
Final Report

Academic Monitoring of the Tour d'Europe

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Management Summary

The road transport sector has to reduce its CO_{2e} emissions. The EU and its member states have set climate neutrality goals in accordance with the Paris Climate Agreement. Several solutions are proposed in addition to the electrification of on-road vehicles. One of these is the use of renewable fuels. Today, several types of renewable fuels with a GHG reduction potential compared to fossil fuels are available with varying degrees of GHG reduction potential - up to a high mark of over 90 %. For waste-based feedstocks, mitigation effects can increase the reduction potential further. These fuels can achieve a considerable GHG reduction in existing vehicle fleets powered by internal combustion engines and could also contribute to new vehicles being sold in the future.

Tour d'Europe is a technology demonstration which aims to show:

- the availability and feasibility of renewable fuels for vehicle fleets across Europe
- the potential of digital monitoring for verified CO₂ well-to-wheel emissions
- the potential for legislative action regarding CO₂ emission performance standards.

European climate legislation related to road transport and its corresponding fuel distribution knows two different approaches. Renewable fuels are documented in national databases with emission factors which represent the climate impact of fuels in a well-to-tank approach. A fuel from a renewable base uses carbon or carbon dioxide from the atmosphere, residues or waste, also known as biogenic or captured CO₂, and has therefore the potential for much lower emission factors compared to the fossil reference of 94 gCO_{2e}/MJ. The Renewable Energy Directive is in place for the calculation of the emission factors.

In contrast, CO₂ emission standards for vehicles follow a tailpipe measurement approach. Since the combustion of carbon-based renewable fuels lead to comparable CO₂ emissions in the test procedure, no advantage based on the use of these fuels is attributed. The use of digital monitoring aims to close this gap to provide certifiable information from the fuel distribution until final energy conversion in the vehicle. Today, tracking and certification is well established for the production and distribution of renewable fuels. However, actions are required to include the final use of these fuels in vehicles to achieve maximum effective greenhouse gas reduction in the vehicle fleet.

What happened during Tour d'Europe

A total of 16 different vehicles of various types, fuel types and from different manufacturers powered by a combustion engine took part in the Tour d'Europe. The vehicle fleet consists of eleven passenger cars and five heavy duty vehicles. A total of eight of the participating vehicles were diesel-powered, while seven were gasoline-powered including one vehicle with E85-flexfuel technology. Finally, one heavy-duty vehicle was powered by BioLNG. The vehicles made a total of 322 refueling stops in 18 different European countries on five different routes across Europe. A wide variety of renewable fuels were used. The vehicles have covered a total of well over 82800 km across Europe. The data also represents the real-life experience of users travelling across Europe. Already today, only 14 % of standard fuel blends had to be used as the result of regional unavailability.

What amount of renewable fuel was used?

The total amount of gasoline-type fuel used during the tour was 1867 l, which corresponds to 17 % of the total fuel during the tour. As part of the gasoline fuel, 797 l of standard gasoline blends were refueled. Furthermore, 206 l of E85, 486 l of fully renewable gasoline and 377 l further blends with proven GHG reduction. A significant amount (around 1069 l – 57 %) of the used gasoline fuel had a certified renewable component.

The second category of fuels is BioLNG. In total, a volume of 2207 l of BioLNG were refueled. This represents a share of 20 % of the total fuel during Tour d'Europe.

Diesel-type fuels were the most common type of fuel used during the tour (approx. 63 % in total). A total of 6886 l of diesel fuel was used: 150 l of B100 and 6080 l of HVO100. This resulted in 90 % of the fuel used being renewable. The amount of standard diesel blends was 656 l.

The GHG reduction achieved by renewable fuels is based on the analysis of the well-to-wheel CO_{2e} footprint of the respective fuel. This takes into account the acquisition of raw materials, processing into fuel, distribution and use in the vehicle. As of today, most of the available renewable fuels are bio-based fuels, gaseous as BioLNG and liquid such as HVO100, B100, Bio-Ethanol and their blends with fossil fuels or other renewable fuels. For these fuels, biological materials such as vegetable oils, residues and waste materials or energy crops are used as feedstocks. This means that the GHG reductions achieved by using renewable fuels are based on the actual fuel that is filled into the vehicle's fuel tank and are therefore real, verifiable and certified according to European regulations. All these fuels are reported and are provided with a proof of sustainability.

How was the GHG reduction of the renewable fuels tracked and verified?

A specially developed monitoring system is used for tracking the fuel and vehicles during the Tour d'Europe. This uses data from the respective vehicle such as tank level, GPS position, time, mileage and other information as well as information from the filling station about the fuel (based on the proof of sustainability). The refueling events can thus be monitored and verified via data synchronization in the cloud and the CO_{2e} emission factor of the tank filling can be determined. Of the total amount of fuel used during the Tour d'Europe, 86 % can be categorized as renewable fuels (or their blends). Of the total fuel amount, 61 % have been fully digitally monitored. For this share of fuel, the emission factors used can be tracked and the refueling events were digitally monitored. The remaining 25 % of the used renewable fuel volume were partially digitally monitored and complemented by a manual monitoring process. The latter was due to, either the emission factor of the fuel not provided on time, or the digital tracking itself being incomplete. However, as the type of fuel and quantity fueled were documented manually by using the receipts from the fuel station the full monitoring could be completed. Finally, only 14 % of the total fuels used in the tour are standard fuel blends, which have also been digitally monitored. This means that despite the challenging availability of necessary information for this monitoring procedure across Europe, all renewable fuels, which corresponds to 86 % of the total amount of fuel used during the Tour d'Europe, could be verified and certified.

Was Tour d'Europe able to reduce its vehicle CO_{2e} impact?

A wide variety of fuels with different GHG reduction potentials were used. The fuel-specific GHG reductions compared to the fossil reference achieved, on a well-to-wheel basis, ranged from 66.5 % to 83.5 % for the liquid fuels. The manure-based BioLNG achieved a reduction of 155.5 % because of avoided methane emissions.

However, all the renewable fuel options used have further reduction potential. This potential results from the use of other feedstocks (e.g. waste materials), and of improved production processes.

The overall result of the Tour d'Europe is expressed as absolute emissions of CO_{2e}. For the overall fuel mix of the Tour d'Europe, including standard fuel blends used during the tour, the total GHG reduction reaches 77 %, showing a significant reduction in well-to-wheel CO_{2e} emissions with the given status of fuel availability. The renewable fuels (and their blends) by themselves achieved an 87 % GHG reduction.

In this context, each improvement of fuel properties would be immediately visible as further GHG reduction. This could be achieved by higher blend rates with or a switch to other types of renewable fuels with higher GHG reduction. This has been demonstrated with the renewable fuels used during the Tour d'Europe.

What has Tour d'Europe shown?

CO₂ Savings Potential



Simple and genuinely feasible as of today. Actual, **verifiable and certifiable CO₂ reduction** by renewable fuels.

Monitoring Available & Necessary



Monitoring based on information about the refueling process is necessary and already in development.
→ **Huge benefit for authorities and users**

Adaptation of Legislation Required



Instead of only measuring tailpipe emissions, the **well-to-wheel CO₂ footprint has to be considered** for renewable fuels.

The GHG reduction potential of future renewable fuels will further grow and reliable monitoring processes will be available.

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List of Abbreviations

(r)WGS	(reverse) water gas shift reaction
B7, B10, B100	fuel blends with 7, 10 and 100 % FAME in Diesel
BEV	battery electric vehicle
Bio-FT	biomass Fischer-Tropsch synthesis
BioLNG	liquefied natural gas produced from biological raw materials
CAN	controller area network
CNF	carbon neutral fuel
CO _{2(e)}	carbon dioxide (equivalent)
CSRD	corporate sustainability reporting directive
DCO ₂	decarboxylation
DFT	Digital Fuel Twin
E5, E10, E85	fuel blends with 5, 10 and 85 % Ethanol (from biomass) in gasoline
ECU	engine control unit
ESRS	european sustainability reporting standards
EU	European Union
FAME	fatty acid methyl ester
FT	Fischer-Tropsch
GHG	greenhouse gas
GPS	global positioning system
HDCO	hydrodecarbonylation
HDO	hydrodeoxygenation
HVO	hydrotreated vegetable oil
HVO100	fuel with 100 % of HVO
ICE	internal combustion engine
ISCC	international sustainability and carbon certification
LNG	liquefied natural gas
MeOH	methanol
MOGD	mobil olefins to gasoline and distillate
MtG	methanol to gasoline
MtJ	methanol to jet

MtO	methanol to olefins
OBD	on-board diagnostics
OEM	original equipment manufacturer
POS	proof of sustainability
RED	Renewable Energy Directive
RFNBO	renewable fuel of non-biological origin
TdE	Tour d'Europe
UDB	union data base
vCNF	vehicle with Carbon Neutral Fuels (carbon neutral fuel only vehicles)
WGMM	Working Group on Monitoring Methodologies of CO ₂ Neutral Fuels
WtW	well-to-wheel

1 Origin & Purpose of the Tour

The Tour d'Europe project is aimed at demonstrating the potential of the use of renewable fuels in the transport sector. It shows the current availability of renewable fuels in Europe and gives an outlook into how the greenhouse gas (GHG) reduction potential of renewable fuels can be utilized with monitoring and certification of fuel use.

1.1 Origin & Legal Framework

The EU has defined its road map towards the Paris Agreement goals in several EU programs and directives. With fit for 55 the goal is set for a climate neutral economy and – as a subgoal – transportation.

The EU has identified alternative fuels as one important component in her drive towards its sustainability and climate action goals. The aviation and shipping sector received clear goals in their respective legislation – ReFuelEU Aviation [1] and FuelEU Maritime [2]. However, the overwhelming majority of CO_{2e}-emissions in the EU transport sector are attributed towards road transport – 73.2 % in 2022 [3]. The EU has set goals in the Renewable Energy Directive (RED) [4–6] towards the use of advanced biofuels and renewable fuels of non-biological origin (RFNBO) and revised the EU fleet regulations, the CO₂ emission performance standards for new passenger cars and vans (-100% emission reduction in 2035) and for heavy-duty vehicles (-90% in 2040) . The requirements for the production of RFNBOs are further defined in delegated acts [7, 8].

Today the majority of used alternative and renewable fuels in the EU are of biological origin. Fuels like FAME and Ethanol are available and are widely used in fuel blends such as B7, B10, E5 and E10. Distributors are obligated to bring a certain amount of renewable fuels into market according to national set goals. National databases to generate proof of sustainability (POS) are implemented to track and trade the distributed amounts of bio-fuels. In Germany, for example, this is tracked by the Nabisy database [9]. In the future an EU Database, called the Union Database (UDB) for RFNBOs and bio-fuels is planned. Part of the information of a proof of sustainability is the type of the biomass and a declaration of CO_{2e} emissions in [MJ/kg]. A given fuel batch therefore has a clear origin and attributed CO_{2e} emissions. The process of feedstock sourcing, production up-to distribution is captured in certified processes.

Furthermore, the Corporate Sustainability Reporting Directive (CSRD) requires companies to prepare CSRD reports according to the European Sustainability Reporting Standards (ESRS). One part of these standards relates to Climate Change (ESRS E1). According to the ESRS, companies must track among others the climate impact of fuels used directly in their vehicle fleets or indirectly in their Scope 3 emissions as down and/or upstream transportation. According to the GHG-protocol these emissions can be calculated directly from emission factors if the amounts and types of fuels are known and tracked. If the fuels are not tracked standard values (e.g. nationwide averages) can be used. However, the full reduction potential of a renewable fuel (like HVO100 with over 90 % of possible reduction in CO_{2e}-emissions) can only be realized for CSRD reporting if the used fuel amounts and types are known. Companies therefore have a need to link used fuel amounts to POS in order to calculate CO_{2e}-Emissions. With this information CO_{2e}-reduced logistics can be realized using ICE technologies and greenhouse gas reduction in company fleets and their balancing can be taken into account.

The current regulatory framework imposes vehicle manufacturers to comply with strict goals regarding the CO₂ emissions of their vehicle fleet. Today the CO₂ emissions are determined according to standardized tests which measure the tailpipe emissions of the vehicle. In this tank-to-wheel approach carbon-based fuels are treated equally independent of the origin of the fuel.

The fleet regulation also requests in its Recital 11 the European Commission to develop a proposal to enable the use of carbon neutral fuels in ICE vehicles after 2035. This Recital is another driver for the introduction of renewable fuels, but in order to ensure compliance, such future vehicles will need a mechanism to ensure only specified renewable fuels are used. In which way such a system will be implemented is part of the discussion and not yet defined.

To summarize, there are four main drivers for the development of the technology:

- The directives and regulations of the EU's Fit for 55 package
- The defined EU targets for the use of RFNBO and advanced and conventional biofuels as well as the general need to decarbonise the transport sector.
- Business requirements to lower their transport emissions in their value chain and track these emissions for CSRD reporting purposes.
- Recital 11 which might offer vehicle manufacturers an alternative technical solution in the future to comply with fleet emission requirements with vehicles exclusively using specified renewable fuels.

1.2 Purpose

The project goals have been set in advance as follows:

“During the Tour d’Europe, ICE light-duty and heavy-duty vehicles will travel throughout Europe between end-February and early May 2025, with a number of stops in selected cities. Local events hosted by policymakers (European, national or local) will be organized in strategic places to promote the role of renewable fuels and engage with relevant media.

These events will gather local and EU stakeholders, and media, to demonstrate to citizens in the constituency of the hosting policymaker, but also to the broader population in the Member State, that there are alternative technologies that can already contribute to the reduction of the CO_{2e} intensity of transport. This is of particular importance in regions where the automotive industry is at the heart of the economy, playing a key role for employment.

The Tour d’Europe will allow sharing information about renewable fuels, including feedstock options, production processes, carbon content and cycle, ease of use and their GHG emission reduction potential.

The Tour d’Europe will furthermore demonstrate the potential provided by a tool (e.g. by DFT – digital fuel twin) that can monitor, verify, measure and certify the use of renewable fuels.

- Support for this project will help safeguard the freedom of mobility for passenger cars and the potential of renewable fuels for light-duty and heavy-duty vehicles, secure competitiveness of EU industries, win the support of the population and increase visibility at local level.“ [10]

Parties implemented all measures necessary to comply with competition law rules, and all activities of the parties were conducted in strict compliance with competition law rules.

1.3 Structure & Members

The Tour d' Europe is supported by a wide range of industrial partners. Several Original Equipment Manufacturers (OEM) provide vehicles for the technology demonstration, so that a comprehensive variety of vehicles – passenger cars as well as heavy duty trucks – and fuel types can be used. The Digital-Fuel-Twin technology which is used to track the fuel and vehicle data during the tour, was developed by Robert Bosch GmbH. Furthermore, several fuel providers as well as associations in the field of renewable fuel production, trade and distribution are part of the group. A full list of participants is provided on the organizer's website¹.

The Institutes IFKM of Karlsruhe Institute of Technology and VKM of Technical University of Darmstadt were tasked to provide an analysis of the collected tour data, to provide evaluation of the used technologies and to prepare this report.

¹ <https://tourdeurope.eu/>

2 Fuels used during Tour d'Europe

The fuels used during Tour d'Europe cover a wide range of fuels available in Europe. The following section discusses some aspects of the production, raw materials and resulting life cycle emissions of the fuel types. This chapter provides a brief overview of the fuels used during Tour d'Europe. The objective is not a comparative/evaluative discussion, but rather to address the renewable fuels pathway in general.

The emission factors for the calculations within this report are used as given by the corresponding proof of sustainability (PoS). These values are defined by the calculation schemes of the *Directive (EU) 2018/2001 of the European Parliament and of the Council* [4] for the calculation of the emission factors. The directive gives typical values for different feedstock and synthesis paths in its annexes. During the Tour d'Europe only specific values from PoS were used.

2.1 HVO

Production: The biomass-based fuel HVO (Hydrotreated Vegetable Oil) is produced from vegetable oils, waste and residues. The triglycerides contained in these feedstocks are treated during the production of HVO. This process is called hydrotreating. The heteroatoms (O, N and S) are removed from the hydrocarbons contained in the feedstock materials. For this process, hydrogen is applied as a reducing agent and suitable catalysts are used. Hydrotreating is a complex process during which multiple chemical reactions take place. Examples of these reactions are saturation, cracking, decarboxylation (DCO₂), hydrodecarbonylation (HDCO), hydrodeoxygenation (HDO), isomerization and various side reactions. [11]

In chemical terms, Hydrotreated Vegetable Oils are mixtures of paraffinic hydrocarbons and contain neither sulfur nor aromatics [12]. The standard EN 15940 defines the quality requirements for paraffinic diesel fuel. The production process of HVO is illustrated in Figure 1. It is important to note that the production process does not generate a singular end product, but a variety of products and by-products. In addition to the end products shown in the figure, other by-products are also produced, such as naphtha. However, these products are further used and are part of the synthesis plant [13].

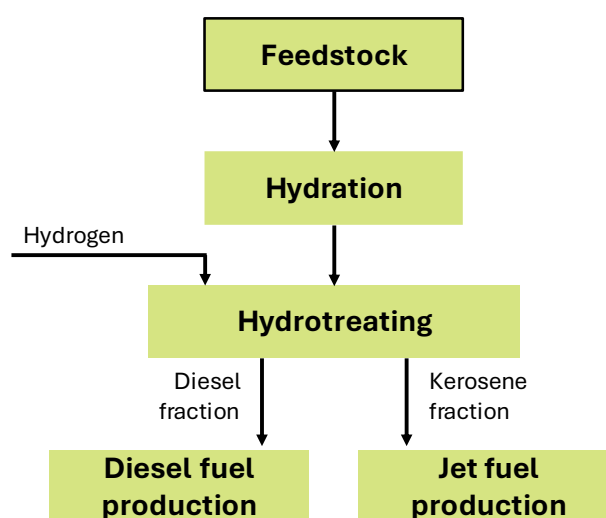


Figure 1: Production of HVO Diesel fuel and HVO Jet fuel, modified figure from [12]

Use: HVO is a drop-in alternative to conventional diesel fuel. Manufacturer approvals exist for many vehicle models and diesel engines used in the existing fleet.

GHG reduction: According to the European Union's *Directive (EU) 2018/2001 of the European Parliament and of the Council* several feedstocks for the production of biofuels can be used which lead to different typical GHG reduction potentials [4]. Furthermore, products with even higher, verifiable greenhouse gas reductions compared to the results of the Tour d'Europe are already available.

2.2 FAME

Fatty Acid Methyl Ester (FAME) can be used as a biodiesel fuel for diesel engines. FAME is produced from vegetable oils, waste and residues. It can be used in pure form (B100) or blended in fossil diesel, which is already common in European B7 diesel fuel (up to 7 Vol.-% of biodiesel). It is fully biodegradable and non-toxic. The standard EN 141214 defines the quality requirements for FAME. [14]

Production: FAME is produced by transesterification of fatty acids and methanol. The oils used as raw materials consist of triglycerides, which are converted into FAME and glycerol during transesterification by replacing the glycerol contained in the triglycerides with an alcohol, usually methanol. This process takes place in the presence of a catalyst, such as sodium hydroxide. Straight-chain methyl esters are formed from the triglycerides and the methanol, which are purified in further process steps so that they meet the requirements of the fuel specifications. The methanol used for production can also be produced from renewable raw materials. The resulting glycerol is considered a by-product of the biodiesel production and is used in other areas. [14]

The basic chemical reaction of the production of FAME is illustrated in Figure 2.

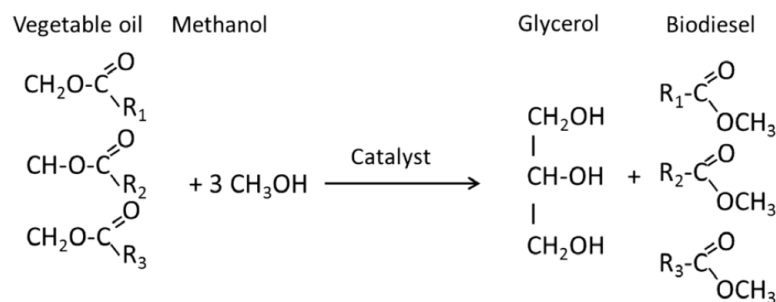


Figure 2: Chemical reactions of the production of FAME from vegetable oil [14]

There are alternative production methods in which FAME is produced using microorganisms or enzymes. However, these processes are only of minor importance [15].

Use: Certain engine components must be adapted for the use of pure FAME (B100). However, approval exists in the vehicle fleet for different biodiesel proportions in conventional diesel.

GHG reduction: The use of biodiesel in vehicles powered by diesel engines significantly reduces CO_{2e} emissions compared to fossil fuels. An overview of the possible CO_{2e} savings is provided by the European Union's *DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*. According to this directive, several feedstocks for the production of biofuels can be used which lead to different

typical GHG reduction potentials [4]. Furthermore, products with even higher, verifiable greenhouse gas reductions compared to the results of the Tour d'Europe are already available.

2.3 Renewable Gasoline

Renewable gasoline can be produced from biomass or as an RFNBO from hydrogen and CO₂ as feedstocks. The EU delegated acts corresponding to RED restrict the source of CO₂ as well as electrical power for the electrolysis [5, 7, 8].

Production: An often-discussed synthesis path uses the Methanol-to-Gasoline process where gasoline is synthesized from renewable methanol. The methanol itself can be synthesized locally or imported. The carbon source can be either based on air captured CO₂ or biogenic CO₂. Alternatively, there exists a synthesis path from methanol using olefines (methanol-to-olefine) followed by the gasoline synthesis (olefine-to-gasoline). A general overview is shown in Figure 3.

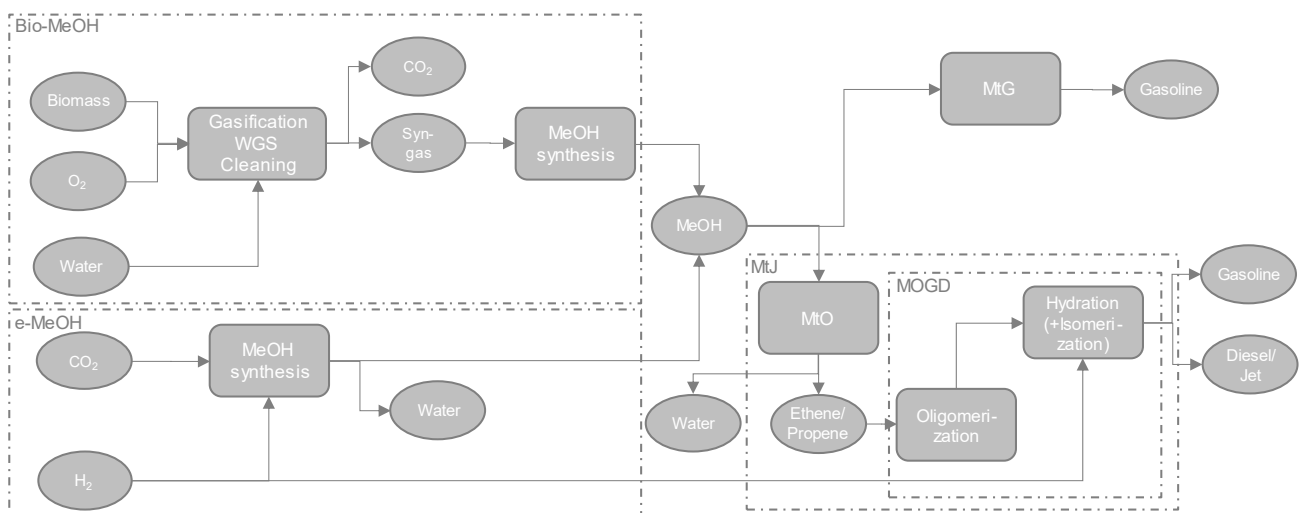


Figure 3: Renewable fuels using methanol synthesis (after [16, 17])

Another, already well-established technology is the Fischer-Tropsch synthesis. To produce renewable gasoline the synthesis gas can be produced from Biomass (Bio-FT) or via CO₂ capture and hydrogen electrolysis. Life cycle assessment of FT-processes reach figures as low as 13 gCO_{2e}/MJ for FT fuels [18]. Figure 4 shows a general overview.

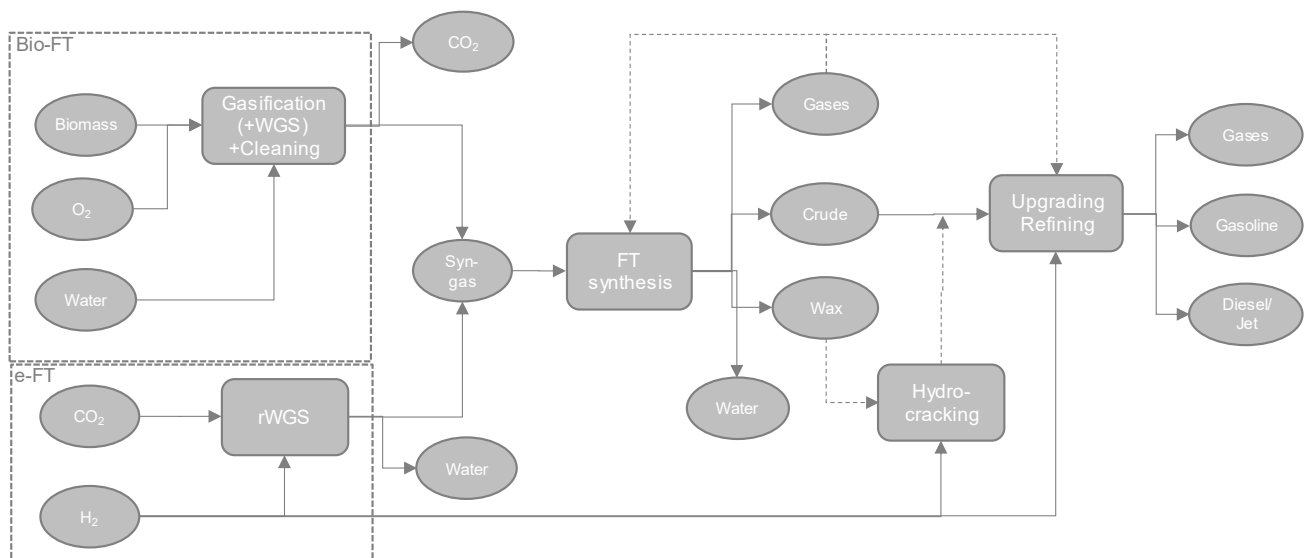


Figure 4: Renewable fuel using Fischer-Tropsch synthesis (after [16, 19, 20])

The synthesis processes are not specific to only produce gasoline fuels. Other fractions like diesel/jet and gases are also produced as valuable by-products in high efficiency processes. The ratios of the products are determined by the process control. A shift between jet fuel and gasoline fractions is often possible in a limited range.

Use: Renewable gasoline is a direct replacement for conventional gasoline and as blend component in gasoline blends.

GHG reduction: The strict requirements for RFNBO regarding the use of electricity from renewable sources for electrolysis and the permitted carbon sources are the basis for the GHG reduction potential of renewable gasoline. A GHG reduction of at least 70 % has to be reached in order to satisfy these requirements. [7, 8]

2.4 E85

Ethanol is widely used as biofuel component for gasoline blends (E5, E10). Ethanol produced from renewable sources offers an immediate GHG reduction. E85 as currently standardised (EN 15293) and placed on the market in Europe still contains a share of conventional gasoline. For a fully renewable fuel this component has to utilize renewable sources, such as e-Naphtha or bio-Naphtha, as well.

Production: Biogenic resources are used for the production of E85.

Use: Manufacturer approval for the use of E85 in vehicles is required. Conversion kits for gasoline engines and flex fuel vehicles are available.

GHG reduction: According to the directive, several feedstocks for the production of biofuels can be used which lead to different typical GHG reduction potentials [4]. Furthermore, products with even higher, verifiable greenhouse gas reductions compared to the results of the Tour d'Europe are already available.

2.5 BioLNG

Production: BioLNG is liquefied natural gas that is produced from biological raw materials. While for conventional LNG fossil gas is processed and liquefied, BioLNG is produced from non-fossil raw materials. Biogas is the basis for BioLNG. This biogas is produced either by fermentation of biomass (e.g. gas from biomass, sewage gas and landfill gas) or by thermal gasification of biological material such as wood residues or waste wood. The biogas then undergoes a treatment process and is finally liquefied. [21]

Use: BioLNG is a direct replacement for conventional LNG, which is used in specialized engines mainly in commercial vehicles.

GHG reduction: The use of BioLNG leads to a significant reduction in well-to-wheel CO_{2e} emissions compared to conventional LNG and can even result in negative CO_{2e} emissions. This can be explained by comparing the use of biomass to produce BioLNG and its widespread use in agriculture as manure. If the biomass feedstock was not further processed into BioLNG but spread directly onto the agricultural fields, decomposition processes would lead to the formation of gases such as methane in particular, which has an exorbitant greenhouse gas impact and would then escape directly into the atmosphere. This can be avoided by controlled conversion to BioLNG and subsequent combustion in the internal combustion engine, which leads to a credit in the WtW CO_{2e} emissions of BioLNG, which in turn can result in negative emission factors for BioLNG. [4, 22]

2.6 Calculating the CO_{2e} Emission Factors of Fuels According to RED

In the European Union, the Renewable Energy Directive mandates that member states must ensure the traceability and sustainability of renewable fuels. For the reporting and trade, national databases exist in several EU countries, e.g. in Germany and Austria, and proofs of sustainability are generated in order to verify the distribution of fuels. Part of the reported values is an emission factor according to RED which takes into account the total emissions for cultivation, processing, transport, and distribution. This value is used during Tour d'Europe to calculate the emissions of the vehicle fleet.

RED [5] contains detailed specifications for reporting the emission factors of renewable fuels.

The individual emissions taken into account in the calculation are:

- emissions from the extraction or cultivation of raw materials
- annualized emissions from carbon stock changes caused by land-use change
- emissions from processing
- emissions from transport and distribution
- emissions from the fuel in use.

Furthermore, emission savings are considered in the overall emission factor:

- emission savings from soil carbon accumulation via improved agricultural management
- emission savings from CO₂ capture and geological storage
- emission savings from CO₂ capture and replacement.

For renewable fuels on a well-to-wheel basis, the CO_{2e} emissions from fuel combustions are balanced by CO₂ that was captured from the atmosphere by biomass while growing via photosynthesis or by direct air capture. The typical values for different feedstocks and processes are detailed in the RED annexes.

Depending on the type of fuel, different feedstocks are permitted. For biomass-based fuels, these feedstocks and the processing method have the greatest influence on the final emission factor. Especially for the use of manure the emission factor can become negative, as the use of the raw material has a greater reduction effect in terms of CO_{2e} emissions, e.g. through the reduction of methane emissions.

Only the renewable component is reported and provided with an emission factor. For the standard fuel blends (E5, E10, B7 and B10) the ethanol and bio-diesel contents are not mandated separately. Distributors subject to quotas report the used renewable fuel in fuel blends in order to reach their obligations or buy certificates from distributors of renewable fuel. Therefore, these fuels are considered as *standard fuel blends* within this study, in contrast to the renewable fuels being used.

3 Digital Fuel Twin as Digital Fuel Monitoring Technology

The following chapter was kindly provided by Bosch.

The Bosch digital fuel twin digitalizes the entire fuel supply chain from production to end consumer, with the aim of providing an accurate, certified proof of the CO_{2e} footprint of the fuel quantities consumed by the vehicle. This concept qualifies DFT as monitoring methodology for potential Carbon Neutral fuel only vehicles (vCNF).

The individual market participants along the fuel supply chain store their specific data in private data rooms so that the data can only be viewed by themselves. In line with the data usage agreement signed between BOSCH (as the DFT operator) and the individual market participants, the DFT algorithm allows specific access to individual data points, so that DFT as a certified and audited service can represent a logical, secure end-to-end chain link from manufacturer to a single vehicle.

Each DFT participant (i.e. Fuel supplier, logistics company, fuel station) is free to choose between different suppliers in the fuel supply chain. Likewise, DFT supports mixed refueling with renewable or fossil fuels in the final application per single vehicle, independent of vehicle type (e.g. passenger car, commercial vehicle), on- or off-road application and including fleet operation. In addition, DFT is capable of handling different fuel types such as liquid (e.g. diesel, gasoline) or gaseous fuels (e.g. methane, hydrogen). Figure 5 illustrates the DFT fuel supply chain and its stakeholders.

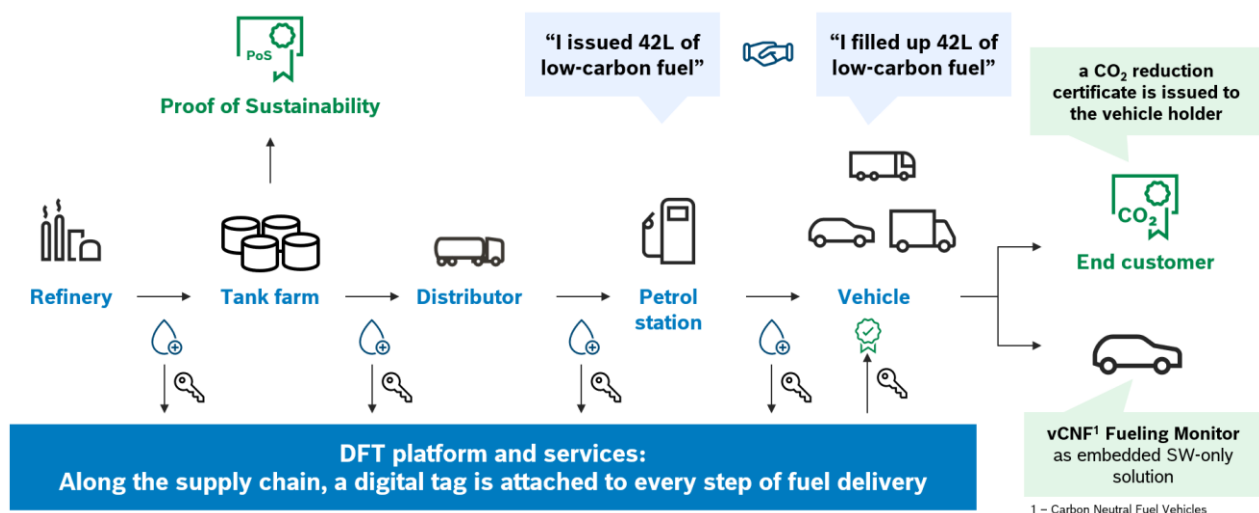


Figure 5: DFT stakeholders and working principle

The setup starts at the tank farm with the proof of sustainability (POS) as main entry information. The POS is originated by an already established certification scheme (e.g. International Sustainability and Carbon Certification (ISCC), RedCERT and similar) and transferred to DFT. DFT will hand it through the fuel supply chain to the end customer. Therefore, each stakeholder needs to be registered on DFT with provided specific data formats and interfaces. It utilizes data, which is already available as per existing fuel supply standards. The data entry points need to be connected to the DFT by one-time digital onboarding via a standardized interface. Optionally, DFT could also onboard stakeholders further upstream of the tank farm, if necessary, depending on POS availability. In addition, DFT includes multiple plausibility monitoring checks, considering blending or mixing of different fuel batches along

the fuel supply chain up to the filling station, as well as in the vehicle. This allows for monitoring of mixing - intended or unintended (manipulation robustness) along the entire fuel supply chain. The default CO_{2e} footprint value of fuel consumed is considered as fossil (worst case assumption). Only if the robust, trustful delivery chain link is created, the CO_{2e} footprint value is updated with respect to the real fuel properties. In addition, if fuel sustainability information is according to CNF criteria, the CNF status of the fuel will be set accordingly. Due to the digital nature of the system, DFT supports real-time data applications as well as reports with delayed data provision.

In the Tour d'Europe for renewable gasoline and renewable diesel the supply chain is fully onboarded/registered on DFT. This allows full tracking of the upstream supply chain. To showcase also a hybrid approach "mass balancing" in the fuel supply combined with digital handshake to the vehicles, the upstream supply chain for fuels E85, B100 and BioLNG is onboarded via mass balancing approach. (WGMM Report , Combined mass balancing with DFT (Option 11), [23]). For these fuels, DFT only recognizes the filling events via the digital handshake and tracks the consumed fuel at the filling station. For the Tour d'Europe, the DFT reported the filled fuel quantities incl. sustainability data per filling station as obligation/mandate to fuel supplier to bring the respective amount (volume) of the fuel into the national or European fuel system. In real world application, the DFT would not only report but also verify the fulfillment of the obligation/mandate by the corresponding fuel supplier.

Considering DFT as a monitoring technology for CNF-only vehicle type, a digital fueling monitor as software variant relying on the existing vehicle hardware is implemented to perform plausibility checks and exchange data with fuel station for every single refilling. It shall be highlighted that the digital handshake operates based only on already standardized vehicle OBD/CAN data without any additional hardware to be placed, neither in the vehicle nor at the fuel station. The software enables the vehicle to perform a digital handshake with filling station to allocate refilling event with filling station. The only prerequisite is a vehicle connection to the internet for communication via OEM cloud with the Bosch DFT cloud.

Specifically for Tour d'Europe, a simplified approach was chosen, in which through the installation of a universal retrofit control unit a direct connection of the vehicle to the DFT cloud was implemented. The retrofit control unit was installed and connected to the OBD/engine CAN enabling access to mandatory vehicle data streams without intruding on the vehicle's proprietary network architecture or requiring OEM-specific gateways and OEM cloud adaptations.

Figure 6 shows the architecture diagram for the vehicle handshake.

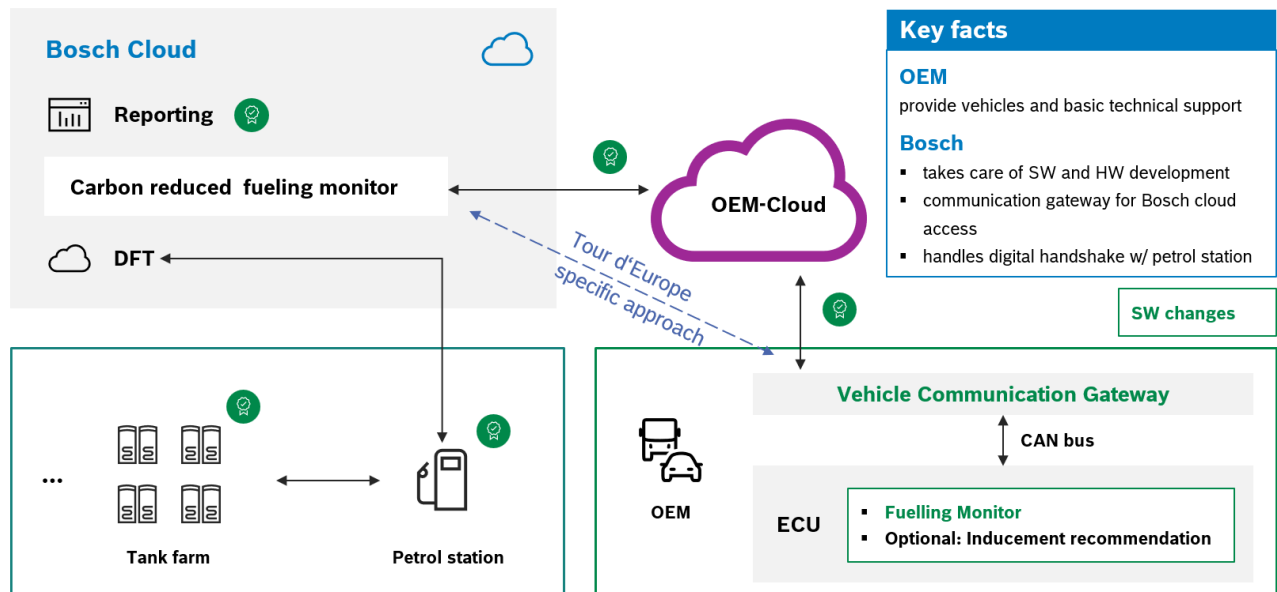


Figure 6: Architecture diagram with digital handshake for TdE

In the digital handshake concept, there is no physical connection between the vehicle and the filling station. All information sharing is done via existing, standardized tools and systems which are connected to the internet. Typically, the OEM vehicle is connected to an OEM cloud, which passes the data through to the Bosch cloud. The Bosch cloud incorporating DFT and respective fuel sustainability info is connected with the filling station via a data link. Vehicle on-board fueling monitor function in the Engine Control Unit (ECU) takes care of filling event recognition, in-use plausibility checks and triggering of the communication to cloud via the vehicle communication gateway. A Carbon reduced fueling monitor, running in the Bosch cloud performs the digital pairing between the recognized filling event of the vehicle and the filling station. The digital handshake incorporates provision of sustainability info of the specific filling event. This data can be made available over product lifetime for in-vehicle usage. OEM can provide sustainability info of vehicle operation via the vehicle dashboard or via own cloud applications for the end user. Further reporting on aggregated view via the cloud is possible.

For TdE the digital handshake was set up in the following way. There are two main data sources, the filling events of a specific filling station and the vehicle filling event. In the vehicle, DFT software calculates vehicle position at refilling, specific time stamps during refilling, and refueled quantity based on CAN signals. This filling event data is sent directly to the DFT cloud along with the vehicle fuel type request. In the DFT cloud it is matched to the right filling station event out of a list of all filling events, appeared at the station.

Besides the CO_{2e} footprint DFT can also enable all market stakeholders (from fuel production to consumption) to utilize Carbon Neutral Fuel (CNF) for a potential new EU vehicle type variant by digital certification. Next to CO_{2e} tracking and certification of sustainability reports of CNF along the fuel supply chain, the DFT is capable of two further features embedded in the vehicle, the Fueling Monitor and the Inducement System. The Fueling Monitor in a vCNF (vehicle with Carbon Neutral Fuel) will assure that the vehicle is only fueled by CNF fuel by performing the vehicle handshake with the DFT cloud and monitoring of vehicles fillings. (c.f. Figure 7) Based on this filling event, the vehicle can check, whether filled fuel was CNF and accordingly can perform an inducement reaction (still to be defined) if check

result is negative e.g. as the wrong fuel was used. Based on this technology DFT is able to track CNF fuels immediately once defined and introduced into the market.

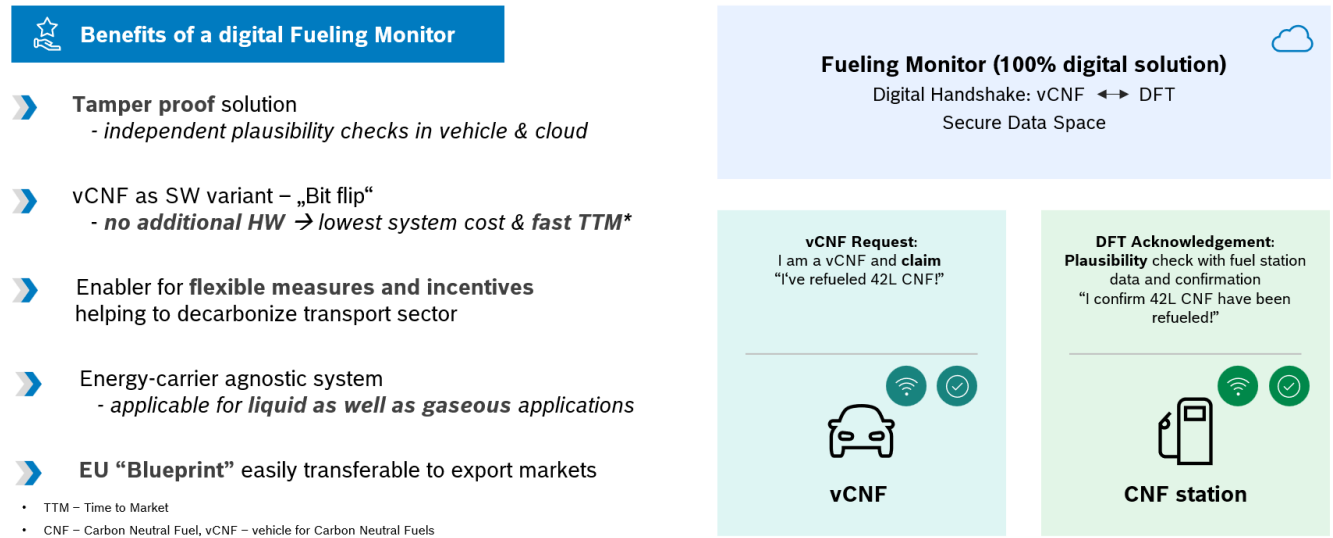


Figure 7: Use-case: Monitoring Methodology for vCNF

For Tour d’Europe an inducement recommendation approach was implemented too (comparable to AdBlue procedures). Two states are possible: “Go” and, “NoGo”. The software will set a “Go” if the fuel is correctly matched and whitelisted. For example, for TdE HVO100 was considered as a whitelisted fuel, according to the CNF definition of the WGMM Report [23]. If the fuel was not correctly detected or not whitelisted a “NoGo” Signal will be applied. This signal is also calibrated as a default, if no upstream information is available.

4 Database of the Tour

The data recorded during the Tour d'Europe and available for this evaluation can generally be classified into two groups.

The first group consists of the cloud data provided by the vehicle and the filling station. This is a list with one entry per refueling event. For each refueling event, relevant information is captured by the vehicle and uploaded to the cloud. The most important data includes:

- Vehicle ID and event ID
- Mileage of the vehicle
- Amount of fuel filled
- Timestamps and GPS coordinates of the vehicle.

In addition to the vehicle data, in the case of onboarded filling stations, further data from the filling station itself is assigned to the refueling event and uploaded into the cloud. These variables are:

- Amount of fuel reported by the fuel terminal or fuel pump
- Timestamps of the refueling process and the transaction at the cash desk
- GPS position of the filling station
- CO_{2e} footprint of the fuel.

The second group consists of data recorded manually by the driver of the vehicle for each refueling event. During the Tour d'Europe, relevant information on the refueling process is documented manually in a logbook in addition to the data automatically stored in the cloud by the DFT. This provides an additional data source for validating the cloud data and a theoretical backup in the event of any malfunctions that may occur during data transmission via the cloud. The most relevant information listed in the logbook is:

- Vehicle ID
- Timestamp of the refueling process (start, end) and of the transaction at the cash desk
- Address and name of the filling station
- Name of the fuel
- Filling level of the fuel tank read from the vehicle's fuel gauge before and after refueling (inaccurate)
- Amount refueled based on the display at the pump or the value on the fuel receipt
- Odometer reading of the vehicle.

Due to the manual procedure, not all information is available in the logbook without gaps for every refueling event. Nevertheless, the logbook provides a good database with only a few missing entries and can therefore be used as a suitable additional data source for the evaluation and analysis of the Tour d'Europe.

5 Methodology

The following section will discuss aspects of data processing. The objective of the data analysis is to evaluate the performance of all routes and vehicles during the Tour d'Europe. The focus is on the overall results achieved, such as the total CO_{2e} savings. For this purpose, all individual refueling events are taken into account and processed accordingly, although individual events are not highlighted in this report.

5.1 Analysis of GPS Information

The location information from the various data sources can be examined for each refueling event. One aspect in this context is the validation of the GPS coordinates reported by the vehicle and/or the filling station using the manual logbook.

As already explained, in the case of a complete tracking, GPS coordinates of the refueling event are transmitted from the vehicle as well as from the filling station into the Cloud. The driver of the vehicle also logs the exact address and the name of the filling station. For verification purposes, the address entered in the logbook is converted into the corresponding GPS coordinates using a geocoding service. These can then be used to validate the other two GPS coordinates by checking whether all the locations of the refueling event are within a certain distance of each other. Figure 8 illustrates the comparison: The three colored points represent the different GPS-coordinates from the vehicle, the filling station and the logbook address. The red circle represents a radius of 50 m around the filling station. If all GPS coordinates lie within this circle, as is the case in the example shown, the GPS coordinates can be validated accordingly.



Figure 8: Visualization of the GPS coordinates from vehicle and filling station (Cloud Data) as well as the logbook address

For further evaluation of the GPS information, the exact locations in Europe where refueling events were recorded are analyzed. For this purpose, the GPS coordinate of the vehicle is displayed on a map for each recorded event, with the color of the respective marker identifying the vehicle. A list of the European countries in which the refueling events took place is also generated. This allows the exact location of the refueling events, the European countries visited during the tour and the number of countries involved to be determined. The map with the refueling events is shown in Figure 9.

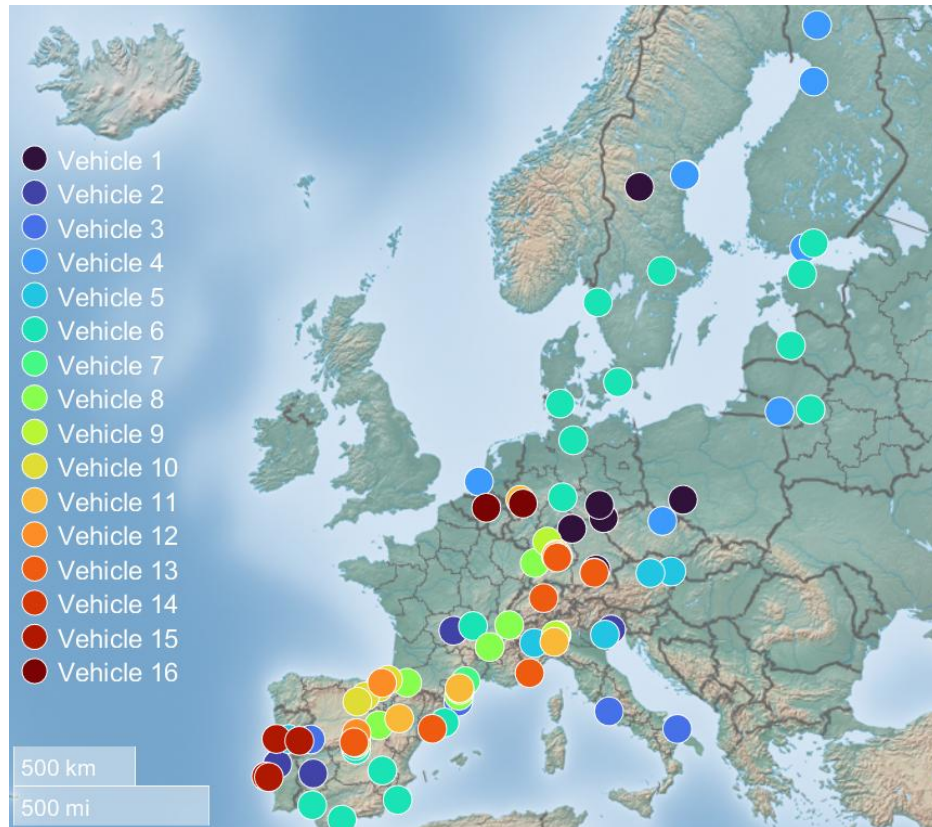


Figure 9: Map with selected refueling events

5.2 Analysis of Fueling Events

One of the main goals of the Tour d'Europe is to show the availability and effective GHG reductions potential while driving a vehicle fleet in Europe. Tour locations, routes and refueling events were chosen by the organizers on short notice, causing that not all information needed to show the potential of the fuels was collected or available in time for the analysis during Tour d'Europe. With a fully deployed DFT, this lack of data would no longer occur. In order to give a full overview of the potential of the used fuels, a classification of the fuels was carried out as shown in Figure 10.

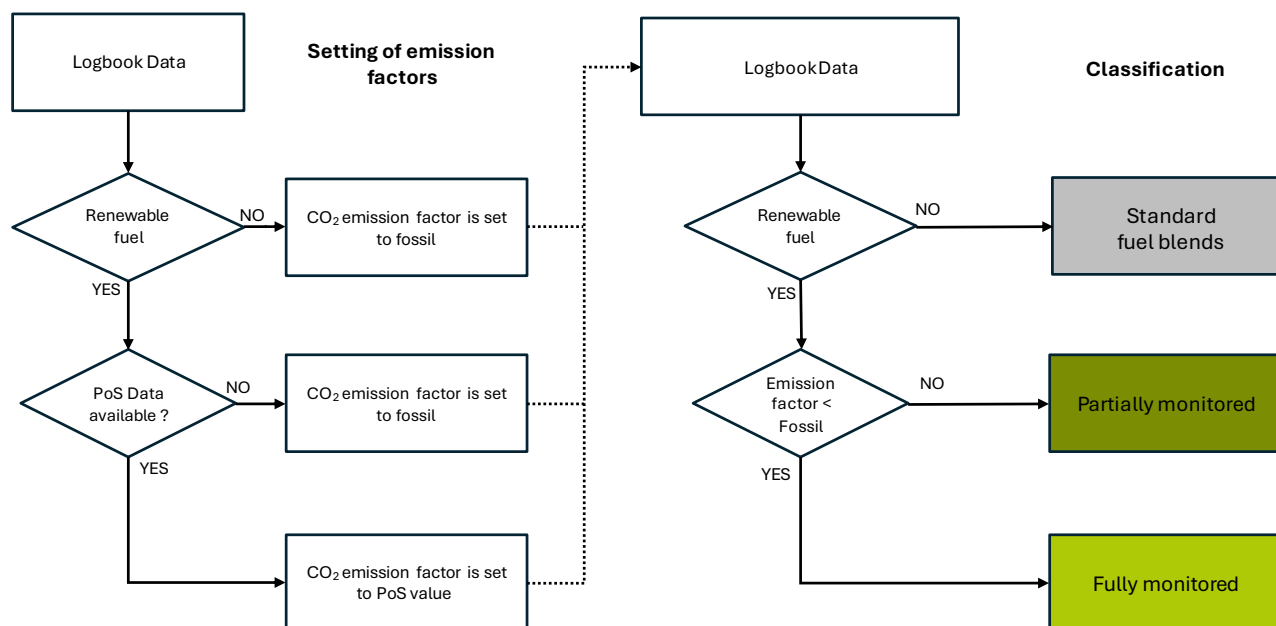


Figure 10: Classification of fuels for the analysis in this report

The data source used is the Logbook which includes a documentation of all the fueling events of the Tour d'Europe. A list of all used fuel names was compiled, and a first decision was made based on the name if the fuel is fossil or not. Ordinarily, all necessary information regarding the respective fueling event and the fuel is available. Thus, the emission factor provided by DFT can be used for further evaluation. Due to delay or missing verified information in DFT, some of the renewable fuels do not have their corresponding sustainability information connected to the Tour d'Europe event. In such a case the emission factor was initially set to the fossil reference value (if not already the case). These specific events were further evaluated using the Logbook and correlated with the corresponding emission factor. In the event of future series implementation, this case would no longer occur, as the availability of sustainability information for renewable fuels is required to verify the CO_{2e} emissions factor.

After this correction, a classification in 3 different classes was performed:

1. **Fully monitored:** All fueling events, which emission factor (RED certified) and refueling events were digitally tracked and confirmed (via DFT).
2. **Partially monitored:** All fueling events, where the emission factor (RED) was not provided on time, where digital tracking in certain locations was incomplete, but where fuel type and amount was manually documented. In these cases the unavailable digital proof was substituted by information documented in the Logbook during Tour d'Europe. The unavailability of these digital proofs are not attributable to the fuels themselves but result from the partial availability of relevant information (PoS).
3. **Standard fuel blends:** All fueling events, which had to use standard fuel blends due to limited availability of renewable fuels at the filling site. For these fuels no GHG reduction is considered as the renewable blend components are already regulated by quotas (E5, E10, B7 and B10). In this category, no classification into fully monitored or partially monitored is performed.

Using this classification the total amount of fuels in the different categories is shown in Figure 11.

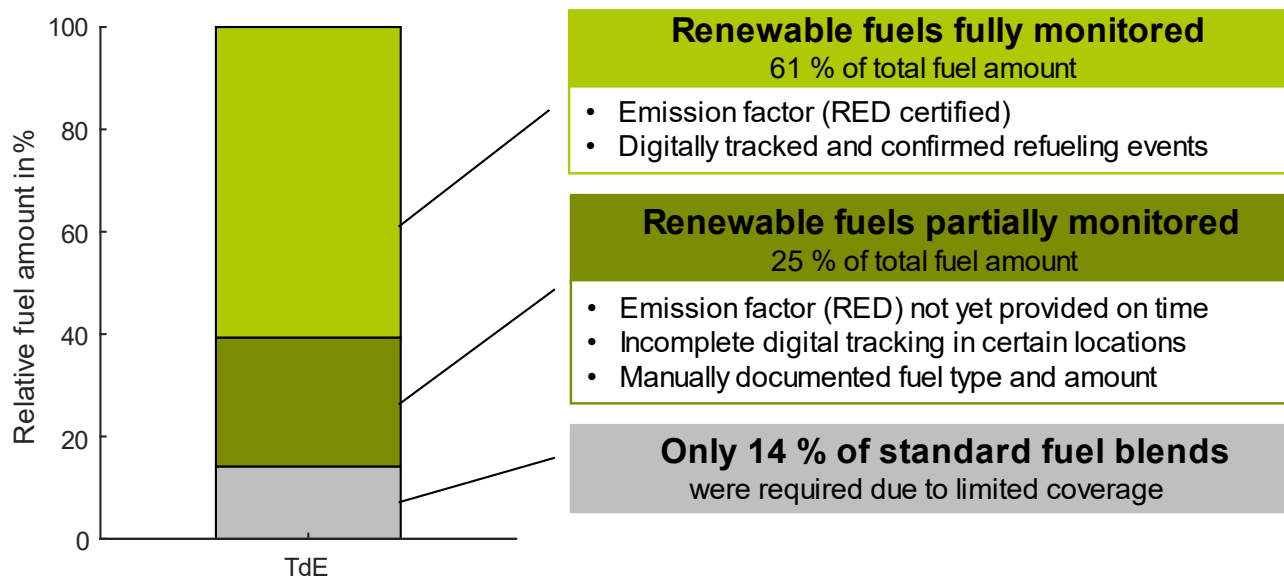


Figure 11: Result of the fuel classification

5.2.1 Fuel Amounts

Fuel type was identified by the name of the fuel (e.g. a commercial name). All fuel amounts corresponding to a given fuel type were then summed up into a total value. If a fuel name could not be matched to a known fuel name, fossil was set as default.

5.2.2 CO_{2e} Emissions

CO_{2e} emissions were calculated from the fuel amount (in liter for liquid fuels and kg for BioLNG) and corresponding emission factors (in gCO_{2e}/l in gCO_{2e}/kg). The fossil reference was set to be 94 gCO_{2e}/MJ. Emission factors of the partially monitored fuels were sometimes not available for the analysis in time. In such cases the mean value of the fully monitored fuels was used instead. This approach is considered to be closest to the actual emissions of the tour emission factors.

In order to achieve highest traceability, the mean values of the different fuel types were calculated using exclusively the fully monitored fuel data. Renewable fuel which was tracked but without a fully digitally monitored emission factor was therefore not considered in this calculation.

6 Results & Evaluation

Starting with an overview, this section presents the overall results of the tour. Finally, further aspects for the practical application of the technologies used are discussed.

6.1 General Analysis of the Tour

A total of 16 different vehicles of various types, fuel types and from different manufacturers powered by a combustion engine took part in the Tour d'Europe. The vehicle fleet consists of eleven passenger cars and five heavy duty vehicles. A total of eight of the participating vehicles were diesel-powered, while seven were gasoline-powered including one vehicle with E85-flexfuel technology. Finally, one heavy-duty vehicle was powered by BioLNG. The vehicles made a total of 322 refueling stops in 18 different European countries on five different routes across Europe. A wide variety of renewable fuels were used, including HVO100, B100, E85, renewable gasoline, various blends and the already mentioned BioLNG. The vehicles have covered a total of well over 82800 km across Europe.

The total amount of gasoline-type fuel used during the tour was 1867 l, which corresponds to 17 % of the total fuel during the tour. As part of the gasoline fuel, 797 l of standard gasoline blends were refueled. Furthermore, 206 l of E85, 486 l of renewable gasoline and 377 l further blends with proven GHG reduction were refueled. A significant amount (around 1069 l – 57 %) of the used gasoline fuel therefore had a certified renewable component.

The second category of fuels is BioLNG. In total, a volume of 2207 l of BioLNG was refueled. This represents a share of 20 % of the total fuel during Tour d'Europe.

Diesel-type fuels were the most common type of fuel used during the tour (approx. 63 % in total). A total of 6886 l of diesel fuel was used: 150 l of B100 and 6080 l of HVO100. This resulted in 90 % of the fuel used being renewable. The amount of standard diesel blends was 656 l.

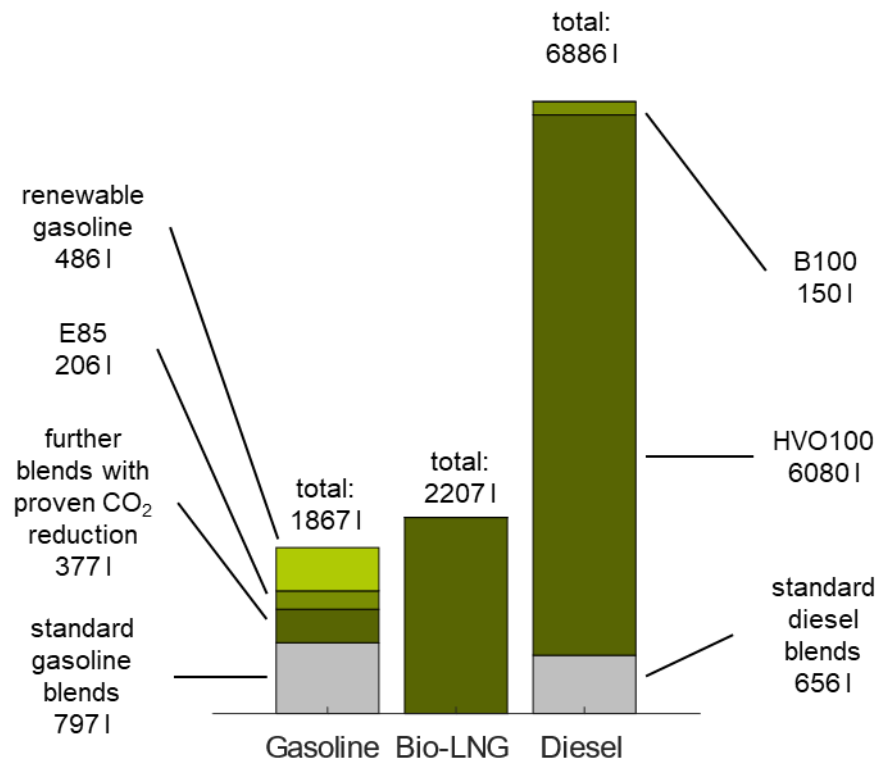


Figure 12: Total fuel amounts used during TdE

The GHG reduction achieved by renewable fuels is based on the analysis of the well-to-wheel CO_{2e} footprint of the respective fuel. This takes into account the acquisition of raw materials, processing into fuel, distribution and use in the vehicle. As of today, most of the available renewable fuels are bio-based fuels, such as HVO100, B100, Bio-Ethanol, BioLNG and their blends with fossil fuels or other renewable fuels. For these fuels, biological materials specified by the renewable energy directive are used as feedstocks. This means that the GHG reductions achieved by using renewable fuels are based on the actual fuel that is filled into the vehicle's fuel tank and are therefore real, verifiable and certified according to European regulations. All these fuels are reported and achieved a so-called proof of sustainability.

6.2 Carbon Footprint Reporting

Emission factors of renewable fuels are calculated according to the renewable energy directive. These values are then reported in a proof of sustainability² in national databases, which are used by energy providers to comply with national goals. In the Tour d'Europe the values from the POS were recorded for the refueling events and are therefore available for assessment of the carbon footprint of the Tour d'Europe.

The values of the specific fuel batch are influenced by the feedstock, the production process and the energy use of the fuel synthesis. Therefore, there is variation in a given fuel type. To give an overview

² In Germany; corresponding documents and databases exist in other European countries

the mean values of the proven (fully monitored) emission factors for each fuel type was calculated. The results are presented in Figure 13.

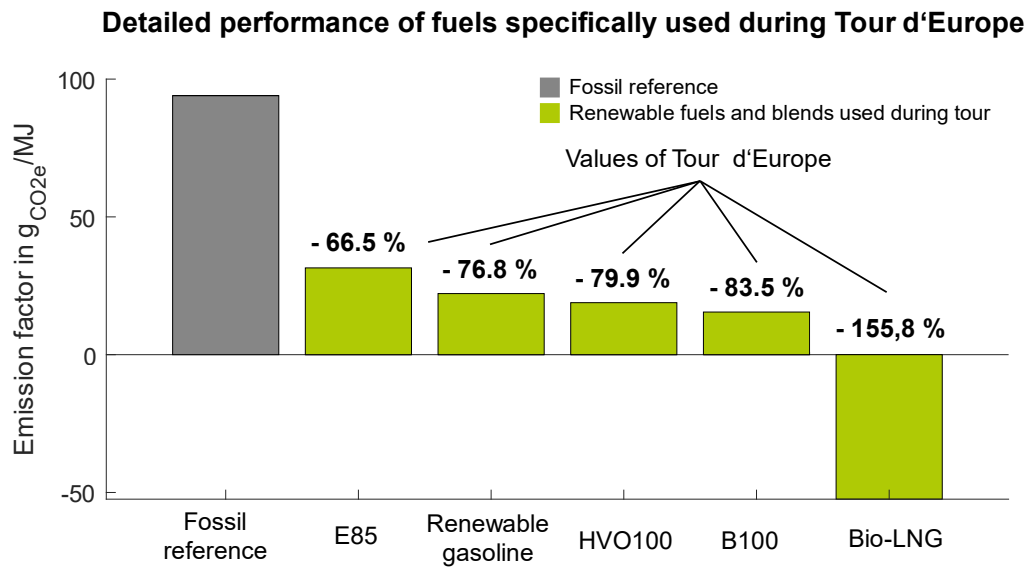


Figure 13: Emission factors of the used fuels

A wide variety of fuels with different GHG reduction potentials were used. The fuel-specific GHG reductions achieved, on a well-to-wheel basis, ranged from 66.5 % to 83.5 % for the liquid fuel options. These values are based on the used fuel batches in the Tour d'Europe. **All the renewable fuel options used have further reduction potential³**, enabled by the use of other feedstocks (e.g. waste materials), and improved production processes. The used E85 fuels still have a fossil gasoline component. Their potential GHG reduction can increase in the future – e.g. by using bio naphtha or other renewable gasoline fuels.

BioLNG achieved a mean emission factor of -52,4 gCO_{2e}/MJ which corresponds with a reduction of -155,8 % compared the fossil reference of 94 gCO_{2e}/MJ. This high reduction is achieved by using mainly waste based feedstocks with a high reduction potential (RED). This high reduction is achieved by accounting the methane emission avoidance to the fuels as described in chapter 2.5.

³ See also section 2.6

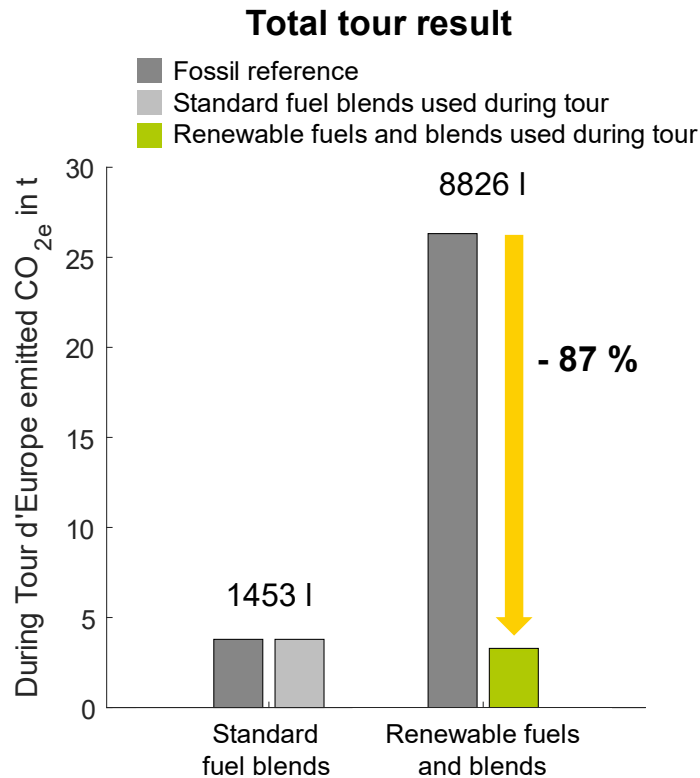


Figure 14: Total tour result

The overall result of the Tour d'Europe is expressed as absolute CO_{2e} emissions in g CO_{2e}/MJ. The data also represents the real-life experience of users travelling across Europe. Already today, only 14 % of standard fuel blends had to be used as the result of regional unavailability. **For the overall fuel mix of the Tour d'Europe, including standard fuel blends used during the tour, the total GHG reduction reaches 77 %, showing a significant reduction in well-to-wheel CO_{2e} emissions with the given status of fuel availability. The renewable fuels (and their blends) by themselves achieved a CO_{2e} reduction of 87 % overall.**

In this context, each improvement of fuel properties would be immediately visible as further GHG reduction. This could be achieved by higher blend rates and/or advanced production of the renewable fuels. The reliable and scalable monitoring of any certified type of renewable fuel has been demonstrated during the Tour d'Europe and is described in the following chapter.

6.3 Technology Evaluation

This section evaluates the used technology regarding its compatibility with different fuel types as well as its impact for the end user. The use for any vehicle producer has to be analyzed along with the upcoming regulation, currently under discussion.

6.3.1 Compatibility with Different Types of Fuels

During Tour d'Europe used fuels were tracked with the DFT tool. In order to fulfil its purpose, information about the used fuels has to be available. A fuel station therefore has to be onboarded and provide the relevant information about a refueling event. In order to assign this information to a specific user (vehicle), the vehicle itself has to be onboarded to the DFT as well. In order to function properly a POS has to be provided to the software tool for the specific batch of fuel that is filled into the vehicle.

For renewable fuels like HVO100 or BioLNG a POS usually is easily available, because each specific fuel batch has a corresponding POS which is provided by the fuel manufacturer and part of its economic value⁴. For these types of fuel, the described approach is working directly. For fuel blends with known blend ratios, POS are available for the renewable component – e.g. the ethanol in E85. Therefore, an emission factor for the fuel blend can be calculated by using the other component's emission factor, which is either the fossil value or the emission factor from its respective POS.

For the standard fuel blends (E5, E10, B7 and B10) the exact content of the renewable component (Ethanol and BioDiesel) is currently unknown at a given fuel station. **Therefore, in such cases the tool has to assume the fuel consists entirely of fossil fuel with a corresponding high emission factor.** Since the majority of fuels today fall into this category a change to the fuel norm would be needed to force specific ethanol and BioDiesel contents in order to enable complete and detailed tracking.

It can also be stated that the use of the DFT and the underlying technology is not dependent on the fuel used. For example, it does not matter whether the fuel is liquid or gaseous, how much is refueled or whether it is a fossil or renewable fuel. Only the mentioned requirements regarding the onboarding of filling station and vehicle as well as the POS are necessary, which is why compatibility with different fuels is fully given.

6.3.2 End-User Impact

The Tour d'Europe showed how the fuel use of a specific vehicle fleet at onboarded fuels stations could prove its GHG reduction in daily operation. Two use cases are prominent for such an approach.

Firstly, a commercial vehicle fleet of any company can lower its Scope 1 emissions⁵ by using specific renewable fuels. This information can then be used to achieve the company's GHG reduction goals (e.g. in the CSRD framework).

Secondly, a logistic service provider can prove the use of renewable fuels to its customer and lower the Tier 3 emissions⁶ for the logistic service in the balance for the customer. So, it is a way to incorporate reduction goals into logistic contracts.

It should also be mentioned that the impact for the user in terms of necessary modifications to the vehicle fleet to enable the use of DFT technology is minor. As already described, the requirements on the vehicle side are limited to access to the vehicle's CAN bus system, e.g. via the OBD interface, and a data connection to the cloud. No other adaptations are necessary. This means that the benefits described require little effort on behalf of the end user.

⁴ POS are regularly traded between companies in order to fulfil obligations. A producer of renewable tool therefore has an additional income from a given fuel amount.

⁵ Tier 1 emissions: Direct emissions from the company, e.g. its own vehicle fleet

⁶ Tier 3 emissions: Indirect emissions of the company, e.g. purchased logistic services

7 Conclusion & Outlook

CO₂ Savings Potential



Simple and genuinely feasible as of today. Actual, **verifiable and certifiable CO₂ reduction** by renewable fuels.

Monitoring Available & Necessary



Monitoring based on information about the refueling process is necessary and already in development.
→ **Huge benefit for authorities and users**

Adaptation of Legislation Required



Instead of only measuring tailpipe emissions, the **well-to-wheel CO₂ footprint has to be considered** for renewable fuels.

The Tour d'Europe highlighted important aspects of the use of renewable fuels in Europe today. It demonstrated the availability of renewable fuels that are currently available at commercial fuel stations in several European countries, as well as their CO_{2e} savings potential. Fuel stations with a regular supply of renewable fuels or fuel blends were selected and equipped with a development version of the DFT tool without changing the existing fueling infrastructure. During the tour, a minority of fuel stops were made at fuel stations with only standard fuel blends.

Based on the certified reductions available today, a link to fuel use was established through digital monitoring of the fueling events. This monitoring and the tools developed for it, which were presented during the Tour d'Europe, can provide users and authorities with reliable information about the emissions of vehicle fleets in use. Monitoring the quantities of renewable fuels used and the corresponding emission factors can help to meet the obligations arising from the specified CSRD and sustainability targets by transparently presenting emissions in the transport and logistics sector.

However, to fully realize the potential of renewable fuels, the carbon footprint of all renewable fuels from well to wheel should be integrated into current fleet and emissions regulations. Currently only tailpipe emissions are considered. There is currently no mechanism in place to harness the GHG reduction potential of renewable fuels to reduce fleet emissions for car manufacturers.

In conclusion, it must be emphasized that there is already a high availability of various renewable fuels throughout the whole of Europe. As demonstrated during the Tour d'Europe, these fuels offer significant and verifiable potential for reducing CO_{2e} emissions of all types of vehicles. The tour also showcased that the technology for monitoring refueling processes and the associated determination of the CO_{2e} footprint of vehicles is available already.

As a result, today's use of renewable fuels can accelerate the reduction of CO_{2e} emissions from vehicle fleets, which – in combination with the monitoring technology – can be tracked and certified and thus make a substantial contribution to climate protection.

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