fifth of the European Union's (EU) total GHG emissions. Under these terms, the decarbonization of road transport is integral to Europe's effort to go climate neutral by 2050.

One year after announcing the EU Green Deal, the EU embarked on a new pathway, by committing to reduce its GHG emissions by at least 55% compared to 1990 levels. The CTP 2020IA underpinning the ambitious Climate Target Plan (CTP) projects that emissions in road transport may reduce by about 20%, and in particular emissions from passenger cars may reduce by about 25% in 2030 compared to 2015. This reduction is attributed to several policies, including the introduction of CO_2 standards for car and van manufacturers, a mandatory sub-target for advanced biofuels in RED II, the provisions of the FQD regarding the reduction of the GHG intensity of transport fuels, and importantly so, the redistribution of mitigation efforts through the ESR and pricing measures that aim to shift travel demand towards more sustainable transport modes. Against this policy background, the road transport sector is projected to achieve significant emission reduction primarily through the deployment of more efficient internal combustion engines, the uptake of electric vehicles and biofuels.

One of the main model-based scenario quantification tools that supports the EC in impact assessments and analysis of policy options is the PRIMES model that is developed and managed by E3-Modelling. PRIMES is an energy system model built in modular fashion that includes the PRIMES-TREMOVE transport model and the PRIMES Biomass supply model, as well as other submodels for other sectors. As a key policy assessment tool, the PRIMES model is frequently updated to include up to date information on technical and economic parameters of its technology portfolio, based on several projects and public stakeholder consultation processes[1], and to include latest policy developments, at EU and national level.

Against this background Pannonia Bio commissioned E3-Modelling to provide a policy-relevant technical background to analyze the drivers for the limiting factors on the uptake of crop-based bioethanol. In doing so, E3-Modelling used the PRIMES-TREMOVE and the PRIMES Biomass supply models to assess a scenario context under which no cap is placed on crop-based biofuels (therefore assuming a change in the current RED II legislation). Pannonia Bio supported E3-Modelling to validate the crop-based bioethanol-relevant portions of PRIMES Biomass supply, and in particular on the techno-economic data of starch-based bioethanol production.

2. Methodology

The study employs a model-based assessment to quantify policy scenarios to provide policy advice. The evolution of the road transport sector and biomass supply is quantified with the PRIMES-TREMOVE transport model and the PRIMES Biomass supply model. Both models are privately owned by E3-Modelling. Short descriptions are provided below and detailed descriptions are available online[2].

2.1. Modelling framework

2.1.1. The PRIMES-TREMOVE Transport model

The PRIMES-TREMOVE transport model has been specifically developed to model a large range of measures for transport including:

- **soft measures**, e.g. eco-driving, deployment of Intelligent Transport Systems, and labelling;
- **economic measures**, e.g. subsidies and taxes on fuels, vehicles and emissions, pricing of congestion and other externalities i.e. pollution, accidents and noise;
- **measures supporting Research and Development**;
- **infrastructure policies for alternative fuels**, e.g. deployment of refueling and recharging infrastructure for electricity, hydrogen, biofuels, LNG, CNG and LPG;
- **regulatory measures**.

To do this, the model projects the evolution of demand for passenger and freight transport by transport mode (road, rail, air, waterborne), vehicle (for example, cars, light commercial vehicles (LCV), trucks and others) and fuel (e.g. oil products, biofuels, electricity, hydrogen, synthetic fuels). It consists of a module that projects demand for transport services of passenger and freight mobility and a module that makes supply meet demand via an optimum technology and fuel mix. The supply module interacts with the demand module through the so-called generalized prices of transportation (measured in Euro per pass/ton km). Different generalized prices are calculated for various alternative trip possibilities that are included in the decision tree of the demand module (e.g. area, time, distance) by transport mode. When the generalized prices differ from the baseline scenario, the model determines the new demand (for each of the various possible trips) based on the price differential relative to the baseline scenario and the elasticities of substitution (different among the various options) while respecting the overall budget (microeconomic foundation).

PRIMES-TREMOVE represents a dynamic system of multi-agent choices under several constraints, which are not necessarily simultaneously binding. The fuel and vehicle choice of agents is endogenous in the model and is based on: (a) internal costs, (b) perceived costs, i.e. market acceptance for each technology, (c) infrastructure availability for the energy carriers. For the purchasing of new vehicles, a menu of technology options is considered; the available technology portfolio for vehicle technologies includes different configurations, different technologies with an impact on fuel consumption and fuel types. The purchase choice of vehicle technologies and fuels follows the approach of discrete choice modelling. Cost elements include all costs over the lifetime of the candidate transport means: purchasing cost, annual fixed costs for maintenance, insurance and ownership/circulation taxation, variable costs for fuel consumption depending on trip type and operation conditions, other variable costs including congestion fees, parking fees and tolled roads. Energy and pollutant emissions calculations are based on the COPERT methodology.

PRIMES-TREMOVE also includes a vehicle stock sub-module which calculates the stock of transport means from previous time periods in order to determine the changes needed to meet demand. It tracks vehicle vintages and formulates the dynamics of vehicle stock turnover by combining scrapping and new registrations.

The model has been used extensively in impact assessments supporting key transport policies at EU level, including the 2011 White Paper on Transport, the Low Carbon Economy and Energy 2050 Roadmaps, the 2030 policy framework for climate and energy, the recast of the Renewables Energy Directive, the European Strategy on Low-Emission Mobility, the proposal for the post-2020 CO_2 emission standards for cars and vans and for the implementation of CO_2 standards on truck manufacturers in the EU, the "Clean Planet for All" Communication, and the scenarios elaborated as part of the CTP[3]. Moreover, PRIMES-TREMOVE is quoted in several scientific papers[4,5].

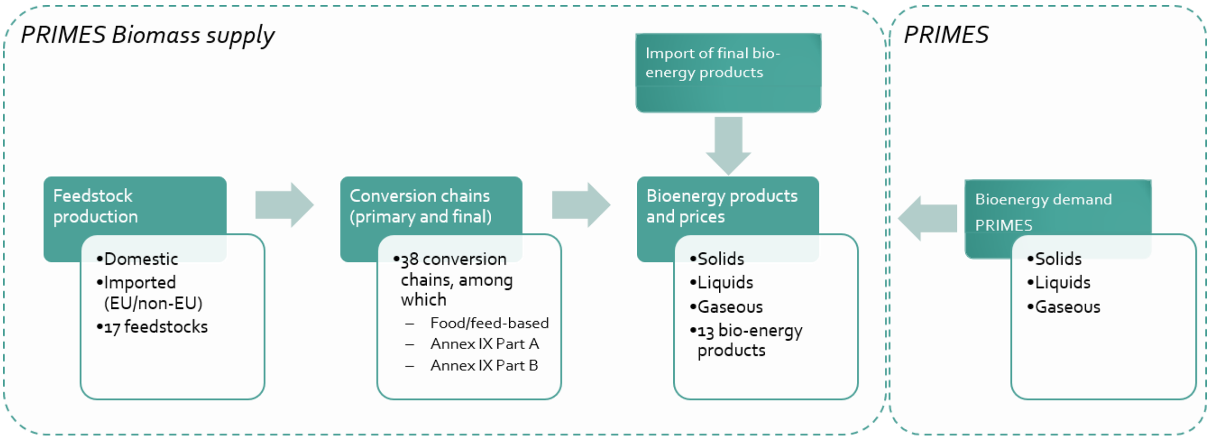
2.1.2. The PRIMES Biomass supply model

The PRIMES Biomass supply model is an economic-engineering model that calculates the optimal use of primary biomass production, agricultural residues, process residues, and waste resources (e.g. municipal solid waste) and investment in secondary and final transformation of biomass feedstock to bioenergy with the aim of satisfying a given demand of final bioenergy products. The PRIMES Biomass supply model is linked with PRIMES energy model and its submodules including PRIMES-TREMOVE (Figure 1), and can be either solved through a closed-loop process or as a stand-alone model.

PRIMES Biomass supply solves a minimization problem for long-term supply costs subject to equilibrium constraints stemming from biomass feedstock cost-supply curves and cost-structures of conversion technologies. The optimization is solved for all EU Member States and the entire time horizon by assuming perfect participation and competition of all market actors, namely, the biomass producers and consumers. The market equilibrium is formulated by Member State and for each bioenergy commodity, requiring total supply from domestic production and imports (intra-EU and extra-EU) to meet the given demand in each time period. The model accounts for overarching constraints stemming from policy restrictions (e.g. sustainability criteria) as well as technical constraints that are fuel-specific (e.g. biofuel blending ceilings).

Given the final demand for bioenergy, the model computes endogenously energy and resource balances for the production of bioenergy commodities from biomass and waste. To do this, the model takes into consideration the required investments in various conversion technologies, the costs of the different bioenergy production pathways and their GHG emissions, and the prices of bioenergy commodities. Detailed description of the model and further applications can be found in literature[6,7]. The conceptual structure of the model is illustrated in Figure 1.

Figure 1 The PRIMES Biomass supply model structure



PRIMES Biomass supply includes 17 different feedstocks, 38 pathways and 13 bioenergy/biofuel products, and are listed in detail in the Annex (see Table 5 and Table 6). These are the most relevant feedstock categories (part of the RED II), commercial biofuel production technologies that supply biofuels today, and prospective conversion technologies when considering the horizon beyond 2030 (see also section 4).

Feedstock cost-supply curves and trade

Feedstocks are represented in the model at crop level, broken down into starch crops, sugar crops, oil crops, lignocellulosic energy crops, residues from agriculture and forestry, process residues, and wastes. The model does not go into further detail (e.g. divide starch crops into maize or wheat, oil crops into rapeseed or soy). In this way, most representative information (data on crop production costs and conversion pathways) concerns the aggregates of crop types. The supply of feedstock is simulated through time dependent cost-supply curves that are specific to each EU Member State. These curves depend on quantities produced annually and exhibit increasing returns to scale, following a rise in production costs.

To estimate feedstock costs of crops (i.e. sugar crops, starch crops, oil crops, and lignocellulosic energy crops), the model aggregates the costs of fertilizers (based on fertilizer input), machinery, land, labor, energy (e.g. diesel input for harvesting) and other unit costs. Unit costs refer to pre-processing costs of primary biomass from farm-to-biorefinery gate ready for final conversion. Depending on the crop and conversion pathway, unit costs may include different components. Unit costs of starch-based crops include the cost of drying and unit costs of oil-based crops include oilseed pressing and extraction of oil. A flat cost is assumed for all Member States.

The model draws a link between domestic feedstock from crops and land use by applying exogenous yield growth trends that are specific per feedstock and country. The use of other feedstock types, such as residues or waste, depends on productivity trends of primary production. Biomass supply and bioenergy demand are found within Member States, which also trade bioenergy commodities, besides feedstock. Imports of bioenergy commodities and biomass feedstock from outside the EU are also available. Yet, the model does not import starch or sugar for ethanol production, but imports ethanol directly. To meet the demand for ethanol, the model will either use domestically produced sugar/starch and/or import ethanol. Exporters of biomass feedstock or bioenergy commodities from outside the EU are subject to their own cost-supply structure. The curves have been developed through cooperation with other models that cover land-use (GLOBIOM), waste and non-CO_2 (GAINS) and agricultural projections (CAPRI). Further details and examples can be found in literature[8].

Conversion processes

The biomass feedstock conversion technologies are characterized by their unit costs, efficiency, and input/output ratios, which are specific to the year of investment. For crop-based biofuel pathways in particular, the conversion technology is based on the techno-economic assessment of one representative technology for starch crops, sugar crops and oil crops. The techno-economic data for these conversion technologies concern a range of process or technologies and are not necessarily crop-specific.

For new installations the technology characteristics evolve over time according to endogenous learning-by-doing curves. Thus, technology costs decrease and technology performance increases as a function of total installed capacity in the EU. As the intertemporal optimization assumes perfect foresight, only capacities with sufficiently high utilization rates will be built. In this way the model simulates the competition between various processing technologies. The techno-economic characteristics of conversion processes are regularly updated based on data from different projects[8].

Model modifications in the present study

The project makes use of data and assumptions that the client has provided and that appear to E3-Modelling to be well-grounded based on the evidence provided. These involve updated techno-economics for certain production routes based on inputs from the industry, and adaptations allowing co-products to be accounted into the model-based cost and emission estimates. As PRIMES Biomass supply operates in a broader modelling context, and to avoid double-counting of elements addressed by other models, co-products related with markets outside the energy system are typically not accounted for. As such, costs of crop production and the conversion technologies are fully allocated to bioethanol and biodiesel, apart from this project where they are allocated as explained below. This may explain why PRIMES Biomass supply may understate GHG savings of some crop-based biofuel production routes.

(a) Costs

Based on the premise that corn-based ethanol from dry milling is the main pathway of European starch-based ethanol production, the production costs of starch-based bioethanol are updated in PRIMES Biomass supply. Until now, wheat was the reference pathway; under the PRIMES Biomass supply technology characterization, the shift to corn is required now that it has been documented that a plurality of ethanol in the EU is corn-based[9]. This is done by considering a co-product credit based on DDGS and corn oil. To ensure consistency and comparability with other crop-based biofuel pathways, co-products of sugar-based ethanol and oil-based biodiesel are also accounted for in the characterization of their respective pathways. The exact approach is determined on a case-by-case basis due to differences in how the pathways are modeled. In addition to the above, pre-processing costs of primary biomass from farm-to-biorefinery gate and in particular those of starch-based crops have been updated. Note that in addition to the structural updates presented in Table 1, certain techno-economic parameters of corn-based ethanol production have also been updated (including capital costs, fixed costs, process efficiency, energy inputs, fertilizer input for corn production). The focus of the update on techno-economic parameters was corn-based ethanol production and not on biofuels in general.

(b) Emissions

Emission factors of every biofuel production chain are the sum of emissions from cultivation (fertilizer application) and emissions from the energy used in each processing step. Changes in carbon stocks, e.g. land use emissions, and indirect land use change emissions are not included, since they are addressed by other specialized models. The PRIMES Biomass supply model may however include these factors indirectly, e.g. via exogenous inputs (e.g. iLUC emission factors).

At the request of Pannonia, emission factors from iLUC have been excluded from the analysis. It should be noted that this is not because of a resistance of the part of Pannonia to the concept of iLUC, but simply a grounded modelling observation that all iLUC emission factors generated over the past decade have been calculated based on econometric models (and as such outside the scope of the models used in the present report).

To estimate the emissions from biofuels production, the model has been adapted to consider co-production and ultimately allocate part of the emissions from each pathway between biofuels and co-products.

The model updates are summarized in Table 1.

Table 1 PRIMES Biomass supply model updates in this project in 2020-2030 unless specified otherwise

Pathway	Costs	Emissions
Starch-based ethanol	Co-product credit of 178 Eur/tonne (2020) and 243 Eur/tonne (2025-2030) to ethanol, based on co-production of DDGS and corn oil, in line with the industry input	About 40% of total emissions from the biofuel production chain are allocated to co-products
Sugar-based ethanol	Co-product credit of a certain amount of ethanol based on co-production beet pulp and molasses	About 10% of total emissions from the biofuel production chain are allocated to co-products
Oil-based biodiesel	Allocating part of pre-processing costs (e.g. of seed pressing) to seed cake (approximately 30-40%)	Allocating part of pre-processing emissions to (e.g. from seed pressing) to seed cake (approximately 30-40%)

2.1.3. Model interaction

The PRIMES-TREMOVE and the PRIMES Biomass supply models simulate in a closed-loop by using internally consistent projections of biofuel demand and prices. PRIMES-TREMOVE uses an initial set of assumptions on crop-based biofuel prices to assess the impacts on all transport segments. The demand for biofuels estimated with PRIMES-TREMOVE is subsequently fed into the PRIMES Biomass supply model, which estimates again the price of biofuels at a commodity level. Model runs are repeated with the new price of biofuels and PRIMES-TREMOVE delivers the final quantified output for each scenario.

2.2. Contextual background of the scenarios

2.2.1. Policy background affecting biofuel production and use in the EU transport

The following section presents existing policies and measures, which are presented in the modelling suite, and may act as drivers or barriers to the deployment of crop-based biofuel production in the EU.

<u>Potential drivers</u>

- Regulatory targets on biofuels blending that differ per Member State. The share of biofuels in the road transport mix is most commonly the result of specific regulatory policies set by governments.

<u>Potential barriers</u>

- Technical fuel blending constraints for bioethanol and biodiesel (e.g. E10, B10) based on the FQD[i];
- Aspects of RED II, such as:
    - the cap on crop-based bioethanol and biodiesel of 7% in 2030;
    - the 1% p.p. growth limit on the increase of crop-based biofuels share in 2030 relative to 2020; this means that if the share of crop-based biofuels is 4% in 2020 in a specific Member State, it cannot exceed 5% in 2030;

[i] The technical possibility to have a higher blend wall through the use of ETBE is also considered.

    - the minimum 1.75% share of advanced biofuels (ANNEX IX Part A biofuels), achieved at EU level but also at Member State level. Advanced biofuels further contribute to the RES-T target with a multiplier;
    - sustainability criteria on GHG emission thresholds, relative to reference fuels;
- EU-wide feedstock potential that determines how much crop-based feedstock for bioenergy production is available;
- CO_2 emission targets on car manufacturers imposing a reduction in the average CO_2 emissions from new car sales by 2030 compared to 2021, promoting the uptake of battery electric vehicles and effectively reducing the sale of ICE engines.

The modelling reflects complex bottom-up interactions among EU regulations, targets, Member State policies and economic criteria. Most importantly, results at EU level are an aggregation of individual Member State results, reflecting, for example, specificities with regards to supply, policies related to blending mandates by Member State.

2.2.2. Scenario definition

In order to assess the impact of certain policies on the uptake of crop-based biofuels from starch, sugar and oil crops in the EU, two scenarios are defined. Both scenarios include the updated methodological aspects agreed between E3-Modelling and Pannonia (see section 2.1.2 (a) and (b)). The scenarios were quantified using PRIMES-TREMOVE and PRIMES Biomass supply, and detailed results are presented in section 3. Where possible, the results were compared to the published results of the CTP 2020IA[10].

The quantified scenarios are described as follows:

First, a ***Counterfactual scenario*** is defined, providing a benchmark against which the effect of policies can be assessed. The Counterfactual scenario builds upon the modelling work that underpins the CTP 2020IA. It includes policies and measures adopted at EU level by the end of 2019. The broad scope of the scenario includes the GHG emission reduction target of at least 55% by 2030 compared to 1990 levels. To achieve this target a range of existing relevant policies in transport are considered. Key policies considered are the revised CO_2 standards for new light duty and heavy goods vehicles, the Clean Vehicle Directive, the Alternative Fuels Infrastructure Directive, RED II and FQD, TEN-T Regulation supported by CEF funding, etc.

The Policy scenario, hereinafter ***No Cap scenario***, assumes the same policies and measures (section 2.2) and techno-economic assumptions (section 2.1.2 (a) and (b)) as the Counterfactual scenario; for example, the mandatory minimum share of Annex IX Part A biofuels is retained by both scenarios. The only difference is that the No Cap scenario removes the policy foreseeing a 7% cap on the contribution of crop-based biofuels in transport in 2030. Removing the cap would show the extent to which the attributes of crop biofuels in the 2020IA have an influence on their uptake.

The analysis covers all EU27. The horizon of the analysis is the year 2030 and the model covers the intermediate years in 5-year time steps. The base year is 2015 and estimations for 2020 include also the COVID-19 impact, since the crisis strongly affected the transport sector. It should be noted that values for 2020 are based on model projections and that they are not statistical values and therefore should be interpreted with caution. For this reason, while this report presents results for 2020, the year 2015 is discussed as a base year (calibrated to statistics) and emphasis is placed in the 2025-2030 period.

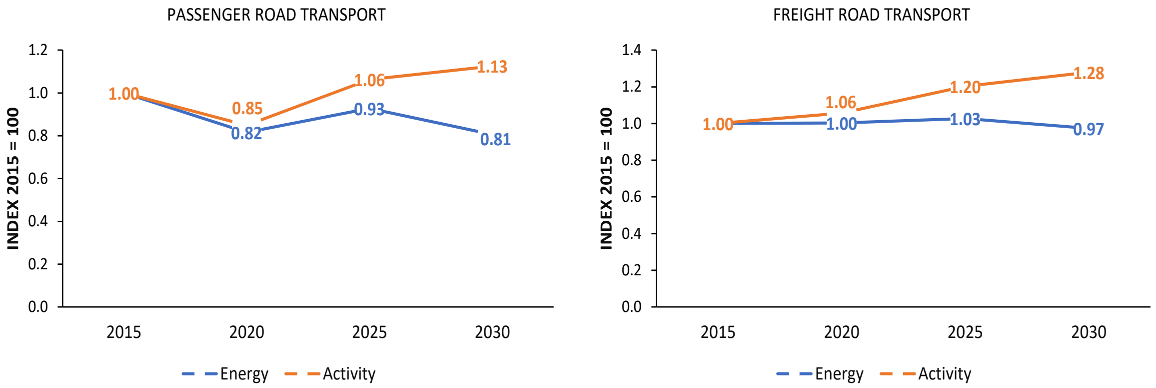
3. Results

This section presents results on the uptake of biofuels in road transport, including cars and vans, LCVs, HDVs, and other road transport modes (e.g. buses and coaches, and two-wheelers). Results are presented for all biofuels used in road transport, namely bioethanol, biodiesel and biomethane. Going forward, the segment of cars and vans is highlighted as it is a major consumer of bioethanol. Detailed tables and additional results are also presented in the Annex of this report.

3.1. Main trends

In the period 2015-2030, a decoupling between activity and energy consumed in transport is projected for both passenger and freight transport (Figure 2). Projections show that, despite the reduction of both transport activity and energy consumption in passenger road transport in 2020, mainly due to the reduced consumption of cars due to the COVID-19 crisis, the transport activity of passenger road transport increases to levels higher than 2015 already by 2025. Meanwhile, the energy consumption reduces, for more energy efficient ICEs are being deployed and Electric Vehicles (EVs) penetrate the market. The decoupling of activity and energy consumption is also prominent in freight road transport. In 2030 while the activity increases by almost 30%, energy consumption reduces to levels lower than 2015, owing to the deployment of more efficient trucks and to some smaller extent due to zero emission trucks. The levels of energy consumption and transport activity in 2020 are based on modelers' estimates of the potential impact of the COVID-19 crisis on mobility in the EU in 2020. Mobility levels, in particular for private transport modes, were significantly reduced during specific months of 2020 (i.e. March, April and May to some extent) resulting in reduced average annual mileages and eventually lower energy consumption in 2020 overall. On the other hand, freight transport was impacted to a smaller extent.

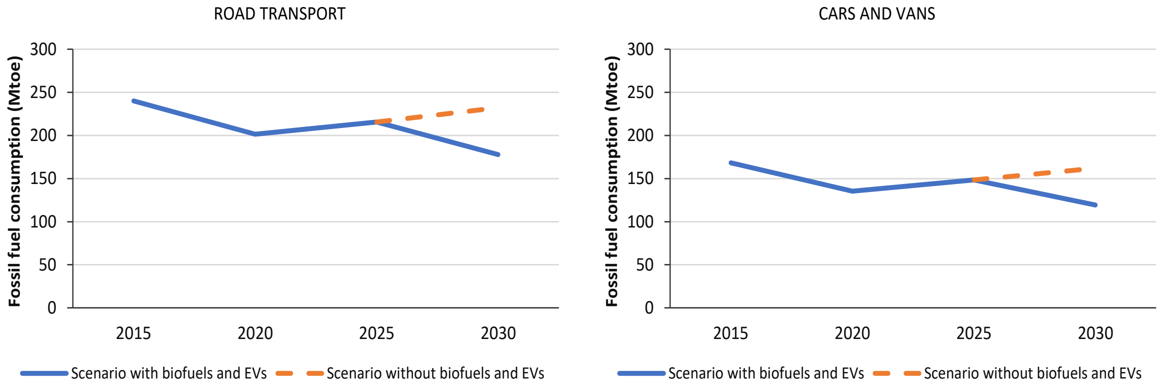
Figure 2 Key trends in activity and energy consumption in passenger and freight road transport



The reduction of fossil fuel consumption in road transport from about 250 Mtoe in 2015 to about 180 Mtoe in 2030 (Figure 3 left) is largely attributed to a switch towards electric mobility and biofuels. The orange line in Figure 3 aims to provide an estimate of what fossil fuel consumption would be without any uptake of EVs and biofuels in road transport by 2030 and considering that only fossil fuels and ICE vehicles would be available. Based on this (simplified) approach, we would end up to around 230 Mtoe of fossil fuel consumption in 2030 (compared to around 180 Mtoe in our scenario), implying that around two-thirds of the reduction in fossil fuel consumption in final energy terms, i.e. 230-180 =

60 Mtoe, is due to the uptake of EVs[ii] and about one-third of the reduction is due to biofuels. Similar findings apply also for the cars and vans segment (Figure 3 right). While cars and vans consume about 70% of fossil fuel used in road transport (i.e. 170 Mtoe compared to 250 Mtoe), the reduction due to the uptake of EVs and biofuels is about 40 Mtoe in 2030 (i.e. 160-120 = 40 Mtoe). This illustrates that the largest part of fossil fuel reduction is achieved by the electrification and the biofuel uptake in the cars and vans segment.

Figure 3 Fossil fuel consumption in road transport and in the segment of cars and vans



3.2. Energy use in transport

Figure 4 shows total fuel consumption in transport in 2015 and projections for 2030 according to two CTP 2020IA scenarios: the baseline scenario and the MIX scenario, together with the Counterfactual and the No Cap scenario developed in this study (section 2.2). The projections in all scenarios show that total energy use in transport reduces from about 340 Mtoe in 2015 to about 321 to 322 Mtoe in 2030 in the three scenarios[iii]. It is important to stress that the three scenarios are developed in the context of the ambitious climate target of 55% GHG emission reduction for 2030, leading to a reduction of oil products due to the deployment of more efficient transport modes and a switch to alternative fuels such as electricity, biofuels, hydrogen, synthetic fuels and natural gas.

The differences between the three scenarios in 2030 are subtle. The scenarios project somewhat higher energy consumption (by about 2.2 Mtoe in the Counterfactual and the No Cap scenario compared to the MIX CTP), primarily due to higher deployment of bioethanol and biodiesel (Figure 5). Liquid biofuel consumption is higher in the No Cap scenario by 2.5 Mtoe than in the MIX CTP scenario in 2030. As explained further below, with respect to bioethanol, this is mainly due to the substitution of ICEs by E85 vehicles, driven by the lower price of the E85 blend, which resulted from the updated cost methodology.

[ii] Not taking into account fossil fuels used for the production of electricity; in the policy scenarios of the CTP 2020IA, less than 20% of the electricity is generated from fossil fuels.

[iii] This part of the analysis extends from road transport to include non-road transport (i.e. rail, aviation and maritime navigation) in order to compare the results of the scenarios developed in the present study with those of the CTP 2020IA that are publicly available.

Figure 4 Fuels in transport in the EU (including aviation and maritime navigation)

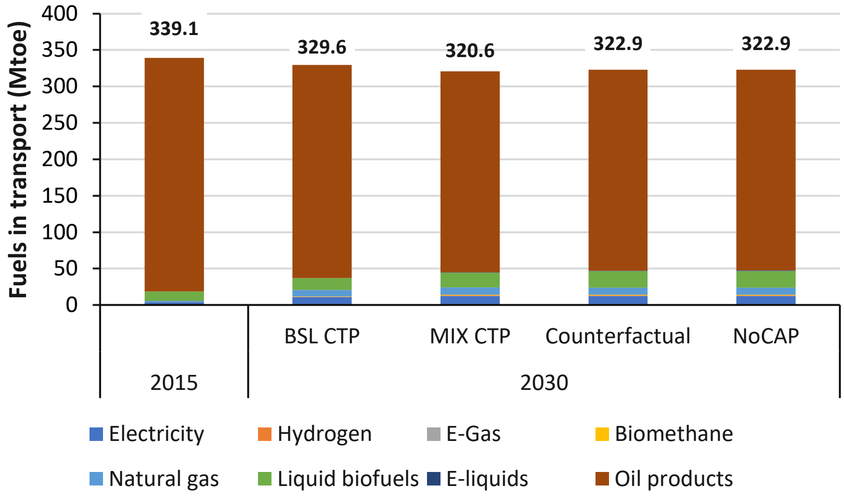
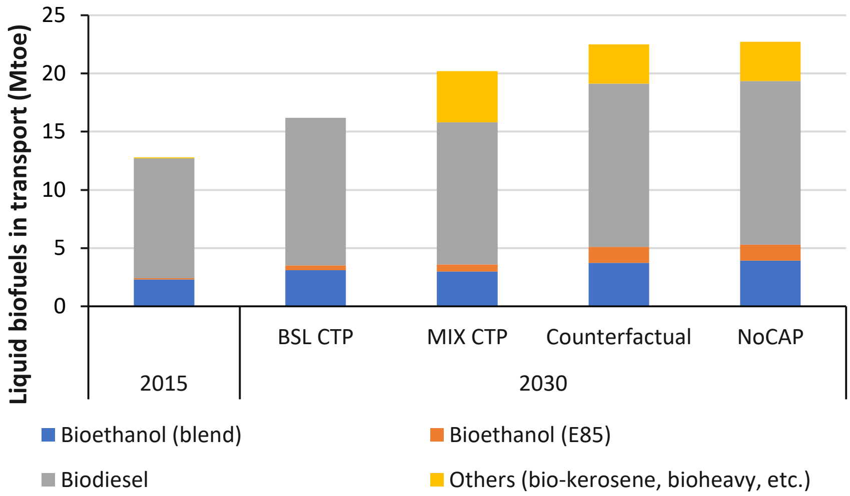


Figure 5 Liquid biofuels used in transport in the EU (including aviation and maritime navigation)



3.2.1. Alternative fuel use in road transport

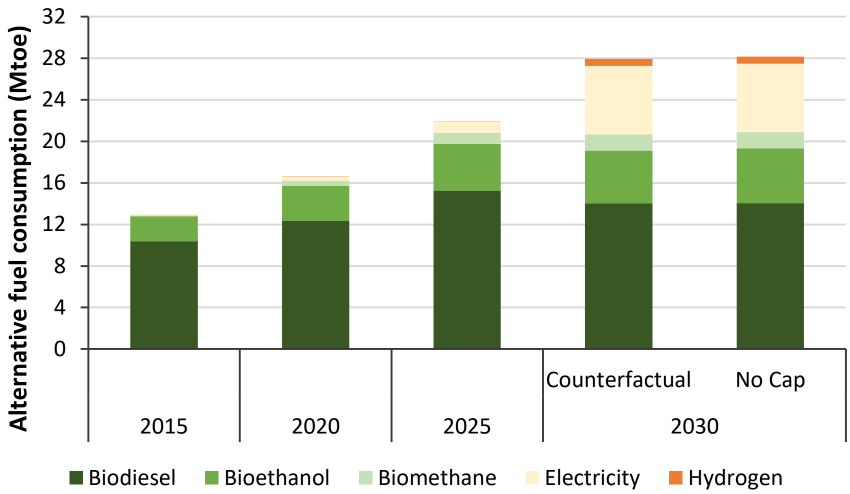
The scenario projections indicate a growing consumption of alternative fuels (i.e. including biofuels, biomethane, electricity, and hydrogen) in road transport. In Figure 6 (and Figure 7) all quantities are reported in energy terms, without considering multiplier of any type. The overall use of alternative fuels in road transport is expected to increase from around 13 Mtoe in 2015 to around 22 Mtoe in 2025 in both scenarios. The increase is due to higher consumption of biodiesel and bioethanol between 2015 and 2025, and to a lesser extend due to biomethane and electricity. In particular, biodiesel increases from 10.4 Mtoe to around 15.3 Mtoe in 2025, while bioethanol increases from 2.4 Mtoe to approximately 4.5 Mtoe in 2025. Of these, about 85% is crop-based biofuels (see also sections 3.2.3 and 3.2.4). Biomethane, increases from less than 0.1 Mtoe in 2015 to about 1.1 Mtoe in 2025. In both scenarios, modelling indicates that in 2025 the contribution of electricity is similar to that of biomethane, i.e. 1.1 Mtoe (total electricity and not only the renewable part), as the uptake of EVs is still limited in 2025.

The consumption of alternative fuels overall is growing between 2025 and 2030, driven primarily by the significantly higher contribution of electricity in cars and vans, but also biomethane and hydrogen in other road transport segments (Figure 6, Figure 7). Scenarios under consideration project a stark rise in electricity consumption between 2025 and 2030, as a result of ambitious CO_2 targets enforced on car and van manufacturers in 2030. The policy assumption is that CO_2 emission targets will bring about a reduction in the average WLTP CO_2 emissions of new car sales in 2030 by around 50% relative to 2021[iv]. In the modelling, the vehicle compliance with the CO_2 targets depends on the WLTP CO_2 label of the cars (e.g. zero for BEVs). This implies that the electricity consumption in road transport would increase to around 6.6 Mtoe in 2030, 85% of which is consumed by the cars and vans segment (Figure 7).

Despite the strong growth of EVs and some displacement of ICE cars and vans, the overall biofuel consumption is envisaged to remain relatively stable in both scenarios between 2025 and 2030 (ranging between 20.7 and 20.9 Mtoe). The projected reduction of biodiesel between 2025 and 2030 is counterbalanced by the increase of bioethanol and biomethane in both Counterfactual and No Cap scenarios. Interestingly, we note that the share of biofuels in total fuel consumption in road transport evolves from 5.1% to 8.6% to 9.7% in 2015, 2025 and 2030, respectively (the respective shares for the cars and vans segment are 4.8% to 7.9% and 8.9% in 2015, 2025 and 2030). The increasing share of biofuels is the result of efforts by Member States to reduce emissions in transport, as part of their commitments deriving from the ESR, the RED II – to some extent – and also due to national policies and measures under the NECPs, which promote the uptake of biofuels.

The share of alternative fuels (including biofuels, biomethane, electricity, and hydrogen) in transport (i.e. including aviation and maritime navigation) is presented in Figure 8[v].

Figure 6 Alternative fuel consumption in road transport in the EU27



[iv] resource.html (europa.eu), pg. 45 (Medium ambition increase case).

[v] This part of the analysis extends the from road transport to include non-road transport (i.e. rail, aviation and maritime navigation) in order to compare the results of the scenarios developed in the present study with those of the CTP 2020IA.

Figure 7 Alternative fuel consumption in cars and vans in the EU27

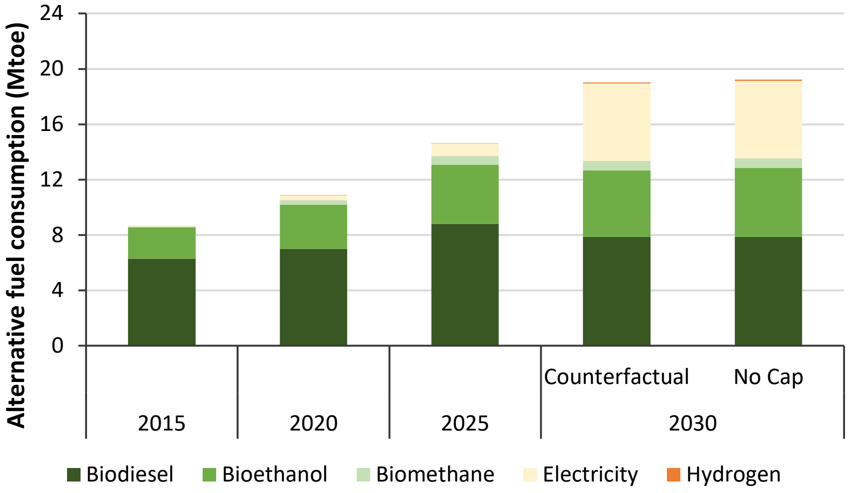
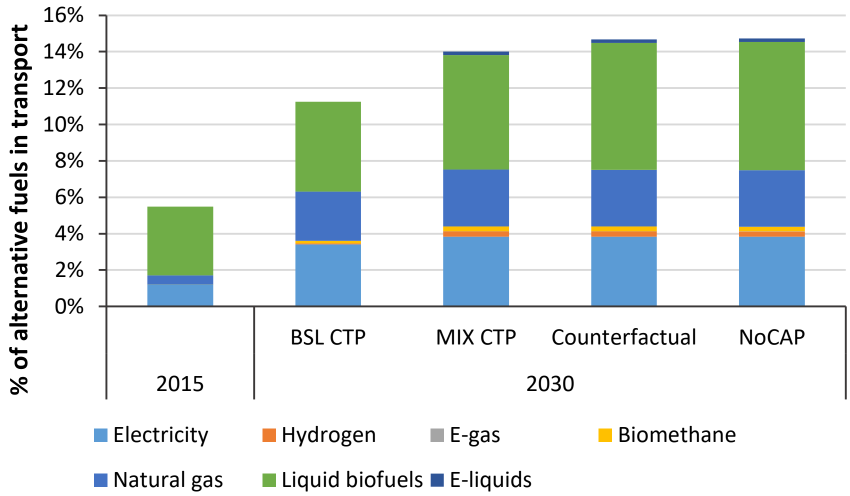


Figure 8 Share of alternative fuels in transport (incl. aviation and maritime navigation)



3.2.2. Biofuel consumption in road transport by segment

Figure 9 - Figure 11 present the consumption of bioethanol, biodiesel and biomethane by road transport segment, and in particular of passenger transport (cars and vans, and "Other" modes such as buses, coaches, and two-wheelers) and freight transport (HDVs and LCVs). In 2025, the projected increase of bioethanol consumption is attributed to its uptake by the cars and vans segment, whilst the additional uptake of biodiesel is owed to its use in both cars and vans and the HDV and LCV segment. The projected increase of biomethane between 2015 and 2025 is driven by the cars and vans segment, while between 2025 and 2030 it is driven by the HDV and LCV segment. The uptake of LNG and biomethane in HDVs is mainly driven by the CO_2 targets on truck manufacturers in 2030, as these fuels and engines allow the manufacturers to comply easier with these targets.

In 2030, cars and vans account for almost 95% of total bioethanol consumption, around 55% of total biodiesel consumption and around 45% of total biomethane consumption. The remainder is primarily consumed by HDVs and LCVs, as the "Other" segments consume less than 5% of the respective biofuels.

Notably, both the Counterfactual and the No Cap scenarios show an increase in bioethanol consumption from 4.5 Mtoe in 2025 to 5.1 Mtoe in 2030 under the Counterfactual scenario and to

5.3 Mtoe in 2030 under the No Cap scenario. Bioethanol consumption continues to rise until 2030 either in blended form or directly as E85. In the case of the No Cap scenario, bioethanol consumption grows by about 0.2 Mtoe compared to the Counterfactual scenario in 2030, as a result of no cap being imposed on crop-based biofuels.

Biodiesel consumption is projected to drop (from 15.3 Mtoe in 2025 to around 14 Mtoe in 2030 in both scenarios). Most of the reduction, or about 1 Mtoe, is met in the cars and vans segment, which sees a reduction from 8.8 Mtoe in 2025 to about 7.9 Mtoe in 2030. The consumption of biodiesel in the HDV segment is reduced by about 0.2 Mtoe, from 5.5 Mtoe in 2025 to 5.7 Mtoe in 2030.

Biomethane use in cars and vans, at 0.6 – 0.7 Mtoe, is relatively stable between 2025 and 2030 in the scenarios, but biomethane use in HDVs and LCVs doubles from 0.4 to 0.8 Mtoe between 2025 and 2030.

Figure 9 Bioethanol consumption in road transport by segment

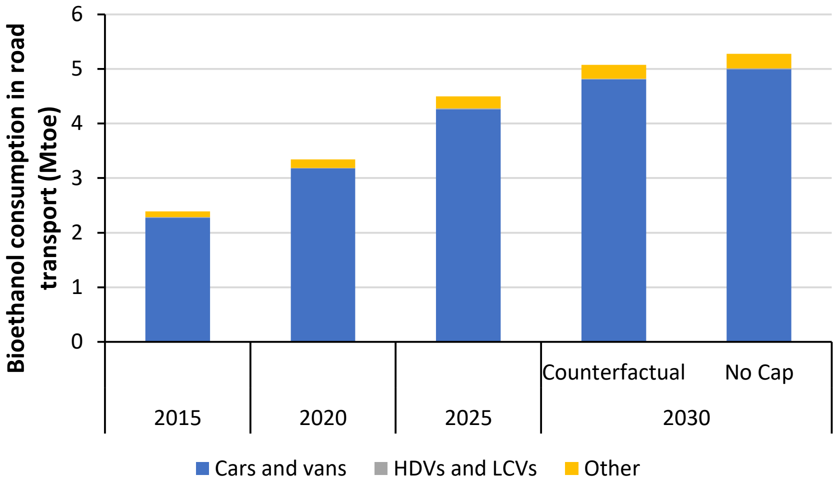
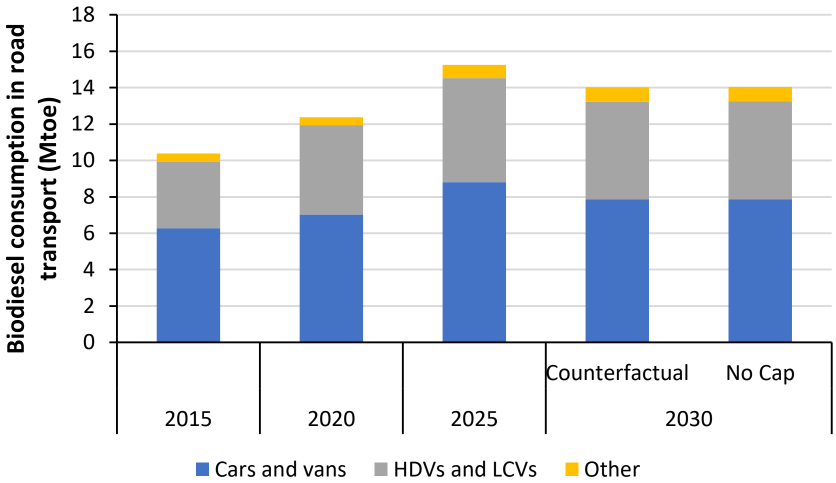
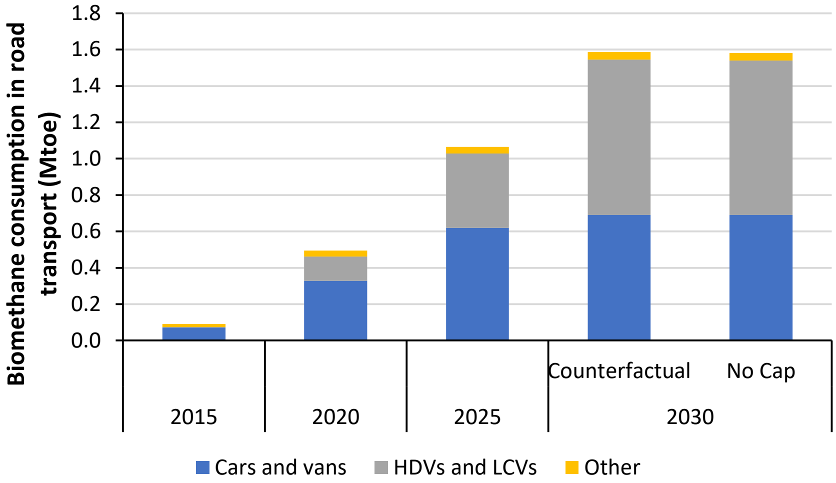


Figure 10 Biodiesel consumption in road transport by segment



Note: biodiesel includes advanced biodiesel

Figure 11 Biomethane consumption in road transport by segment



3.2.3. Biofuel consumption in road transport by biofuel type

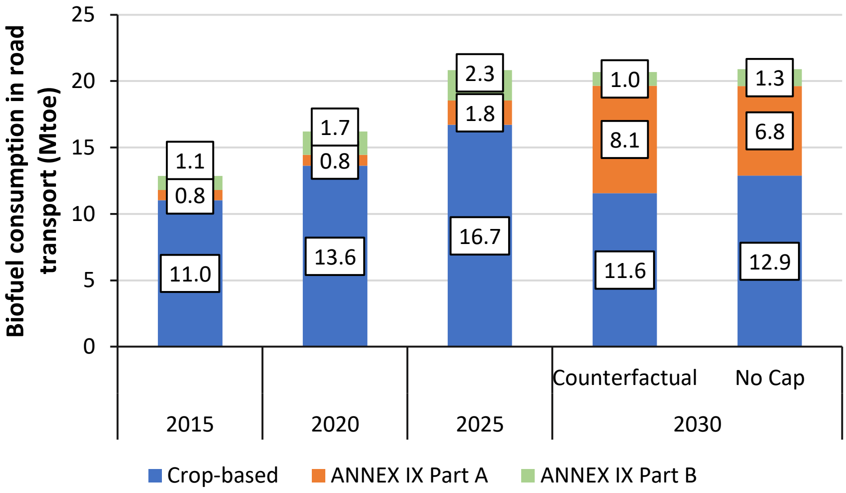
Below we present the developments in total biofuel consumption in road transport (i.e. bioethanol, biodiesel and biomethane), split into crop-based[vi], ANNEX IX Part A and ANNEX IX Part B biofuels (Figure 12). Modelling results show a strong increase in the consumption of crop-based biofuels in road transport in 2025 relative to 2015 (i.e. from 11 Mtoe to 16.7 Mtoe in 2025), with about two-thirds consumed in the cars and vans (i.e. 7.2 Mtoe in 2015 and 11.1 Mtoe in 2025; Figure 13). This is the result of the intensification of climate policies by countries as we approach 2030. At the same time, some increase in ANNEX IX Part A and Part B biofuels is also projected over the same time horizon (i.e. from 0.8 Mtoe in 2015 to 1.8 Mtoe of ANNEX IX Part A biofuels in 2025 and from 1.1 Mtoe in 2015 to 2.3 Mtoe of ANNEX IX Part B biofuels in 2025). ANNEX IX Part A biofuels represent around 40% of total ANNEX IX biofuels in 2015 (around 0.8 Mtoe of Annex IX Part A category biofuels, and around 1 Mtoe of ANNEX IX Part B biofuels[11]). In 2025 the cars and vans segment consumes about 75% of total ANNEX IX Part A biofuels and about 55% of total ANNEX IX Part B biofuels used in road transport (Figure 13).

The picture changes between 2025 and 2030 when a shift from crop-based towards ANNEX IX Part A biofuels takes place, in line with the provision of the RED II for a minimum 1.75% share of ANNEX IX Part A biofuels achieved at EU level and Member State levels. The use of ANNEX IX Part A biofuels in road transport is projected to grow from 1.8 Mtoe to 8.1 Mtoe and 6.8 Mtoe in the Counterfactual and the No Cap scenarios, respectively, in 2030. The use of ANNEX IX Part A biofuels in cars and vans is projected to grow from 1.3 Mtoe to 5.1 Mtoe and 4.3 Mtoe in the Counterfactual and the No Cap scenarios respectively, in 2030. In both scenarios, the minimum 1.75% share of ANNEX IX Part A biofuels is respected, albeit with some higher margin in the Counterfactual scenario as crop-based first-generation biofuels are constrained. At the same time, consumption of crop-based biofuels is projected to reach 11.6 Mtoe in the Counterfactual scenario, in which the constraints on crop-based biofuels still apply. Conversely, in the No Cap scenario, crop-based biofuels consumption is projected to increase to 12.9 Mtoe in 2030, in the absence of the cap on the contribution of crop-based biofuels in transport.

[vi] These are non-Annex IX, crop-based biofuels.

In the cars and vans segment, the consumption of crop-based biofuels is 7.7 Mtoe in the Counterfactual, increasing to 8.6 Mtoe in the No Cap scenario in 2030.

Figure 12 Total biofuel consumption in road transport per type of biofuel



Note: 2015 based on the SHARES tool[11]

Figure 13 Total biofuel consumption in cars and vans per type of biofuel

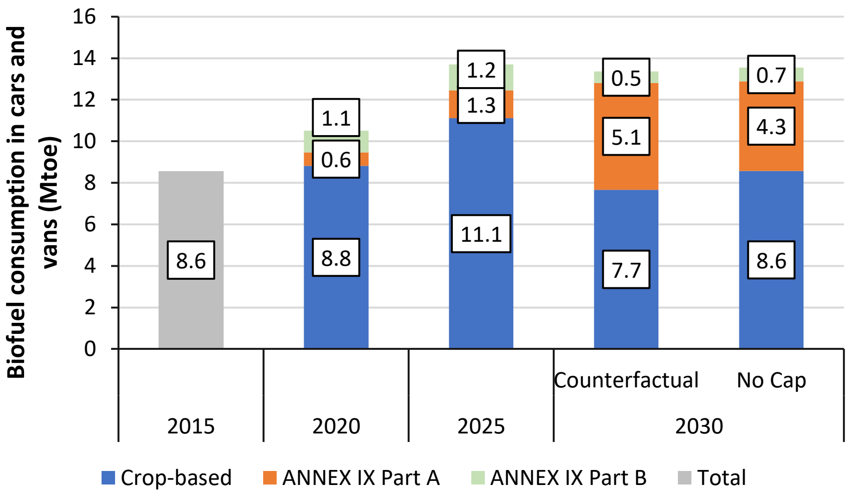
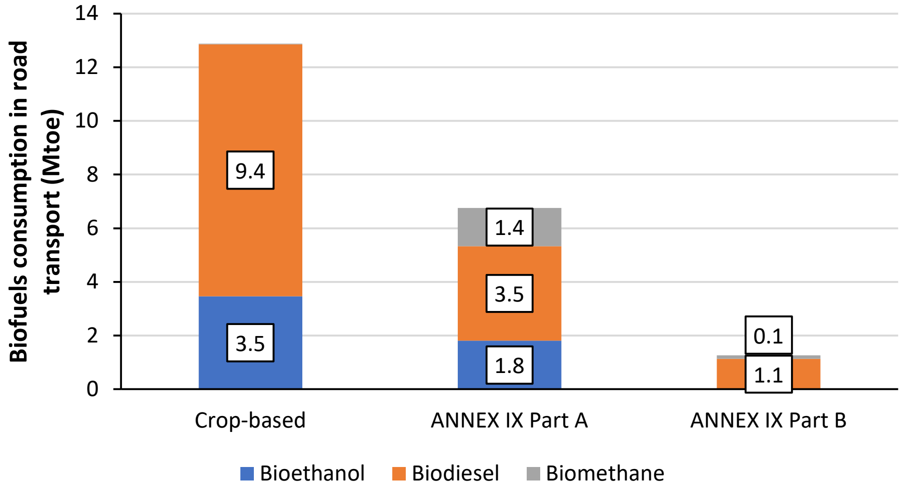


Figure 14 presents the consumption of bioethanol, biodiesel and biomethane in road transport split into crop-based, ANNEX IX Part A and ANNEX IX Part B biofuels in the No Cap scenario in 2030. Biodiesel is the main biofuel across all three categories. It represents about three-quarters of total crop-based biofuel consumption, about half of total ANNEX IX Part A biofuel consumption and about 90% of ANNEX IX Part B biofuel consumption. Bioethanol represents about 25% of crop-based and ANNEX IX Part A biofuel consumption and biomethane about 25% of ANNEX IX Part A and 10% of ANNEX IX Part B biofuels. In 2030, the biofuel blending shares are about 8%, 10%, and 13% for bioethanol, biodiesel and biomethane, respectively. As such, biomethane is allocated to natural gas in higher shares than biodiesel and bioethanol in their diesel and gasoline counterparts, reflecting to some extent the flexibility of fuel suppliers to manage their compliance.

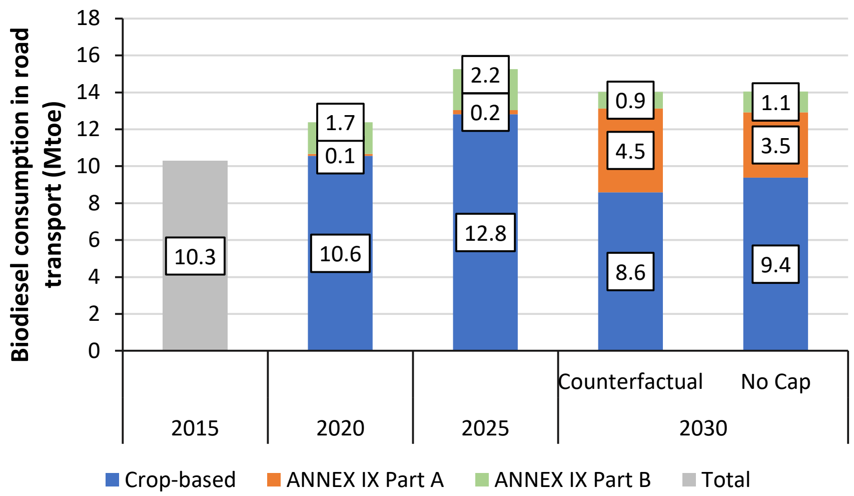
Figure 14 Biofuel consumption in road transport split by biofuel type in the No Cap scenario in 2030



Biodiesel consumption in road transport

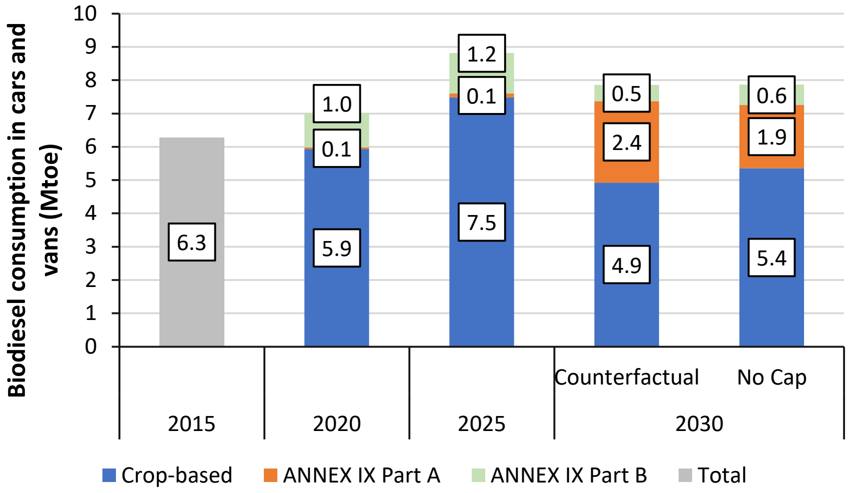
The developments vary when considering the split of biodiesel (Figure 15) into crop-based and ANNEX IX Part A and B biofuels. The modelling reveals a peak in 2025 and some reduction in 2030 relative to 2025. Crop-based biodiesel is also projected to peak in 2025, reaching around 12.8 Mtoe and dropping in 2030 down to 8.6 Mtoe in the Counterfactual scenario and 9.4 Mtoe in the No Cap scenario. The displacement of crop-based biodiesel is mainly the result of the overall reduction in the use of diesel (as biodiesel is mainly used in blends) and the uptake of ANNEX IX Part A biodiesel, driven by the minimum 1.75% share of the RED II. The reduction of ANNEX IX Part B biodiesel in road transport between 2025 and 2030 is due to the use of used cooking oil for the production of biofuels in non-road transport segments. In the case of the No Cap scenario, the modelling indicates that in 2030, crop-based biodiesel would at least remain at levels similar to those in 2015. In contrast, the modelling points to a reduction relative to the 2015 levels in the Counterfactual scenario. These trends are similar in both cars and vans segment (Figure 16) and HDVs, the former consuming about 70% and the latter about 30% of total biodiesel used in road transport.

Figure 15 Biodiesel consumption in road transport by type of biofuel



Note: 2015 based on EUROSTAT

Figure 16 Biodiesel consumption by cars and vans per type of biofuel



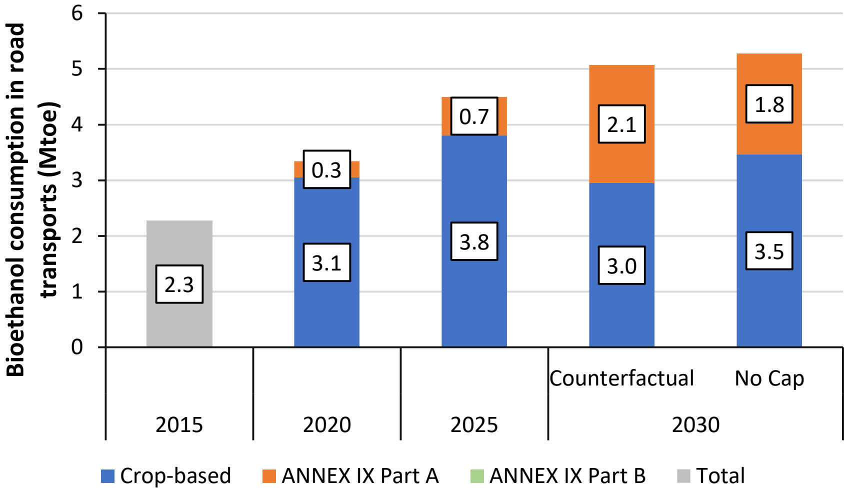
Bioethanol consumption in road transport

The outlook for bioethanol develops differently compared to biodiesel. Projections show a growing market for bioethanol for 2025 and 2030 (Figure 17). The overall bioethanol consumption in road transport is projected to increase to around 4.5 Mtoe in 2025 and 5.1 and 5.3 Mtoe and 2030. The consumption in the cars and vans segment is projected to increase to around 4.3 Mtoe and to around 5 Mtoe in 2025 and 2030 respectively, compared to 2.3 Mtoe in 2015 and 2.7 Mtoe in 2019 (Figure 18). Total bioethanol consumption is also shown to increase by about 0.2 Mtoe in the No Cap scenario compared to the Counterfactual scenario in 2030, owing to the lift of the cap on crop-based biofuels.

The use of crop-based bioethanol in road transport is projected to peak in 2025 to around 3.8 Mtoe and then reduce to about 3 Mtoe in the Counterfactual scenario and 3.5 Mtoe in the No Cap scenario, driven by the removal of the cap on crop-based biofuels. The reduction in the consumption of crop-based bioethanol between 2025 and 2030 is due to the combined impact of the decreasing demand for blended gasoline and the FQD limits. Yet, the ethanol blend in the gasoline pool is about 14% in volume terms in 2030, enabled by the use of oxygenates such as ETBE.

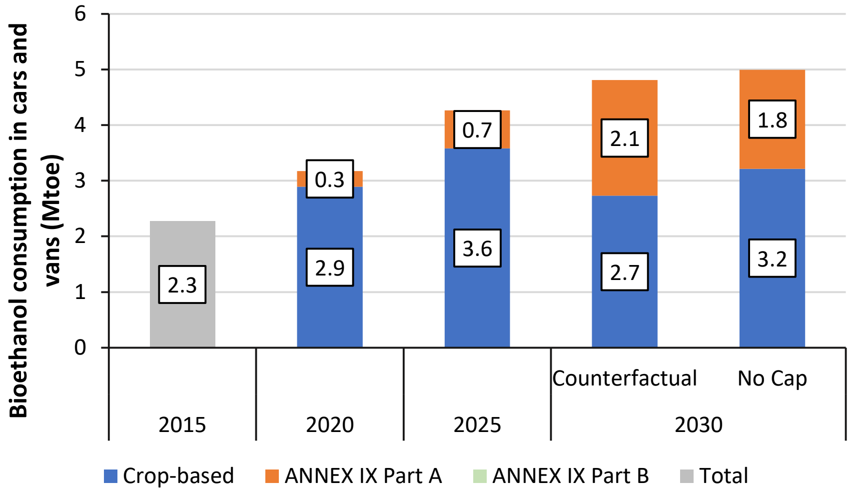
Modelling indicates the uptake of ANNEX IX Part A bioethanol, that within the horizon to 2030 it reaches its peak in 2030 due to the RED II provisions on ANNEX IX Part A biofuels (i.e. 2.1 and 1.8 Mtoe in the Counterfactual and the No Cap scenario, respectively). A significant use of bioethanol is envisaged in special car types like E85 cars (around 25% of the total use of bioethanol in cars and vans in the No Cap scenario in 2030). Here we note that ICE gasoline engines could be converted to E85 vehicles thus potentially substituting part of the ICE gasoline fleet, in countries that there is refueling infrastructure available (e.g. France, Sweden). We identify that the availability of E85 fuel supply infrastructure represents a much higher factor limiting new E85 cars uptake and existing ICE gasoline modifications than the potential difference in the price of the vehicle (either when purchased directly from a dealership or when modified by the vehicle owner). In specific cases of infrastructure availability and ICE gasoline vehicles conversion to E85, the uptake of bioethanol for the E85 fleet could be higher. As such, removing the cap on crop-based biofuels leads to a higher uptake of bioethanol, and in particular of crop-based bioethanol, to the detriment of ANNEX IX Part A bioethanol in 2030.

Figure 17 Bioethanol consumption in road transport per type of biofuel



Note: 2015 based on EUROSTAT

Figure 18 Bioethanol consumption by cars and vans per type of biofuel

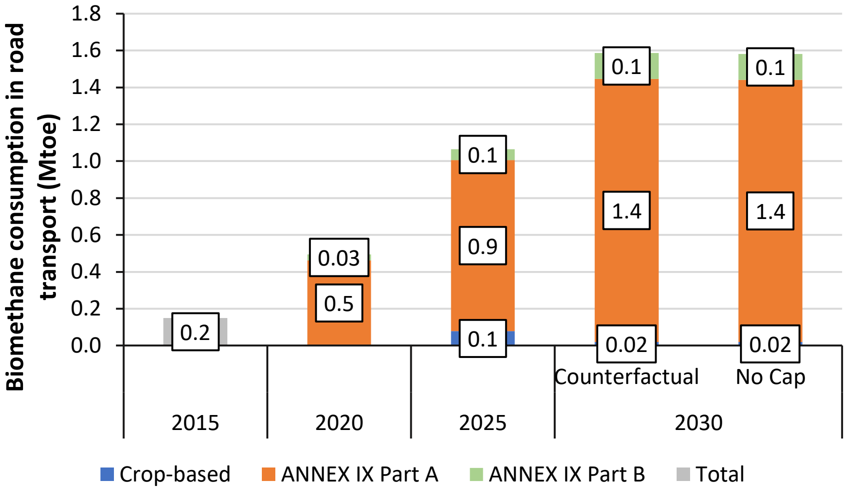


Biomethane consumption in road transport

Biomethane also contributes towards achieving the ANNEX IX Part A biofuel provisions in the EU by 2030, as set out in the RED II, and therefore it sees a significant growth compared to 2015. By 2030, about 1.6 Mtoe of biomethane are consumed (Figure 19).

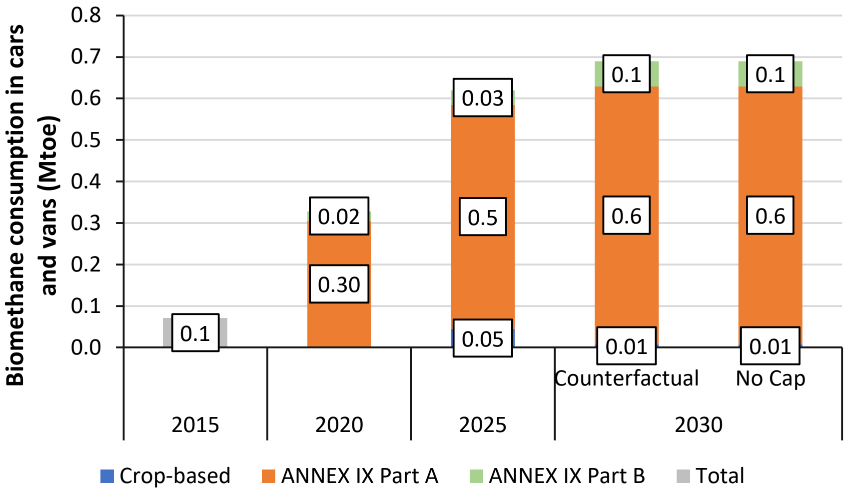
While the largest quantities are used in trucks (almost 1 Mtoe in 2030), there is also a positive impact on the uptake of CNG cars, driven by the CO_2 emission targets on car and truck manufacturers. In particular, biomethane consumption in cars and vans increases by a factor 10 between 2015 and 2030, from 0.07 Mtoe to about 0.7 Mtoe in the No Cap scenario (Figure 20). Despite the uptake of CNG vehicles, the levels of CO_2 standard considered in the Green Deal CTP MIX scenario, become sufficiently stringent and reach levels which show a clear pathway towards zero emission vehicles.

Figure 19 Biomethane consumption in road transport per type of biofuel



Note: 2015 based on EUROSTAT. Biomethane in 2015 is ANNEX IX Part A

Figure 20 Biomethane consumption by cars and vans per type of biofuel



Note: Biomethane in 2015 is ANNEX IX Part A

3.2.4. Biofuel production chains

This section discusses the main elements of production chains that are deployed in order to supply the crop-based, ANNEX IX Part A and ANNEX IX Part B demand for biofuels. In this project, the focus of techno-economic data updates was on crop-based bioethanol production from corn and as such the production of crop-based bioethanol is discussed in more detail than the other biofuel production routes.

The figures below present the domestic production of crop-based bioethanol in terms of final product (Figure 21) and feedstock demand (Figure 22) to produce the quantities used in road transport. The production of starch-based bioethanol is projected to more than double in 2030 compared to 2015, in the No Cap scenario. In 2015, consumption of starch-based bioethanol was about 1.4 Mtoe. In the Counterfactual scenario, consumption of domestic starch-based bioethanol reaches 2.5 Mtoe in 2030. The No Cap scenario may stimulate additional 0.45 Mtoe domestic production of starch-based bioethanol and additional 0.05 Mtoe of sugar-based bioethanol, both compared to the Counterfactual scenario. Based on exchanges between Pannonia Bio and E3-Modelling, it was pointed out that the current trend in the ethanol industry points to a shutdown of existing sugar-based ethanol capacity and that there are little prospects for investments in new capacity in the near future. Such trends are in line with the outlook presented in Figure 21 and Figure 22. It is shown that the market for starch-based ethanol has significantly higher prospects than sugar-based ethanol. The demand can all be met with domestically available starch crops.

Figure 21 Domestic crop-based bioethanol production for road transport per crop type

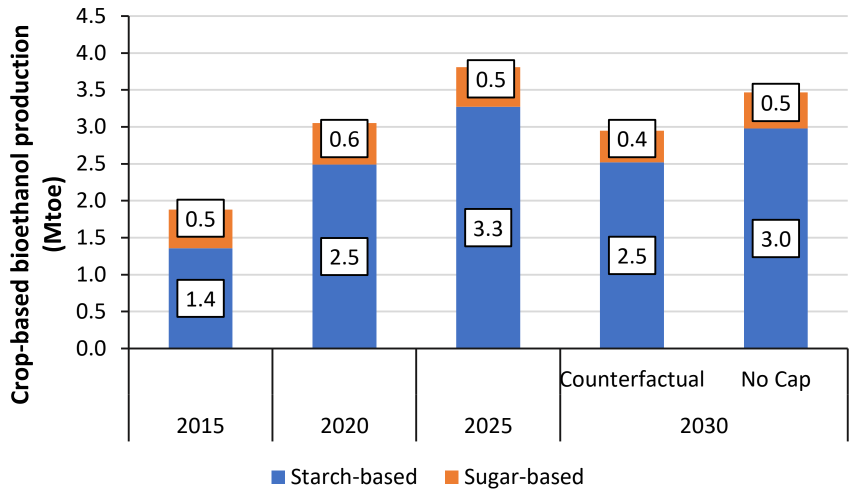
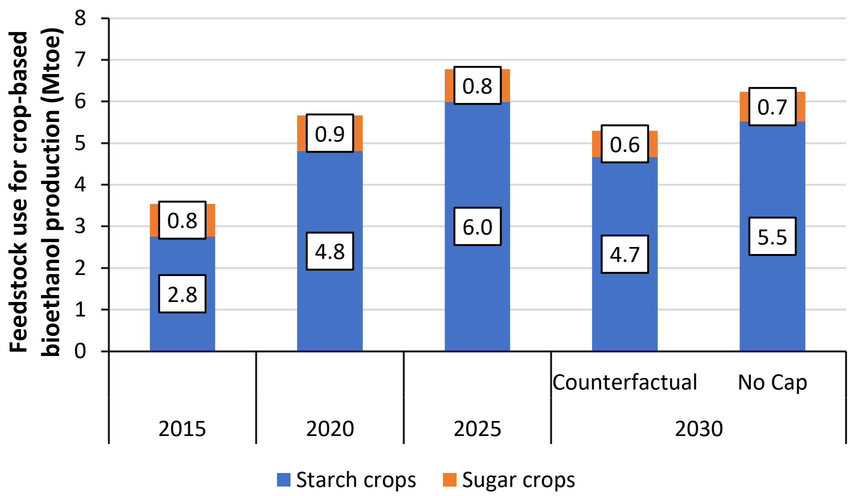


Figure 22 Feedstock use for domestic crop-based bioethanol production for road transport per crop type



Note: Feedstock consumption is not allocated. Co-product allocation is applied to costs and emissions (section 2.1.2)

The demand for ANNEX IX Part A bioethanol is met by the deployment of cellulosic ethanol production technologies reaching about 2 Mtoe/yr in 2021-2030 and requiring about 5.5 bn Euro of investments. Additional investments will be required in the period after 2030, as the demand for cellulosic bioethanol continues to grow and stabilize for about one more decade, driven by the maturity of advanced conversion technologies and also due to the fact that gasoline ICE cars will still be in circulation. However, the post-2030 horizon has not been the focus of this study.

In 2030, domestic biodiesel production is largely based on the vegetable oil FAME (about 8 Mtoe in 2030), and partly also for vegetable oil HVO (about 1.2 Mtoe in 2030). Advanced conversion technologies using ANNEX IX Part A feedstocks produce about 3.5 Mtoe in 2030. The production of ANNEX IX Part B biodiesel is UCO-based HVO (around 1.1 Mtoe in 2030). Finally, the production of biomethane is primarily from chains using ANNEX IX Part A feedstocks, whether produced by anaerobic digestion or advanced gasification routes towards 2030.

The production costs of the main biofuel production chains are presented in Table 2.

Table 2 Biofuel production costs in Eur/toe in 2030

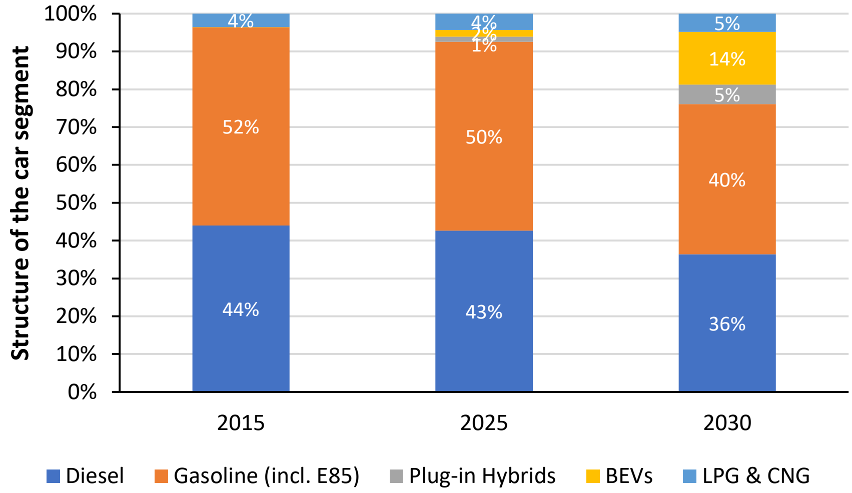
Bioethanol	**Eur/toe**
Starch-based	565
Sugar-based	915
Cellulosic ethanol	1,545
Biodiesel	
Vegetable oil FAME	690
Vegetable oil HVO	1,100
UCO HVO	1,150
Advanced biodiesel	1,860
Biomethane	
Anaerobic digestion	670
Advanced gasification	870

3.3. Development and structure of the car fleet

The composition of the stock of vehicles in the EU affects, as one would expect, the use of fuels in the cars and vans segment. Underneath, we present the structure of the stock of cars in the No cap scenario (Figure 23). The scenarios project a transition from ICE car technologies towards advanced powertrains after 2025. The modelling indicates a continuing dependence on ICE (gasoline and diesel) cars between 2015 and 2025; these technologies represent around 96% of total stock of cars in 2015 and are projected to hold 92% of total stock of cars in 2025. Electric cars (BEVs and PHEVs) are projected to start making higher inroads from 2025 (representing 3% in 2025). LPG and CNG cars would also see their share in the total stock to increase by around 0.7 p.p. between 2015 and 2025.

The stock of cars undergoes a restructuring towards 2030 as a result of a transition to EVs. Notably, BEVs see their share in the total stock of cars reaching about 14% in 2030; PHEVs are projected to hold 5.2% of the total stock of cars in the EU in 2030. The uptake of these advanced powertrains comes at the expense of the ICE diesel and gasoline cars, both of which are projected to still represent 76% of the total stock of cars in 2030. The uptake of BEVs is the result of the implementation of the CO_2 emission standards on car manufacturers, which by 2030 prescribe that the average WLTP CO_2 emissions from new car sales will need to decrease by about 50% compared to 2021. Modelling results indicate that BEVs would represent around 40% of the new car sales in 2030 under this level of policy ambition; in 2025, they would represent around 9% of the total new car sales.

Figure 23 Structure of the car segment in the EU in the No Cap scenario



E85 cars are also projected to retain a growing share in the total stock of cars, mainly as a result of the cost-competitive prices of bioethanol and to some extent due to the absence of the cap on the use of crop-based biofuels. E85 cars are projected to grow and reach 0.6% in the total stock of cars in 2030 (or around 1.4 million cars in the EU); in 2025, the share of E85 cars in the total stock would be around 0.3% (or about 3.6% of the total AFV fleet compared to about 2.2% in 2018). In the modelling, we assume that E85 cars come at 1,000 to 1,500 Euro purchasing cost premium compared to ICE gasoline counterparts. It should be noted, that there is evidence to suggest that in specific markets (e.g. France) the purchasing price of ICE gasoline and E85 vehicles is comparable. For these markets, the cost premium should be significantly lower and as such the uptake of E85 vehicles could be higher than what indicated in the present analysis, provided that there is E85 fuel supply infrastructure availability. Hence it is under this perspective that the cost difference of E85 cars relative to gasoline cars could become a criterion in the vehicle purchase decision. The discussion section offers the perspective on the impact of the E85 price relative to gasoline price on the E85 vehicle uptake. Finally, the share of LPG and CNG cars out the total stock of cars is also growing, mainly as a result of a further uptake of CNG cars and their lower WLTP CO_2 label, and to a much less extent as a contribution from LPG cars.

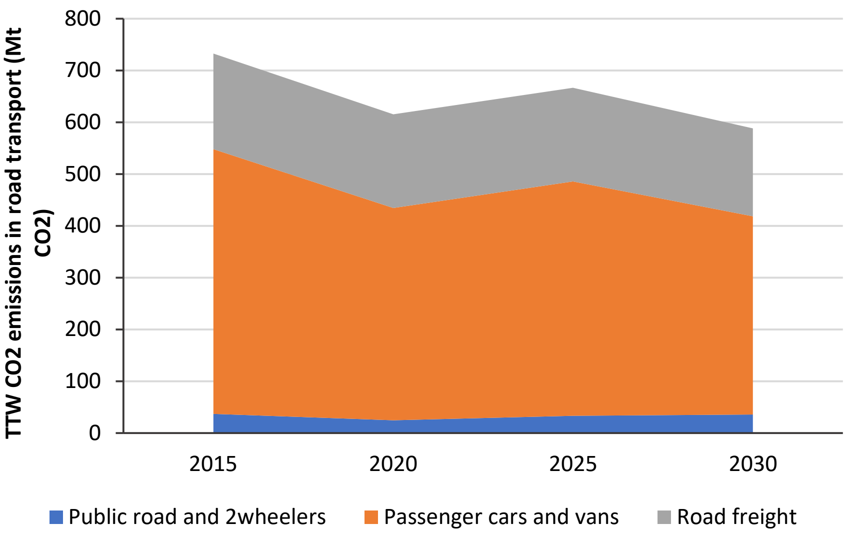
3.4. CO2 emissions

CO2 emissions in the No cap scenario

The COVID-19 crisis has had a significant effect on the transport system in 2020, leading to a reduction in both transport activity and energy consumption. In road transport, the effects of the pandemic were particularly noticeable in the passenger cars segment, supported by the projection for a steep reduction of Tank-to-Wheel (TTW) CO2 emissions between 2015 and 2020 (Figure 24). In the first months of 2020 in particular passenger transport activity and the related energy consumption fell drastically. After 2020 the rebound in transport activity of the various road transport modes and in particular that of cars and vans is projected to lead to higher TTW CO_2 emissions in road transport.

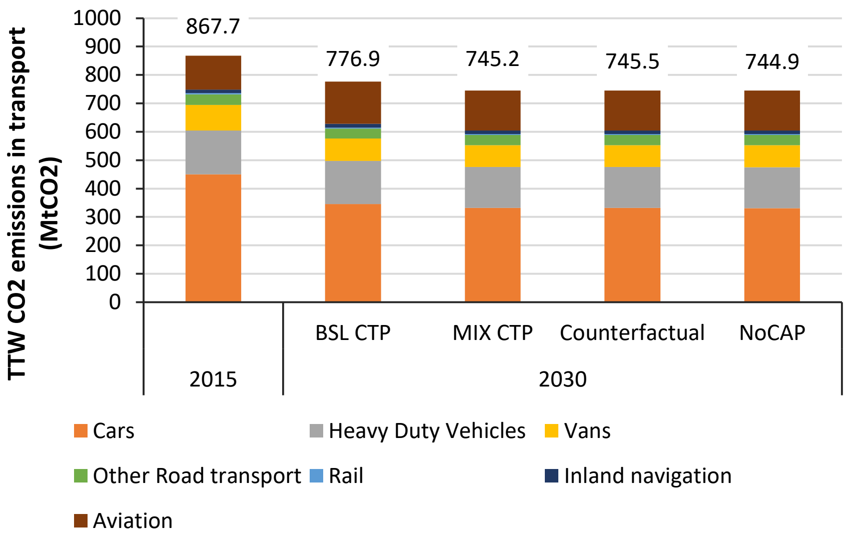
From 2025 towards 2030 CO_2 emissions follow a decreasing trend, driven mainly by the developments in the cars and vans segment. The reduction in the TTW CO_2 emissions of cars and vans is the result of the decreased fossil fuel consumption and the uptake of alternative fuels consumption in these sectors between 2025 and 2030. The uptake of electro-mobility represents the key driver for the reduction of the TTW CO_2 emissions in road transport, shortly followed by the contribution of biofuels.

Figure 24 TTW CO2 emissions in road transport



The higher use of biofuels in the No Cap scenario is expected to further decrease the TTW CO2 emissions from road transport by about 0.4 Mtons compared to the MIX scenario of the CTP[vii] in 2030 (Figure 25)[viii].

Figure 25 TTW CO2 emissions in transport



3.5. Carbon abatement costs

Figure 26 presents the cost of CO_2 abatement for different biofuel types and electric driving for 2030. Crop-based bioethanol is the cheapest across all alternative fuels, demonstrating negative abatement

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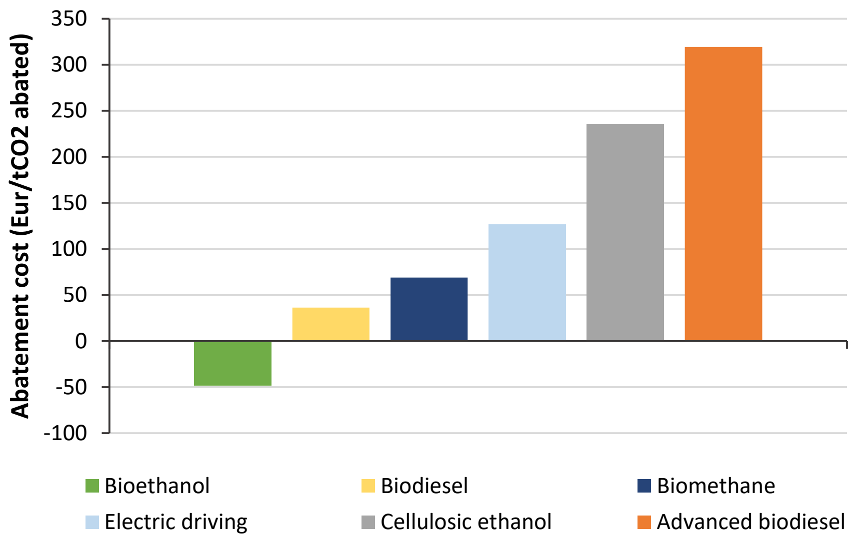
[vii] https://ec.europa.eu/clima/sites/clima/files/eu-climate-action/docs/2030_climate_target_plan_figures_en.xlsx

[viii] This part of the analysis extends the from road transport to include non-road transport (i.e. rail, aviation and maritime navigation) in order to compare the results of the scenarios developed in the present study with those of the CTP 2020IA that are publicly available.

costs driven by the lower price of bioethanol compared to the higher pre-tax gasoline price (Table 3), after taking into account the credits for co-products (as described in section 2.1.2).

Notably, crop-based bioethanol and biodiesel show lower abatement costs than electric mobility (battery electric vehicles), for which we estimate abatement costs of about 125 Eur/t CO_2 using the average emission factor of EU power production in 2030. Advanced biofuels from lignocellulosic feedstocks show the highest abatement costs by a factor 1.9-2.5 compared to electric driving.

Figure 26 Cost of CO_2 abatement for alternative fuels in the cars segment in 2030



For the calculation of the carbon abatement costs of battery electric cars, we considered the overall cost of the vehicle taking into consideration the additional capital cost related to the purchasing of the BEV relative to the conventional counterpart.

Table 3 Alternative and fossil fuel prices used in the estimation of carbon abatement costs in 2030

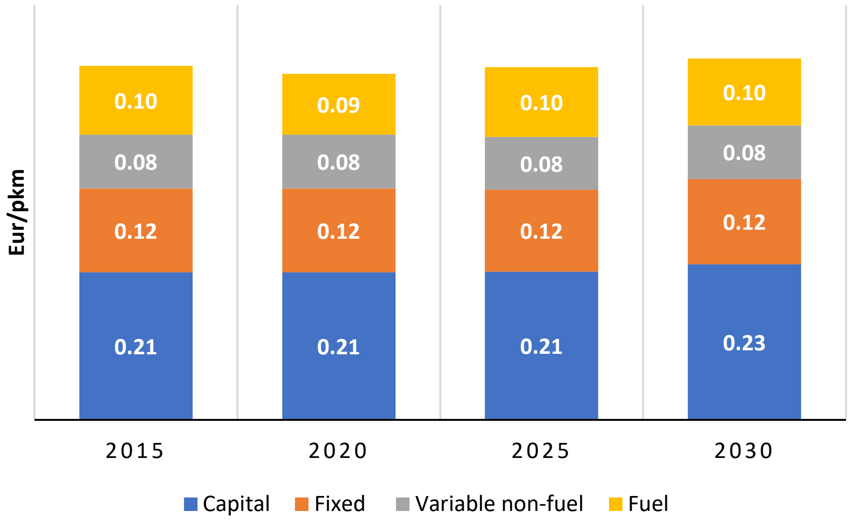
Fuel	Pre-tax price (Eur/toe)
Bioethanol	710
Cellulosic ethanol	1,670
Biodiesel	970
Advanced biodiesel[ix]	1,840
Biomethane	820
Electricity	0.25 (Eur/kWh)
Gasoline	851
Diesel	842

[ix] Drop-in advanced biodiesel (e.g. FT diesel).

3.6. Cost of ownership and use of cars in the No Cap scenario

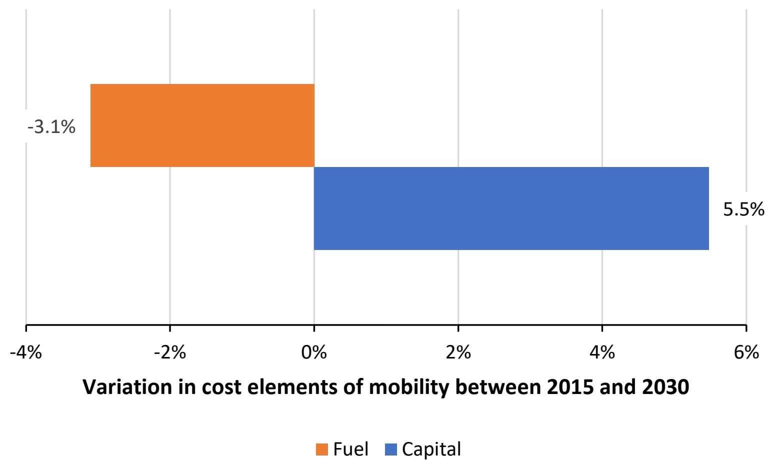
Figure 27 shows the unit cost of transport by cars. The cost indicator includes capital, fuel, fixed and variable non-fuel costs and is expressed in Euro/pkm. The capital cost element of the total cost includes the annuity payment for capital related to the vehicle purchasing expenditures. Fuel costs represent the expenditures for fuel purchasing, while fixed and variable non-fuel costs include costs like operation, maintenance, insurance, etc. The total cost indicator shows the structure of the costs of mobility by car aggregated for the total EU system.

Figure 27 Structure of mobility cost by car



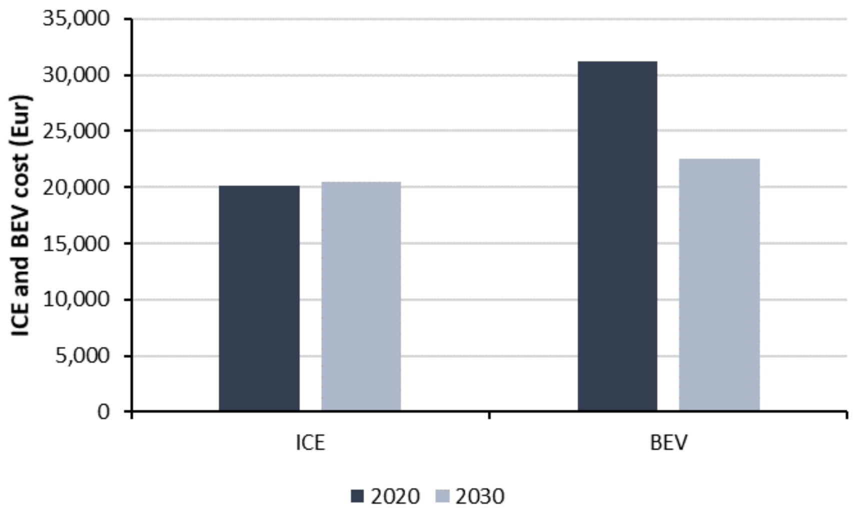
The scenario indicates that the total unit cost of mobility by car would increase by about 2% in 2030 relative to 2015 (or by 0.011 Euro/pkm). This increase is mainly associated with an increase in the capital costs (i.e. 5.5% in 2030 relative to 2015), which is the result of purchasing more capital-intensive car technologies (e.g. BEVs and PHEVs). On the contrary, transport users are expected to record some savings in their fuel expenditures, which are mainly attributed to the uptake of more energy efficient car technologies (e.g. more efficient ICE cars) but also thanks to the fuel savings of EVs (Figure 28). Other types of costs are found to remain relatively stable in the time horizon.

Figure 28 Variation in cost elements of mobility by car between 2015 and 2030



The modelling confirms a transition towards more capital-intensive transport equipment which comes with the benefit of lower running costs in the time horizon until 2030. The extent of the additional capital costs related with the purchasing of vehicle technologies such as EVs is clearly associated with the developments in the automotive industry and the potential reductions in the cost of batteries. So far, data from industry, studies and scientific literature suggest a strong reduction in the costs of batteries, which positively affects EV costs (Figure 29). This trend is expected to continue in the coming years and this assumption is considered in the present modelling.

Figure 29 Cost of Internal Combustion Engine and Battery Electric Vehicles (300 km range) in 2020 and 2030



4. Insights - Policy messages

The modelling and the scenario analysis offer policy insights as regards the prospects of the bioethanol uptake in the EU road transport sector in 2030.

How could crop-based bioethanol contribute more to EU transport decarbonization in line with the EU Green Deal climate ambition objectives in 2030? What are the restraining factors for higher bioethanol uptake by 2030, when marginal cost abatement practices and literature suggest that crop-based bioethanol is the cheapest road transport decarbonization option? Broadly similar questions appear warranted for crop biodiesel as it is a similarly relatively cheap road transport decarbonization option.

The scenario runs in this project are built on the policy setup and climate ambition scope of the scenarios of the Climate Target Plan of the European Commission as published in September 2020. The modifications of the scenarios quantified in this study relate to updates in the parametrization of bioethanol in terms of production costs and emissions, as well as undertaking a projection which eliminates the crop cap of the RED II directive.

The model-based approach taken for the purposes of this study goes beyond the simple less-sophisticated approaches which associate the uptake of the various decarbonization options with marginal abatement cost curves. The modelling suite considers in a bottom-up way current EU legislation for the transport sector and on fuels, as well as detailed vehicle stock projections and parametrization of refueling infrastructure availability which all interact to produce the fuel mix in the scenarios projections. These complexities are considered in the modelling and allow to draw conclusions on the factors which can constrain higher market uptake of bioethanol in the EU transport sector.

Influence of model updates on the uptake on crop-based bioethanol

The modification of the scenarios related to technical parametrization, were focused on updating the techno-economic parameters of crop-based bioethanol production from starch, and on considering co-products in production cost and emission estimates of crop-based biofuels. These updates effectively led to an improved cost profile of bioethanol, with lower than previously estimated, costs. The updated production costs ultimately led to negative abatement costs for crop-based bioethanol followed by crop-based biodiesel. The analysis within this study, however, demonstrates that costs are only one part of the puzzle affecting the uptake of crop-based biofuels, as increased consumption is mainly observed in car types such as E85. As discussed below, policy considerations such as the removal of the cap on crop-based biofuels is the main factor enabling higher penetration of bioethanol to levels limited by other policy considerations (e.g. FQD).

With respect to GHG emissions, Annex V of each iteration of the RED contains the methodology pursuant to which each biofuel producer must calculate the GHG intensity of each consignment of biofuel produced. Under this methodology, total emissions are allocated across all products and not just to biofuels. Because crop-based biofuels usually result in roughly equal quantities of fuel and non-fuel products (such as animal feed, food, biomaterials), this means that for some chains, the GHG emissions involved in the production of a unit of biofuel, when calculated with PRIMES Biomass supply, may have been higher than the GHG emissions that a biofuel producer would certify under the RED. In effect, however, higher emission profiles were not acting as a limiting factor as the limits of the sustainability criteria were not constraining the use of bioethanol. The lower emission profile of crop-based bioethanol did not enable additional uptake of ethanol, as this was realized in the policy scenario in which no cap on crop-based biofuels was imposed.

With respect to the representation of biofuel production chains, PRIMES Biomass supply has a higher level of aggregation compared to the detailed pathways listed in RED II (Annex V), and does not have a one to one correspondence with these legal categories. Under the current RED (2009), as well as under RED II, which enters into force in July 2021, there are four broad categories of relevant biofuels, which are:

1. Biofuels that fit the definition of food- and feed-based (in this report referred to as crop-based biofuels);
2. ANNEX IX Part A biofuels, which are also called advanced biofuels[x] ;
3. ANNEX IX Part B biofuels, which are based on used cooking oil and animal fats[xi]; and
4. Biofuels that fit the definition of biofuels but none of the three categories above (these can generally be called "residue biofuels" but possibly also include other things). In all policy analysis at the EU level, this category is assumed not to be a separate category of biofuels. In contrast, the actual EU biofuels market currently trades large quantities of this type of biofuel, which are not crop-based biofuels and therefore are not subject to any restrictions.

Further disaggregating certain biofuel categories in PRIMES Biomass (i.e. to those in point 4 above), could improve the distribution of non-Annex IX biofuel production chains projected by the model, yet this would not affect the overall demand for non-Annex IX biofuels. This is demonstrated by the No Cap scenario, which as discussed below, shows that other factors influence their additional uptake.

Deployment of advanced technologies

The modelling showed that the uptake of advanced biofuels may reach 7 to 8 Mtoe in 2030. In particular, the demand for ANNEX IX Part A bioethanol in the No Cap scenario reaches about 1.8 Mtoe and requires around 2 Mtoe/yr of installed capacity by 2030. Such demand levels are driven by the broader decarbonization context of the EU, promoting less carbon intensive transport fuels, and by EU policies (e.g. RED II) requiring certain shares of advanced biofuels in transport. The feasibility of the supply system to meet this demand, as assessed with PRIMES Biomass supply, takes a forward-looking approach, having a full foresight on the uptake of advanced biofuels in 2030, anticipating it already by 2020. As such, the analysis here considers certainty on the market for advanced biofuels and a sufficient timeframe for investment planning and construction for the required capacity at full scale (i.e. in this particular case the 10-year period between 2020 and 2030). Here one should consider that, according to reported figures, the planned capacity investments on advanced bioethanol from cellulosic sugars is only a fraction of the demand projected in 2030 (i.e. around 0.2 Mtoe/yr[12]), and therefore a significant upscale on investments in the coming decade will be required. Investment reality often requires stronger signals, in the absence of which the required upscale of advanced biofuel production plants may not materialize fully, possibly leading to import dependency of the EU on advanced biofuels to meet the necessary demand.

The developments in road transport after 2030, are certainly pertinent on providing such signals for the timely deployment of advanced biofuel production technologies. While the post-2030 horizon has not been the focus of this study, the market for advanced biofuels, and in particular that of ANNEX IX Part A bioethanol will continue to grow and stabilize for one more decade. Additional demand for ANNEX IX biofuels may also emerge from non-road transport segments such as aviation and maritime, which also need to decarbonize. Both these factors provide positive signals on the need for advanced bioethanol (e.g. alcohol-to-jet) and biodiesel production capacity in the EU (see also footnote xv). On

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[x] not to be confused with how non-EU jurisdictions define advanced biofuels.

[xi] perplexing often called "waste-based" biofuels (indeed, much used cooking oil imported into the EU for biofuels production is not waste, but animal feed).

the other hand, electrification of road transport is a key strategy for decarbonization, also due to synergies with other sectors of the energy system. Electrification will undoubtedly lead to a high uptake of EVs to the detriment of ICE vehicles. To date, however, it is unclear how the policy scene will evolve around the prospects of ICE cars in the time horizon after 2030 and the extent to which the ICE vehicle fleet may decline. For example, crediting systems on ANNEX IX Part A biofuels could allow car manufacturers to continue selling ICE cars, thereby the latter remaining in the market. These considerations are part of the modelling approach taken in the present study, by assuming an economic lifetime for investment decision making on biofuel production capacity between 20 and 25 years. As such, given the uncertainty in the policy developments post-2030, the economic lifetime on investment decisions assumed in this study is justified. Such aspects can be substantiated quantitatively further by expanding the temporal scope of the analysis to post-2030. That said, it should be noted that several advanced biofuel production chains to-date are still inherently uncertain and the developments on techno-economics, R&D and policy are still ongoing. More research is needed in this regard to identify a sustainable and plausible outlook on the horizon to 2030 and beyond.

Bioethanol as a blend

In the modelling, bioethanol use in the EU road transport takes place through two main channels:

- in blended form with gasoline: this blended fuel is used by all petrol cars in the EU countries; limits apply to the ethanol blending with gasoline are prescribed by the FQD;
- or in "pure" form, i.e. E85 blends which are supplied in dedicated pumps in selected EU countries and are used by E85 Flex Fuel cars, which are either certified as such by OEMs or are the result of inexpensive after-market conversions.

In the context of a 55% GHG emission target, by 2030, with a strengthening of CO_2 standards and maintenance of the current RED II caps on crop-based fuels -as was the case for the scenarios published in the Climate Target Plan-, the cost of the biofuel is only a small part of the factors determining their market penetration.

The strengthening of the CO_2 standards -which according to current regulation is based on the WLTP labelling system- do not allow to provide any credits for the use of biofuels in the system. Therefore, in a context of more stringent CO_2 regulations, the sales of ICE-based vehicles will necessarily decrease in order to allow manufacturers to comply. Zero emission cars will make significant inroads to the detriment of ICE cars and, therefore, a decreasing market trend for liquid fuels is expected. As an example, even if E20 was to be established across the whole EU as the common petrol blend, under current legislation this would not lead to a decrease of the WLTP CO_2 label of ICE gasoline cars by 20% due to the mix with bioethanol.

Eliminating the limitations of crop-based fuels has a positive effect on the penetration of bioethanol. Modelling shows some additional 0.5 Mtoe of bioethanol consumption in the cars and vans segments in 2030 compared to a scenario retaining the crop-based cap of RED II.

The Fuel Quality Directive limits a wider uptake of bioethanol in a blended form with gasoline. Despite lifting the constraint on the crop-based biofuels, the modelling retains the current FQD provisions and shows that this limits a potentially larger contribution from bioethanol in the EU road transport sector. While FQD limitations on E10 grade were reasonable during the introduction of the directive, it is not evident if it still would remain relevant in 2030. A large part of cars is able to run on higher than E10 blends today and this number would be even higher in 10 years' time. It should be noted that the model includes options for higher blend walls, enabled technologically by the use of oxygenates such as ETBE. In 2030, under the current FQD limitations, the ethanol blend in the No Cap scenario reaches around 13% in volume terms.

Raising the current FQD limitations to E20 or E30 could result in a maximum of additional 3-3.5 and 6-6.5 Mtoe of bioethanol in the EU in 2030, respectively, in cars and vans segment, compared to the results of the No Cap scenario. This would have to be combined with a No Cap setting, otherwise the RED II crop-based cap would prove to be a binding constraint.

Higher bioethanol petrol blends do not require modifications in the existing infrastructure of fuel distribution to the car market. Hence, allowing for higher bioethanol blends has the potential to allow for additional emission reductions without any additional changes to the refueling infrastructure if the RED II crop cap and FQD provisions were lifted.

Bioethanol distributed as E85 fuel

The modelling analysis indicates a fleet of 1.4 million E85 cars in the EU in the No Cap scenario in 2030, driven by updated assumptions in the pricing of bioethanol and the accounting of co-products and the absence of the cap on crop-based biofuels. In addition, we note that since existing ICE gasoline vehicles can be converted to E85 vehicles – which is not considered in the present analysis. Therefore, the E85 vehicle fleet and subsequently the bioethanol uptake could be higher than what indicated in the present study, provided that there is E85 refueling infrastructure available (e.g. France[xii], Sweden). Moreover, there is evidence to suggest that in specific markets (e.g. France) the real price difference between ICE gasoline and E85 cars is negligible, leaving the fuel price difference as the main driving factor for the new vehicle choice. Obviously, the above makes sense for countries that there is infrastructure availability; in countries with no infrastructure the future infrastructure build up is also bound on political decisions. However, which factors could prevent the E85 fleet reaching such or higher number in the EU by 2030? Price fluctuations and the uncertainty on taxation of E85 fuel are two major risk factors on the uptake of E85 fuel consumption and E85 flex fuel cars in the time horizon 2025-2030.

Why bioethanol has not made significant inroads up to now in the EU and in particular in countries with traditionally high numbers of E85 cars? Ethanol prices are found to differ remarkably in the EU compared to other markets like the US due to different raw material price, product (i.e. bioethanol) technical specifications and sustainability criteria. Both EU and US ethanol prices show some variability which, probably, also has to do with ethanol use for other non-transport markets and reflect opportunity costs of ethanol producers. In particular for the US market, fuel suppliers had to put E85 on sale as a means to meet their compliance obligations with renewable fuel standards/targets. Contrastingly, up until today, fuel suppliers in the EU comply to the FQD target of reducing GHG emissions from fuels supplied by 6% in 2020 relative to 2010, mainly through the blending of biofuels with fossil counterparts and much less with the contribution of E85 being sold as a separate fuel. Hence, in the 2025 and 2030 horizon, considering that higher (than 2020) shares of biofuels are projected to be blended with fossil counterparts, the compliance will be much easier; hence fuel suppliers would not need to sell cheap E85 to comply with the target. It is uncertain how this trend will develop in the future. According to a study from Irwin (2019)[13], E85 prices are largely following the ethanol price trends in the US.

Variability and fluctuations in the ethanol prices have largely impacted selected EU markets regarding the uptake of E85 cars. A prominent example is that of Sweden which recorded a strong market uptake of E85 cars up until 2015. Ethanol price in energy terms was less expensive than gasoline, hence consumers tended to use more E85 fuel (Figure 30). At the same time, a strong growth of E85 car

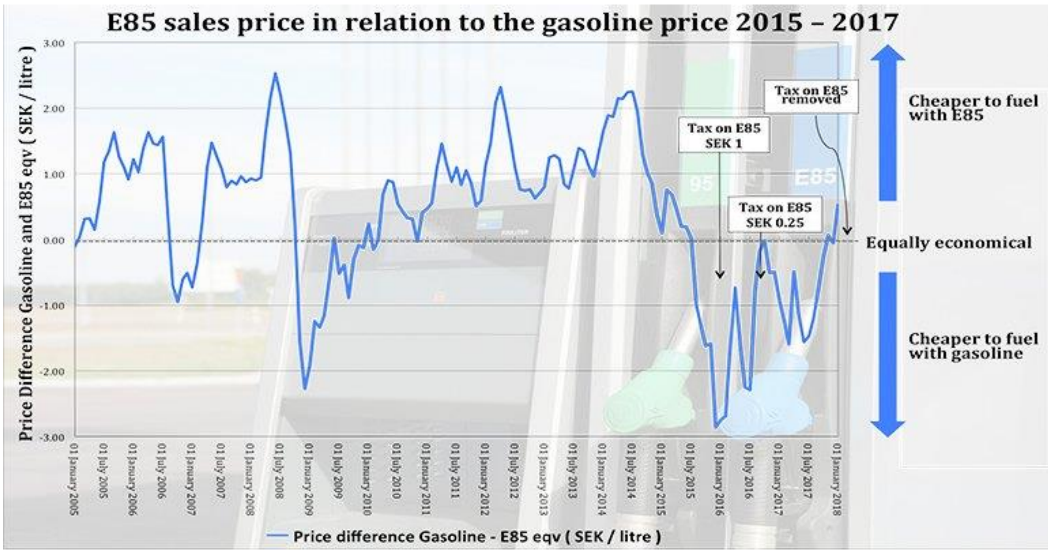
[xii] https://www.fuelsandlubes.com/total-steps-up-deployment-of-e85-fuel-in-france/

purchases was recorded, as more people tended to using a renewable fuel and at the same time enjoy savings in their fuel expenditures, considering also the lower energy density of the biofuel compared to gasoline. The moment the Swedish government-imposed excise tax on E85, in 2016, E85 fuel turned out to be less economical to use than gasoline, which resulted in a reduction in the consumption of E85 and a stagnation in the sales of E85 cars. When the tax on E85 was removed in 2018, E85 fuel gained again a cost competitive advantage relative to gasoline.

The Swedish government has asked for approval to continue the tax exemption of liquid biofuels in 2021, which was granted by the European Commission[xiii]. However, there is uncertainty whether such exemption would remain in place in the years after 2021 or whether it would apply to selected biofuels (e.g. crop-based or not). This poses a high risk for the E85 fuel market opportunities in the future.

Low oil prices negatively impact on the competitive advantage of bioethanol, despite some correlation between oil prices and bioethanol. Low oil prices, eventually increase the price gap between petrol blend and E85 fuel. On such occasion, the vast majority of consumers will still continue refueling their cars with fuels which leads to savings in the household's budget. Conversely, high oil prices are expected to lead to a growing market of E85 fuel consumption.

Figure 30 Price difference between gasoline and E85 in Sweden



Source: Bioenergy International [14]

Scaling the production and supply of E85 fuel will require some modifications in the existing fuel supply and distribution infrastructure, especially in less developed markets. Distribution infrastructure cannot be considered as a truly constraining factor as the existing petrol refueling stations can be modified/retrofitted to allow the supply of E85 blend. However, such modifications will still require some costs which need to be accounted for.

Both biofuels consumption and electromobility will contribute in reducing transport CO_2 emissions in 2030. We identify complementary relationship between the two options on the timescale up to 2030. Consumers not being able to purchase BEVs may still purchase an ICE conventional car which can run on higher biofuel blends. The latter presupposes that certain policy aspects (e.g. RED II crop-based caps

xiii https://bioenergyinternational.com/policy/european-commission-approves-swedens-tax-exemption-for-high-blend-biofuels, Bioenergy int. b [15] and FQD) are alleviated. The balance between BEVs and biofuels in reducing transport decarbonization by 2030 can be influenced by the cost evolution of BEVs this decade. If battery costs continue a strong decreasing trend until 2030, people would tend to purchase more BEVs, as these cars also offer significantly lower running costs.

The following table provides an overview of factors which can have an impact on the future of bioethanol in the EU road transport sector.

Table 4 Factors influencing the uptake of bioethanol and expected impact on its market uptake

Factors influencing the uptake of bioethanol in the EU	Expected impact on bioethanol uptake
External factors	
Oil prices	Oil price trajectory determines a price gap between petroleum products and E85 price; the smaller the gap the lower the uptake of E85. When oil prices increase, E85 becomes more competitive. Contrastingly, for gasoline blends, a high oil price may result in lower gasoline blend demand and eventually lower bioethanol consumption (as the latter is offered in blended form with gasoline)
Bioethanol price fluctuation	As above, fluctuation increase or decrease the competitive advantage of E85 fuel relative to gasoline
Compliance	The price of E85 may also be shaped by compliance targets (e.g. from the US market and policy environment). Fuel suppliers may need to sell E85 fuel at pump prices lower than E10 to meet their compliance target in order to attract the demand from E85 vehicle users
Price of electric cars	If prices of EVs continue decreasing, the shift towards EVs will accelerate and eventually lead to a shrinking fleet of ICEs; the latter will lead to lower sales of petrol blends and bioethanol
Regulatory measures	
CO_2 standards	More ambitious than today's regulation targets on car manufacturers can be met only with low or zero emission cars (when measured on WLTP); less ICE cars will be sold therefore the market for all liquid fuels will decrease
RED II	Limits crop-based biofuels; also emphasizes on the use of ANNEX IX part A biofuels
FQD	E10 petrol blends is a significant constraining factor for higher use of bioethanol in road transport; opting for E20 or E30 blends and no cap on crop-based biofuels could imply substantial potential for bioethanol use in EU road transport

Taxation	Excise taxes on biofuels act to their detriment and to the benefit of petroleum products. This is mainly related to biofuels sold in separate pumps like E10, E20 and E85

Future research

In order to explore further the uptake of crop-based biofuels in road transport, the work carried out in this project could benefit further from soliciting industrial expertise also for other biofuel production chains that are included in the model, and in particular on the techno-economic assumptions of commercialized and non-commercialized technologies. The current project focused on the review of techno-economic data of corn-based ethanol and to a limited extent on other biofuels.

To assess the potential for additional uptake of starch-based bioethanol, the element that could be explored further relates with including extra-EU imports of primary feedstock (i.e. starch and sugar crops (e.g. from the Balkans or Ukraine) and not only of final biofuel product.

Finally, while the present analysis includes a wealth of technological options in its available portfolio, some niche options which are commercialized are not included. This for instance, includes ethanol engines for heavy duty transport (i.e. ED95) or HVO blends with gasoline. Considering such elements in future work could demonstrate further possibilities for bioethanol uptake.

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Annex

Table 5 Primary feedstock in the PRIMES Biomass supply model

Feedstock	Notes
Classified as food and feed crops in RED II	
Starch crops	maize, wheat, barley, etc.
Sugar crops	mainly sugar beet, but also sweet sorghum, etc.
Vegetable oil crops	rapeseed, sunflower, etc.
Classified as feedstocks for ANNEX IX Part A biofuels in RED II	
Energy crops (annual)	herbaceous crops (miscanthus, switchgrass, etc.)
Energy crops (perennial)	wood crops (willow, poplar, etc.)
Forestry products	wood as platform (i.e. managed forestry for bioenergy)
Forestry and process residues	e.g. branches, tops, leaves, sawdust, bark
Agricultural and process residues	e.g. straw, stalks, husks, shells
Wood waste	e.g. post-consumer waste
Black liquor	
Industrial solid waste	e.g. rejects from the paper and pulp industry
Manure	
Sewage sludge / gas	waste water treatment sludge / waste water treatment recovered gas
Landfill gas	recovered landfill gas
Municipal solid waste	household waste
Classified as feedstocks for ANNEX IX Part B biofuels in RED II	
Used cooking oil	collectable used cooking oil
Animal fats	categories 1 and 2

Table 6 Production pathways in the PRIMES Biomass supply model

Feedstock	Pathway	Product
- Sugar crops - Starch crops	- (Saccharification), fermentation	Bioethanol
- Cellulosic feedstock[xiv]	- Enzymatic hydrolysis, fermentation	
- Cellulosic feedstock	- Enzymatic hydrolysis, fermentation, catalytic upgrading - Enzymatic hydrolysis, fermentation, deoxygenation - Hydrothermal upgrading, deoxygenation, upgrading - Pyrolysis, deoxygenation, upgrading - Pyrolysis, gasification, FT synthesis, upgrading	Biogasoline
- Cellulosic feedstock - Black liquor	- Gasification, FT synthesis, upgrading	
- Oil crops - Used cooking oil	- Transesterification	Biodiesel
- Oil crops - Used cooking oil	- Hydrotreatment, deoxygenation	HVO
- Cellulosic feedstock	- Hydrothermal upgrading, deoxygenation - Pyrolysis, hydrodeoxygenation - Pyrolysis, gasification, FT synthesis	Advanced biodiesel
- Cellulosic feedstock - Black liquor	- Gasification, FT synthesis	
- Cellulosic feedstock	- Gasification, biomethanol/bioDME synthesis	Biomethanol/BioDME
- Used cooking oil	- Hydrotreatment and deoxygenation	Biokerosene[xv]
- Cellulosic feedstock	- Alcohol-to-Jet - Gasification, FT synthesis - Hydrothermal upgrading, deoxygenation - Pyrolysis, deoxygenation - Pyrolysis, gasification, FT synthesis	
- Used cooking oil	- Transesterification, heavy oil production	Bioheavy fuel oil
- Cellulosic feedstock	- Pyrolysis - Hydrothermal upgrading	
- Manure - Sewage sludge - Agricultural residues - Animal waste - Starch crops (energy maize fraction)	- Anaerobic digestion / upgrade (2 pathways)	Biogas Biomethane

[xiv] Lignocellulosic crops (annual and perennial, including woody crops); Forestry products; Forestry residues; Agricultural residues; Wood waste.

[xv] Biokerosene can be produced from any type of ethanol source, whether crop-based or produced from cellulosic feedstocks. At this stage, however, in the model, the Alcohol-to-Jet pathway includes production only from cellulosic feedstocks.

Feedstock	Pathway	Product
- Cellulosic feedstock - Black liquor	- Gasification, syngas to biogas/biomethane (2 pathways)	
- Cellulosic feedstock	- Catalytic hydrothermal gasification (dry), syngas to biogas/biomethane (2 pathways)	
- Agricultural residues - Sewage sludge - Manure - Animal waste	- Catalytic hydrothermal gasification (wet), syngas to biogas/biomethane (2 pathways)	
- Landfill gas	- Landfill gas recovery	Waste gas
- Municipal solid waste - Industrial waste	- RDF preparation	Waste solid
- Cellulosic feedstock	- Solid biomass preparation (small and large scale)	Solid biomass (small and large scale)
- Black liquor	- Black liquor preparation	Bioliquid

Table 7 Key trends in transport activity and energy consumption of passenger road transport

Index 2015 = 100	2015	2020	2025	2030
Energy	1.00	0.82	0.93	0.81
Activity	1.00	0.85	1.06	1.13

Table 8 Key trends in transport activity and energy consumption of freight road transport

Index 2015 = 100	2015	2020	2025	2030
Energy	1.00	1.00	1.03	0.97
Activity	1.00	1.06	1.20	1.28

Table 9 Fossil fuel consumption in road transport

Mtoe	2015	2020	2025	2030
Scenario with biofuels and EVs	240	201	216	178
Scenario without biofuels and EVs			216	232

Table 10 Fossil fuel consumption in road transport

Mtoe	2015	2020	2025	2030
Scenario with biofuels and EVs	168	135	149	119
Scenario without biofuels and EVs			149	162

Table 11 Fuels in transport in the EU (including aviation and maritime navigation)

Mtoe	2015	2030			
		BSL CTP	MIX CTP	Counterfactual	No CAP
Electricity	4.1	11.2	12.32	12.29	12.29
Hydrogen	0.0	0.2	1.0	1.0	1.0
E-Gas	0.0	0.0	0.0	0.0	0.0
Biomethane	0.0	0.5	0.8	0.8	0.8
Natural gas	1.7	8.9	9.99	9.98	9.97
Liquid biofuels	12.8	16.3	20.2	22.5	22.7
E-liquids	0.0	0.0	0.6	0.6	0.6
Oil products	320.5	292.5	275.7	275.6	275.5
Total	339.1	329.6	320.6	322.9	322.9

Table 12 Liquid biofuels used in transport in the EU (including aviation and maritime navigation)

Mtoe	2015	2030			
		BSL CTP	MIX CTP	Counterfactual	NoCAP
Total	12.8	16.2	20.2	22.5	22.7
Bioethanol (blend)	2.3	3.1	3.0	3.7	3.9
Bioethanol (E85)	0.1	0.4	0.6	1.4	1.4
Biodiesel	10.3	12.7	12.2	14.0	14.0
Others (bio-kerosene, bioheavy, etc.)	0.1	0.0	4.4	3.4	3.4

Table 13 Alternative fuel consumption in road transport in the EU27

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Biodiesel	10.4	12.4	15.3	14.0	14.0
Bioethanol	2.4	3.3	4.5	5.1	5.3
Biomethane	0.1	0.5	1.1	1.59	1.6
Electricity	0.1	0.4	1.1	6.6	6.6
Hydrogen	0.0	0.0	0.0	0.7	0.7
Total	13.0	16.6	21.9	28.0	28.2

Table 14 Alternative fuel consumption in cars and vans in the EU27

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Biodiesel	6.3	7.0	8.8	7.9	7.9
Bioethanol	2.3	3.2	4.3	4.8	5.0
Biomethane	0.1	0.3	0.6	0.69	0.7
Electricity	0.1	0.4	0.9	5.6	5.6
Hydrogen	0.0	0.0	0.0	0.1	0.1
Total	8.7	10.9	14.6	19.0	19.2

Table 15 Share of alternative fuels in transport (incl. aviation and maritime navigation)

%	2015	2030			
		BSL CTP	MIX CTP	Counterfactual	No CAP
Electricity	1.2%	3.4%	3.8%	3.8%	3.8%
Hydrogen	0.0%	0.0%	0.3%	0.3%	0.3%
E-gas	0.0%	0.0%	0.0%	0.0%	0.0%
Biomethane	0.0%	0.1%	0.3%	0.3%	0.3%
Natural gas	0.5%	2.7%	3.1%	3.1%	3.1%
Liquid biofuels	3.8%	4.9%	6.3%	7.0%	7.0%
E-liquids	0.0%	0.0%	0.2%	0.2%	0.2%

Table 16 Bioethanol consumption in road transport by segment

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Bioethanol	**2.39**	**3.34**	**4.50**	**5.07**	**5.28**
Cars and vans	2.3	3.2	4.3	4.8	5.0
HDVs and LCVs	0.01	0.02	0.02	0.0	0.0
Other	0.1	0.2	0.2	0.2	0.3

Table 17 Biodiesel consumption in road transport by segment

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Biodiesel/advanced biodiesel	**10.4**	**12.4**	**15.3**	**14.0**	**14.0**
Cars and vans	6.3	7.0	8.8	7.9	7.9
HDVs and LCVs	3.6	4.9	5.7	5.4	5.4
Other	0	0	1	1	1

Table 18 Biomethane consumption in road transport by segment

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Biomethane	**0.09**	**0.50**	**1.07**	**1.59**	**1.58**
Cars and vans	0.07	0.33	0.62	0.69	0.69
HDVs and LCVs	0.00	0.13	0.41	0.85	0.85
Other	0.02	0.03	0.04	0.04	0.04

Table 19 Total biofuel consumption in road transport per type of biofuel

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Total	**12.9**	**16.2**	**20.8**	**20.7**	**20.9**
Crop-based	11.0	13.6	16.7	11.6	12.9
ANNEX IX Part A	0.8	0.8	1.8	8.1	6.8
ANNEX IX Part B	1.1	1.7	2.3	1.0	1.3

Table 20 Total biofuel consumption in cars and vans per type of biofuel

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Total	**8.6**	**10.5**	**13.7**	**13.4**	**13.6**
Crop-based		8.8	11.1	7.7	8.6
ANNEX IX Part A		0.6	1.3	5.1	4.3
ANNEX IX Part B		1.1	1.2	0.5	0.7

Table 21 Biofuel consumption in road transport split by biofuel type in the No Cap scenario in 2030

	Crop-based	ANNEX IX Part A	ANNEX IX Part B
Bioethanol	3.5	1.8	0.0
Biodiesel	9.4	3.5	1.1
Biomethane	0.0	1.4	0.1

Table 22 Biodiesel consumption in road transport per type of biofuel

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Total	**10.3**	**12.4**	**15.3**	**14.0**	**14.0**
Crop-based		10.6	12.8	8.6	9.4
ANNEX IX Part A		0.1	0.2	4.5	3.5
ANNEX IX Part B		1.7	2.2	0.9	1.1

Table 23 Biodiesel consumption in cars and vans type of biofuel

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Total	**6.3**	**7.0**	**8.8**	**7.9**	**7.9**
Crop-based		5.9	7.5	4.9	5.4
ANNEX IX Part A		0.1	0.1	2.4	1.9
ANNEX IX Part B		1.0	1.2	0.5	0.6

Table 24 Bioethanol consumption in road transport per type of biofuel

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Total	**2.3**	**3.3**	**4.5**	**5.1**	**5.3**
Crop-based		3.1	3.8	2.95	3.47
ANNEX IX Part A		0.3	0.7	2.12	1.81
ANNEX IX Part B					

Table 25 Bioethanol consumption by cars and vans per type of biofuel

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Total	**2.3**	**3.2**	**4.3**	**4.8**	**5.0**
Crop-based		2.9	3.6	2.73	3.21
ANNEX IX Part A		0.3	0.7	2.08	1.78
ANNEX IX Part B		0.0	0.0	0.00	0.00

Table 26 Biomethane consumption in road transport per type of biofuel

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Total	**0.2**	**0.5**	**1.1**	**1.6**	**1.6**
Crop-based		0.0	0.1	0.0	0.0
ANNEX IX Part A		0.5	0.9	1.4	1.4
ANNEX IX Part B		0.03	0.1	0.1	0.1

Table 27 Biomethane consumption in cars and vans per type of biofuel

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Total	**0.07**	**0.33**	**0.62**	**0.69**	**0.69**
Crop-based		0.00	0.05	0.01	0.01
ANNEX IX Part A		0.30	0.5	0.6	0.6
ANNEX IX Part B		0.02	0.03	0.1	0.1

Table 28 Domestic crop-based bioethanol production for road transport per crop type

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Starch-based	1.4	2.5	3.3	2.5	3.0
Sugar-based	0.5	0.6	0.5	0.4	0.5

Table 29 Feedstock use for crop-based bioethanol production for road transport per crop type

Mtoe	2015	2020	2025	2030	
				Counterfactual	No Cap
Starch crops	2.8	4.8	6.0	4.7	5.5
Sugar crops	0.8	0.9	0.8	0.6	0.7

Table 30 Structure of the car segment in the EU in the No Cap scenario

%	2015	2025	2030
Diesel	44%	43%	36%
Gasoline	52%	50%	40%
Plug-in Hybrids	0.1%	1%	5%
BEVs	0.1%	2%	14%
LPG & CNG	4%	4%	5%

Table 31 TTW CO2 emissions in road transport

Mt CO2	2015	2020	2025	2030
Public road and 2wheelers	37	25	33	36
Passenger cars and vans	511	410	452	383
Road freight	185	181	181	170

Table 32 TTW CO2 emissions in transport

Mt CO2	2015	2030			
		BSL CTP	MIX CTP	Counterfactual	No CAP
Cars	450.1	345.3	331.6	331.6	331.2
Heavy Duty Vehicles	153.8	151.6	143.9	143.9	144.0
Vans	91.0	79.2	77.2	77.2	77.2
Other road transport	36.9	35.5	35.7	36.1	35.7
Rail	4.3	3.4	3.5	3.5	3.5
Inland navigation	12.1	12.9	12.6	12.6	12.6
Aviation	119.5	149.0	140.5	140.6	140.6

Table 33 Cost of CO2 abatement for alternative fuels in the cars segment in 2030

Eur / t CO2 abated	2030
	No CAP
Bioethanol	-48
Cellulosic ethanol	235
Biomethane	69
Biodiesel	36
Advanced biodiesel	320
Electric driving	127

Table 34 Structure of mobility cost by car

Eur/pkm	2015	2020	2025	2030
Capital	0.21	0.21	0.21	0.23
Fixed	0.12	0.12	0.12	0.12
Variable non-fuel	0.08	0.08	0.08	0.08
Fuel	0.10	0.09	0.10	0.10

Table 35 Variation in cost elements of mobility by car between 2015 and 2030

%	2015
Capital	5.5%
Fuel	-3.1%

Table 36 Cost of Internal Combustion Engine and Battery Electric Vehicles (300 km range) in 2020 and 2030

Euro	2020	2030
ICE	20194	20494
BEV	31270	22543

Table 37 Evolution of fuel use in road transport in the No Cap scenario - Cars and LCVs (including freight)

Mtoe	2015	2020	2025	2030
Gasoline	60.8	50.6	53.2	40.6
Diesel	111.7	89.3	98.4	80.3
Bioethanol	2.3	3.2	4.3	5.0
Biodiesel	6.9	7.8	9.8	8.8
Natural gas	1.5	1.0	2.2	3.2
Biomethane	0.1	0.3	0.6	0.7
LPG	5.9	5.1	6.7	6.8
Other alternative fuels	0.0	0.0	0.0	0.1
Electricity	0.1	0.4	1.1	6.2

Table 38 Evolution of fuel use in road transport in the No Cap scenario - HDVs (trucks)

Mtoe	2015	2020	2025	2030
Gasoline	0.0	0.0	0.0	0.0
Diesel	49.6	48.3	46.6	39.5
Bioethanol	0.0	0.0	0.0	0.0
Biodiesel	3.0	4.1	4.8	4.5
Natural gas	0.0	0.4	2.4	6.3
Biomethane	0.0	0.1	0.4	0.8
LPG	0.0	0.0	0.1	0.2
Other alternative fuels	0.0	0.0	0.0	0.6
Electricity	0.0	0.0	0.0	0.1

Table 39 Evolution of fuel use in road transport in the No Cap scenario - Other (e.g. buses, coaches, two-wheelers)

Mtoe	2015	2020	2025	2030
Gasoline	3.6	2.8	3.3	3.2
Diesel	8.5	5.2	7.4	7.2
Bioethanol	0.1	0.2	0.2	0.3
Biodiesel	0.5	0.4	0.7	0.8
Natural gas	0.1	0.1	0.2	0.3
Biomethane	0.0	0.0	0.0	0.0
LPG	0.0	0.0	0.0	0.0
Other alternative fuels	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.3

Table 40 Evolution of fuel use in road transport in the No Cap scenario - Total

Mtoe	2015	2020	2025	2030
Gasoline	64.3	53.4	56.5	43.8
Diesel	169.8	142.8	152.4	127.1
Bioethanol	2.39	3.3	4.5	5.3
Biodiesel	10.4	12.4	15.3	14.0
Natural gas	1.6	1.5	4.9	9.8
Biomethane	0.1	0.5	1.1	1.58
LPG	5.9	5.1	6.8	7.0
Other alternative fuels	0.0	0.0	0.0	0.7
Electricity	0.1	0.4	1.1	6.6

Table 41 Bioethanol production for road transport in the No Cap scenario

Mtoe	2015	2020	2025	2030
Bioethanol	**2.4**	**3.3**	**4.5**	**5.3**
Starch-based	1.4	2.5	3.3	3.0
Sugar-based	0.5	0.6	0.5	0.5
Lignocellulosic-based			0.2	1.8
Imports	0.5	0.3	0.5	0.0

Table 42 Bioethanol production cost

Eur/toe	2015	2020	2025	2030
Bioethanol				
Starch-based	1105	673	604	566
Sugar-based	1165	963	947	916
Lignocellulosic-based	2049	1856	1808	1544
Imports	1423	1439	1456	1473

Table 43 Biodiesel/advanced biodiesel production for road transport in the No Cap scenario

Mtoe	2015	2020	2025	2030
Biodiesel/advanced biodiesel	**10.4**	**12.37**	**15.26**	**14.04**
Vegetable oil FAME	8.50	10.48	11.26	8.17
UCOME	1.53	0.56		
Vegetable oil HVO	0.22	0.08	1.55	1.22
UCO based HVO	0.13	1.15	2.22	1.13
Other "advanced" biodiesel		0.09	0.13	3.52
Imports			0.10	

Table 44 Biodiesel/advanced biodiesel production costs

Eur/toe	2015	2020	2025	2030
Biodiesel/advanced biodiesel				
Vegetable oil FAME	1273	693	685	693
UCOME	902	1229		
Vegetable oil HVO	1262	1436	1093	1097
UCO based HVO	1315	1462	1130	1151
Other "advanced" biodiesel			2497	1858
Imports	957	1198	1207	1216

Table 45 Biomethane production cost

Eur/toe	2015	2020	2025	2030
Anaerobic digestion	695	678	697	668
Advanced gasification	901	878	885	872

Table 46 Split of ANNEX IX biofuel types used in road transport

Mtoe	2020	2025	2030
Bioethanol			
Part A	0.29	0.69	1.81
Part B			
Biodiesel/advanced biodiesel			
Part A	0.09	0.23	3.52
Part B	1.71	2.22	1.13
Biomethane			
Part A	0.46	0.93	1.42
Part B	0.03	0.06	0.14

Table 47 Investments on bioethanol production capacity in 2021-2030

	Mtoe/yr	Meuro
Crop-based	0.4	270
Advanced	2.1	5472