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Analysis of European vehicle technology development based on the A3PS roadmaps and presentations at the Eco-Mobility conferences

ausgeführt zum Zwecke der Erlangung des akademischen
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Aims and Objectives of the Study

Die Mobilität hat sich aufgrund der Anforderungen an Luftqualität und Klimaneutralität stark diversifiziert. Vor allem die Elektromobilität hat im Individualverkehr deutlich zugenommen. Daneben gewinnen hybridisierte Antriebe und, vor allem im Schwerverkehr, alternative Kraftstoffe an Bedeutung. Ebenso ist auch Wasserstoff als klimaneutraler Kraftstoff für brennstoffzellen-elektrische Antriebe oder VKM ein intensiv diskutiertes Thema. Die Steuerung und Förderung dieser Transformation durch Forschung und Entwicklung wird in Österreich von dem Verein A3PS unterstützt, die einmal jährlich ihre Erkenntnisse im Rahmen der internationalen Eco-Mobility Tagung für Industrie und Öffentlichkeit zugänglich macht.

Es ist die Aufgabe dieser Bachelorarbeit, die Roadmaps der Arbeitsgruppen und die Vorträge der Eco-Mobility Konferenzen ab 2010 zu sichten, mit den Roadmaps auf EU-Ebene (ERTRAC, EUCAR, CLEPA, EARPA) zu vergleichen und der tatsächlichen Marktdurchdringung der diversen Antriebskonzepte innerhalb Europas gegenüberzustellen. Die Studie soll den Individual- und Güterverkehr abdecken. Eine Einordnung der Resultate vor dem Hintergrund politischer Entscheidungen soll erfolgen.

Die Ergebnisse sind in englischer Sprache in einer Bachelorarbeit zu dokumentieren und als Poster-Präsentation auf der Eco-Mobility Tagung zu präsentieren. Die Arbeit wird aktiv von den Mitarbeitern und Mitgliedern der A3PS unterstützt. Es wird bei erfolgreicher Bearbeitung eine Prämie in Aussicht gestellt.

October 2025

Statutory Declaration

Ich habe zur Kenntnis genommen, dass ich zur Drucklegung meiner Arbeit unter der Bezeichnung

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nur mit Bewilligung der Prüfungskommission berechtigt bin. Ich erkläre weiters an Eides statt, dass ich meine Bachelorarbeit nach den anerkannten Grundsätzen für wissenschaftliche Arbeiten selbständig ausgeführt habe und alle verwendeten Hilfsmittel, insbesondere die zugrunde gelegte Literatur genannt habe.

Weiters erkläre ich, dass ich dieses Bachelorarbeitsthema bisher weder im In- noch im Ausland (einer Beurteilerin/ einem Beurteiler zur Begutachtung) in irgendeiner Form als Prüfungsarbeit vorgelegt habe und dass diese Arbeit mit der vom Begutachter beurteilten Arbeit übereinstimmt.

Wien, am 24.10.2025

Peter Straubinger

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Abstract

In recent years global challenges such as climate change and air pollution have become increasingly more important. With road transportation being a major contributor to these problems, the reduction of CO_2 and other pollutant emissions becomes necessary. More advanced and alternative powertrain solutions, as well as sustainable energy carriers have gained relevancy, for passenger vehicles, as well as trucks and buses. The Austrian Association of Advanced Propulsion Systems discusses and publishes the current and future research and development demands of the Austrian automotive industry in roadmaps. The aim of the study is to compare the projected research, and development demands of different powertrain technologies listed in the roadmaps, to the actual change in the existing vehicle fleet and the new registrations, in both Austria and the European Union. Furthermore, the influence of political decisions should be taken into consideration.

Among new registrations hybrid and battery electric passenger vehicles have gained significant market share in recent years, while the new number of vehicles powered by both diesel and petrol has declined in the past few years. In the total European and Austrian fleet, the number of alternatively powered cars has steadily increased; however, most vehicles are still propelled by internal combustion engines. For trucks and buses, diesel engines have remained dominant for both new registrations, as well as the existing fleet. The roadmaps correctly projected, the continuing dominance of the internal combustion engine, the mentioned need for research and development activities for battery and hybrid electric vehicles matches well with the new registration numbers. Despite being discussed extensively in the roadmaps, the amount of fuel cell vehicles has remained negligible. Vehicles powered by natural gas, were also mentioned to provide the opportunity to reduce emissions, but in Austria the number of these vehicles remains small, in the European Union only a few countries have a sizable fleet of these vehicles.

The roadmaps also contain information about the research and development demands for renewable energy carriers, such as fatty methyl esters, hydrogenated vegetable oils, bioethanol and hydrogen. The focus hereby is on the use of renewable energy and advanced feedstock to produce these sustainable fuels. As of 2025, bioethanol, hydrogenated vegetable oil and fatty methyl esters are used to fuel road transport, other sustainable energy carriers are not produced at a commercial scale.

The political influence on the Austrian automotive sector is displayed in the restructuring and recategorization of the 2022 roadmap compared to the previous editions. The main cause of this shift could be the announcement of new fleet emission standards and a future ban on internal combustion engines by the European Union, which put significant pressure on automotive manufacturers by favoring vehicles which do not emit CO_2 during driving.

Compared to the actual development of the mobility sector, the roadmaps correctly projected the dominance of the internal combustion engine, the increasing electrification of passenger cars and the increasing importance of sustainable fuels.

Kurzfassung

Die Austrian Association for Advanced Propulsion Systems erstellt seit 2011 Roadmaps, welche die aktuelle Forschungs- und Entwicklungsbereiche in der österreichischen Automobilindustrie zusammenfassen. Da die Reduktion von CO_2 Emissionen im Straßenverkehr und Luftqualität immer wichtiger werden, gewinnen alternative Antriebssysteme und nachhaltige Kraftstoffe immer mehr an Bedeutung. Das Ziel dieser Arbeit ist, die Roadmaps zu analysieren, zusammenzufassen und diese mit der tatsächlichen Mobilitätsentwicklung in Österreich und der Europäischen Union zu vergleichen, auch soll der politische Einfluss auf die Branche betrachtet werden.

Unter den Neuzulassungen im PKW-Bereich wurden hybrid und batterieelektrische Fahrzeuge immer beliebter, welche in den Roadmaps als attraktive und bedeutende Technologien genannt wurden. Diesel PKW hingegen werden immer seltener zugelassen, machen aber dennoch gemeinsam mit Benzin betriebenen Fahrzeugen einen Großteil der Fahrzeugflotte aus, dies spiegelt sich auch in allen Roadmaps wider, da die Verbrennungskraftmaschine als die am dominanteste Antriebstechnologie gesehen wurde. Erdgas- und LPG-Fahrzeuge hingegen sind innerhalb der Europäischen Union nur in vereinzelten Ländern relevante Antriebs Technologien. Die Anwendung von Brennstoffzellen in der Mobilität wurde intensiv in den Roadmaps thematisiert, jedoch ist bis jetzt nur eine geringe Anzahl dieser Fahrzeuge zugelassen. Dieselantriebe wurden im Bus und Nutzfahrzeugbereich als relevanteste Technologie geführt, welches sich auch in den tatsächlichen Zulassungszahlen zeigt, dennoch gewinnen auch in diesen Bereichen alternative Antriebe zunehmend an Bedeutung. Die Roadmaps thematisieren auch die Forschung und Entwicklung von erneuerbaren Kraftstoffen, wie zum Beispiel Biodiesel, hydriertes Pflanzenöl und Bioethanol. Im Vordergrund stehen vor allem die Verwendung von nachhaltigen Rohstoffen und Abfallprodukten zur Treibstoffproduktion.

Der Einfluss von politischen Entscheidungen, spiegelt sich vor allem in der Neustrukturierung der Roadmap von 2022 wider. Da zu dieser Zeit die Europäische Union unter anderem neue Flottengrenzwerte und die Renewable Energy Directive II angekündigt hat. Die Verbrennungskraftmaschine rückte somit in den Hintergrund und Antriebe, welche während der Fahrt kein CO_2 ausstoßen wurden stark priorisiert.

List of Abbreviations

A3PS	Austrian Association for Advanced Propulsion Systems
BEV	Battery Electric Vehicle
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DME	Dimethyl Ether
ERTRAC	European Road Transport Research Advisory Council
ETBE	Ethyl tertiary-butyl ether
EU	European Union
FAME	Fatty Acid Methyl Esters
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gases
H_2	Hydrogen
HVO	Hydrogenated Vegetable Oil
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
MTBE	Methyl Tert-Butyl Ether
NO_x	Nitrogen Oxide
OME	Oxymethylene Ether
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PHEV	Plug-In Hybrid Electric Vehicle

1 Introduction

The Austrian Association for Advanced Propulsion Systems (A3PS) yearly hosts the Eco-Mobility conference to present the current challenges, research and development demands regarding the automotive industry to the public; additionally, starting in 2011, roadmaps are published to summarize these developments of relevant technologies. Since then vehicle, powertrain and fuel technology have evolved significantly. In this period the effects of greenhouse gas emissions caused by burning fossil fuels in conventional internal combustion engines have become increasingly more apparent. To address the resulting challenges, primarily climate change and air pollution, the European Union (EU) introduced stricter new emission regulations and set mandatory targets for the adoption of renewable fuels. To reach these targets new zero emission vehicles, hybrid powertrains and sustainable fuels are necessary.

In recent years more alternatively powered vehicle concepts such as battery electric vehicles, fuel cell electric vehicles, plug-in hybrids and hybrid-electric vehicles have entered the market and thus, the number of newly registered vehicles with alternative powertrains has increased in Austria and the EU. To reduce the greenhouse gas and pollutant emissions created by conventional internal combustion engines different sustainable fuels are being used, simultaneously other renewable energy carriers are examined for their CO_2 reduction potential.

The aim of this bachelor’s thesis is to compare the research and development demand published in the A3PS roadmaps and presentations held at the conferences to the actual development of the mobility sector in Austria and the EU.

2 Fundamentals

2.1 Automotive Powertrains

Different powertrain technologies have been developed to propel vehicles. The most common ones being vehicles with internal combustion engines, battery electric vehicles, hybrid electric vehicles and fuel cell electric vehicles. Historically the internal combustion engine fueled by diesel and gasoline has been the dominant powertrain solution in the automotive sector. However, stricter emission regulations, climate change policies and the need to reduce the dependency on fossil fuels have increased interest and the relevance of alternative powertrains.

These powertrains can be categorized by the main energy carrier used to supply the energy needed for propulsion. While internal combustion engines use the combustion of liquid or gaseous fuels, the electric energy needed to propel an electric vehicle can be provided by a battery, a generator or a fuel cell. Thus, it can be differentiated between a battery electric vehicle, hybrid electric or a fuel cell electric vehicle.

2.1.1 Internal Combustion Engine

The internal combustion engine is the most widespread powertrain technology in vehicles, of which gasoline and diesel engines are the most common. These engines produce the power needed for propulsion by burning fuel and therefore converting the chemical energy stored in the fuel to mechanical energy. [1, p. 1]

At present, most diesel and petrol engines are four stroke piston engines, the four strokes are intake, compression, combustion and exhaust stroke. Internal combustion engines can be separated into spark ignition engines, which use petrol or other fuels (ethanol, liquified petroleum gas (LPG), natural gas, hydrogen) and compression ignition engines which operate on diesel or surrogate fuels such as hydrogenated vegetable oils (HVO) or fatty methyl esters (FAME). [1, p. 295, 296]

2.1.2 Battery Electric Powertrain Technologies

The demand for vehicles which emit no greenhouse gases (GHG) while driving has increased in recent years. Electric powertrains use the electric energy stored in batteries to propel the vehicle forwards. These batteries are charged externally and if the electricity is produced by renewable sources the amount of lifetime emission including vehicle production can be significantly lower than for conventional vehicles with combustion engines. However, the amount of lifetime GHG emissions strongly depends on the electricity mix used for charging [2, p. 16, 18]. Additionally, new public fast charging infrastructure is mandatory to provide energy for these vehicles.

2.1.3 Hybrid Electric Powertrains

Powertrain concepts which use a combination of electric motors, and an internal combustion engine are called hybrid propulsion systems. This combination allows for a more efficient operation of the engine, thus reducing fuel consumption and the amount of CO_2 and other greenhouse gases (GHG) emitted compared to vehicles which are solely powered by internal combustion engines. Furthermore, the battery can be significantly smaller than for purely electric vehicles.

These powertrains can be categorized as follows: micro-, mild, full hybrid systems, range extender and plug-in hybrid drivetrains. Mico Hybrids are 12V systems which allow for a start/stop function [3, p. 55]. With mild hybrid concepts, it is possible to increase efficiency by recuperating energy during breaking and assist the combustion engine during acceleration. Because of regulations regarding the safety of high-voltage systems, these powertrains often operate at 48 Volt [3, p. 65-67]. Full hybrid vehicles are able to drive short distances using only electrical energy, which is solely feasible with higher voltage systems.

Plug-In hybrid vehicles (PHEV) have larger batteries, that can be externally charged and offer additional pure electric driving range. The combustion engine is then used for longer-distance travel. [1, p. 24] A range extender system is an electric vehicle which carries an additional combustion engine as a generator to extend the range of the vehicle. However, the combustion engine is not directly connected to the wheels. [3, p. 72]

2.1.4 Hydrogen Fuel Cell Vehicles

Hydrogen has the highest energy-to-mass content of any fuel and can thus, be used as an energy carrier to generate the required electricity for propulsion on board of the vehicle [4, p. 378]. This can be achieved by using a polymer electrolyte membrane fuel cell (PEMFC) which generates electricity through a chemical reaction between hydrogen and oxygen in the air. At the anode, the hydrogen protons are separated from the electrons, the hydrogen ions pass through the membrane, which separates the cathode from the anode side of the fuel cell. The electrons then pass through the electrical circuit of the vehicle. At the cathode the hydrogen ions, electrons, and oxygen react to form water. As hydrogen is not very dense, the gas needs to be stored in high-pressure tanks up to 700 bar or as a liquid, which requires cooling, and therefore, large tanks are necessary [4, p. 449, 456]. Furthermore, an additional battery is still needed.

2.2 Alternative Fossil Fuels

These types of fuels are not renewable, however in comparison to diesel and gasoline these alternative energy carriers exhibit the capability to reduce the amount of CO_2, NO_x or particulate matter emitted. As short-chain hydrocarbons have a lower carbon to hydrogen ratio, this results in lower CO_2 emissions compared to longer-chain hydrocarbons and virtually no soot formation.

2.2.1 Natural Gas

While natural gas is a fossil fuel, mainly composed of methane, passenger cars powered by compressed natural gas (CNG) can achieve a reduction of CO_2 emission up to 20%, which makes it an attractive alternative energy carrier. [4, p. 140] As a fuel it is mostly used in retrofitted petrol cars, which can run either on gasoline or CNG. [4, p. 139]

2.2.2 Liquified Gas

Liquefied petroleum gas is a derivative of the crude oil and natural gas extraction and refining process and is most commonly a mixture of mostly propane and butane. [4, p. 101] Natural gas can also be liquified (LNG) and used in spark ignition engines, conclusively these fuels can be used to further diversify the vehicle fleet.

2.3 Renewable Energy Carriers

Renewable energy carriers play a major role in decarbonizing the transportation sector. These fuels can be produced from renewable feedstock and electricity, thus reducing the amount of carbon emissions compared to fossil fuels. Feedstock for such fuels, for example, can be biomass, industrial waste, hydrogen, cooking oil or captured carbon from the air. Renewable fuels provide the opportunity to reduce CO_2 emissions produced by the existing vehicle fleet as already existing infrastructure can be utilized. The following chapter will provide an overview of the most relevant fuel types.

2.3.1 Liquid Fuels

2.3.1.1 Fatty Acid Methyl Esters

Fatty acid methyl esters often referred to as biodiesel, make up most of the renewable fuels blended with fossil diesel [4, p. 316]. Biodiesel is most commonly produced out of vegetable oils, animal fats or waste materials such as used cooking and frying oil. Currently diesel sold in the European Union contains 7% renewable diesel (FAME). [5]

2.3.1.2 Hydrogenated Vegetable Oil

The feedstock of hydrogenated vegetable oil is mainly vegetable oils, residue fats and other waste materials. The fuel is produced by hydrogenating the raw materials in a catalytic reaction. HVO can be blended with fossil diesel at any rate or used as a pure renewable fuel. As HVO is chemically very similar to fossil diesel [4, p. 355] it can be used in vehicles without modifications to the fuel system and engine. [4, p. 351]

If green hydrogen is used for production and the feedstock is sustainably sourced or waste material, CO_2 savings of up to 90% compared to fossil diesel are possible. [6, p. 4, 5]

2.3.1.3 Bioethanol

Bioethanol is currently the most widely used biofuel for gasoline engines, as in the European Union petrol is sold with a bioethanol share of up to 10% [5]. As a fuel ethanol can be used as pure fuel or mixed with fossil gasoline in any percentage. However, fuels with an ethanol content exceeding 10%, require modification to the engine and fuel system. [4, p. 229] Ethanol is produced by fermenting and distilling the sugar, starch or cellulose contained in the feedstock. The feedstock utilized is dependent on the region, plants which contain sugar, starch and cellulose are suitable, and range from corn, sugar cane, sugar beet to wheat. However the cultivation of these crops may interfere with food production. [4, p. 214, 215]

2.3.1.4 Methanol

For methanol production, biomass or CO_2 captured from the air, combined with hydrogen can be used as feedstock. [4, p. 250] Methanol is either employed as a blending component for gasoline or purely; nevertheless, vehicles must be modified to accommodate the use of methanol as fuel. [4, p. 265] Challenges for the utilization of methanol as a fuel include its corrosive properties and its toxicity.

Other synthetic fuels can be produced by using methanol such as methyl tert-butyl ether (MTBE), which is mixed with petrol because of its anti-knocking properties. Other substitutes for diesel engines that can be manufactured out of methanol are synthetic fuels such as dimethyl ether (DME) or oxymethylene ether (OME). These fuels are attractive because of their lower emissions and favorable auto-ignition properties. [4, p. 276-282]

2.3.1.5 Fischer-Tropsch Fuels

The Fischer-Tropsch process converts syngas, a mixture of carbon monoxide and hydrogen, to produce liquid hydrocarbons. Sustainable fuels for spark and compression ignition engines can be obtained, if the syngas is produced by gasification of organic waste or biomass. [4, p. 162, 163]

2.3.2 Gaseous Fuels

2.3.2.1 Hydrogen

As water is the most abundant resource on earth, the use of hydrogen as fuel seems reasonable. However, today hydrogen is primarily produced by reforming natural gas, thus, utilizing electrolysis powered by renewable energy is seen as an attractive solution. [4, p. 373] Fuel cells and internal combustion engines can both be fueled by hydrogen but fuel cells require high purity hydrogen to operate.

Hydrogen offers a higher energy density per mass unit compared to other fuels and no CO_2 is produced during combustion. But the storage of this gas is challenging as it either needs to be liquified under extremely low temperatures or compressed under high pressure. [7, p. 394]

The use of hydrogen as a fuel for road transportation also requires a new refueling station network and other infrastructure. Additionally, green hydrogen would need to be mass-produced by electrolysis for hydrogen to become economically attractive.

2.3.2.2 Biomethane

Biomethane is a sustainable energy carrier as it is mostly produced locally from waste and renewable materials. Its purified form is very similar to natural gas and thus can be stored, used and mixed with natural gas. [4, p. 142]

3 A3PS Roadmaps

The Austrian Association for Advanced Propulsion Systems is a partnership of the Austrian Federal Ministry for Innovation, Mobility and Infrastructure (FMIMI), research institutions and industry partners [8]. Its main objective is the creation of a platform for the discussion and analysis of current and future research as well as development trends in the Austrian automotive sector. [9, p. 9]

In this regard the A3PS publishes roadmaps, with the aim of summarizing the current research and development demands, trends and challenges for the Austrian automotive industry. The content of the roadmaps is compiled by working groups composed of representatives from research institutions and industry partners. These roadmaps provide insights in the short-, medium- and long-term future regarding advanced powertrains, such as internal combustion engines, full and partial electric powertrains and fuel cell vehicles. Other subject areas which are not further elaborated on in this thesis include life cycle assessment, advanced powertrain integration technologies, vehicle control systems, automated driving and lightweight design. [9, p. 6]

3.1 Roadmap 2015+ (2011)

The following section summarizes the key points of the roadmap "Eco-Mobility aus Österreich 2015^{plus}", published by the A3PS in 2011. This report provides an overview of the short- (2011-2015), medium- (2015-2020) and long-term perspective (2020-2030) of the relevant development areas of the Austrian automotive industry. The roadmap differentiates the following powertrain technologies: optimized conventional drive trains, electric and partially electric powertrains. Renewable fuels are listed in a separate chapter. [10, p. 1]

In this report it is projected that conventional combustion engines will remain the powertrain with the biggest market share in the short-, medium- and long term. In order to reach the goal of replacing fossil fuels and having a largely emission free vehicle fleet, the roadmap suggests that new efficient power train technologies and solutions must be developed. [10, p. 2, 13]

3.1.1 Light Vehicles

The first chapter of the roadmap focuses on optimized diesel and gasoline engines, distinguishing between light vehicles, heavy-duty and bus applications.

Further development of diesel and gasoline engines is mentioned to still have a potential in reducing emissions and fuel consumption. According to the authors, the use of natural gas, biogas and hydrogen as fuel for spark ignition engines can significantly reduce CO_2 emissions. This multi fuel operation could be realized with little additional research and development. It is stated that the operation of internal combustion engines with hydrogen as fuel is a possible bridge technology towards electric vehicles. The roadmap also reports that first micro hybrids allowing for the use of start/stop systems are already available on the market. [10, p. 13]

The chapter Electric and partially Electric Power Trains contains following propulsion systems: battery electric, hybrid electric and fuel cell vehicles.

It is suggested that hybrid electric vehicles offer better efficiency and emit less CO_2 during operation than conventional internal combustion engines, due to for example being able to recuperate energy while breaking. In the long-term alternative engines such as Wankel engines could be used in hybrid vehicles, but in the short term conventional thermodynamic powertrains will be used. Nonetheless, it is stressed that even better potential regarding emissions reduction is offered by battery electric and fuel cell vehicles, as these do not emit CO_2 during driving. [10, p. 18]

3.1.2 Heavy-Duty Vehicles and Buses

For heavy-duty vehicles and buses optimized diesel engines and gas engines are seen as the most relevant powertrain solutions. Natural gas as fuel offers the possibility of reducing CO_2 emission up to 25%, a further reduction would be possible with the use of biogas, with the added benefit of it being an Austrian resource. [10, p. 16]

Whereas the report projects that for long distance transport battery electric trucks and buses are not suitable, for depot-bound operation battery electric vehicles, hybrid and fuel cell powertrains are viewed as relevant technologies. This statement is further emphasized by the conclusion that city buses are even seen as an early market for polymer electrolyte membrane fuel cell vehicles. [10, p. 22]

3.1.3 Renewable Fuels

As proposed by the authors of this roadmap renewable fuels will not only be important as a blending component to conventional fuel, but also as a substitute, especially for the heavy-duty sector because of their volumetric energy density. [10, p. 2]

It is anticipated that in the medium term (2015-2020) the FAME and bioethanol content in diesel and petrol can reach up to 10% and that algae as a feedstock is a vision for the future. In the long term (2020-2030) a HVO content of around 30% is mentioned. The role of biomethane as a fuel for transportation is seen as unclear, because of the required purification and as converting vehicles is seen as unattractive. A mentioned advantage of hydrogen is that it can be obtained in a variety of ways. It can be produced out of biomethane and water; however, hydrogen is primarily extracted from natural gas; furthermore, it is only projected to fully enter the market in the long term. [10, p. 25-28]

3.2 Roadmap 2025+ (2015)

The timespan covered by the "Eco-Mobility 2025^{plus}" published by A3PS in 2015, is separated as follows: short term (2015-2020), medium term (2020-2025) and long term (2025+). The powertrain technologies in this roadmap are organized into categories in the following order: Advanced thermodynamic powertrains, electric powertrains and fuel cell technologies. [11, p. 3]

3.2.1 Powertrains

As predicted by the previous roadmap, vehicles powered by advanced internal combustion engines have remained dominant and still make up most of the market share. As there are still improvements to be made regarding emissions, it is seen as realistic that diesel as well as gasoline engines can reach a peak efficiency of 50%. Furthermore, the report declared that spark ignition engines operated with natural gas and biogas could reduce CO_2 exhaust emissions by up to 20%, compared to conventional gasoline powertrains. [11, p. 12, 13]

Battery electric and hybrid vehicles are both mentioned in the same chapter. Despite the considerable research and development effort, battery electric powertrains are seen as an attractive technology as there is no local CO_2 emission during driving. Additional benefits include their superior energy efficiency compared to internal combustion engines and the different driving experience. Further research and development are said to still be required, especially for the battery to increase efficiency, reduce cost, improve energy density and substitute rare earth minerals in the long-term perspective. However, it is also reported that battery technology has improved significantly. To maximize the positive effect of battery electric vehicles for the environment, an adequate charging network powered by renewable electricity is indispensable. [11, p. 19, 20]

Compared to the 2011 roadmap the importance of hybrid powertrains is further emphasized as 48V hybrid systems are seen as especially relevant since these can be mass produced in smaller competitively priced vehicles. Moreover, micro hybrid systems are mentioned as a key development area, however their environmental impact is seen as negligible as these systems do not allow for regenerative breaking and sailing. Thus, it is concluded that the hybrid technology with the largest potential to reduce CO_2 emissions is the Plug-In hybrid. [11, p. 19, 22]

While it is mentioned that first fuel cell vehicles were sold in 2014, the roadmap highlights that significant investments in research and development would be essential to fully introduce this technology to the market. Nevertheless, the use in city buses is still considered to be a possible first market for PEM fuel cells. [11, p. 28, 29]

For heavy-duty applications and the bus sector this roadmap comes to the same conclusion as the previous, specifically stating that hybrid systems and battery electric vehicles are seen as relevant for depot-bound operations. However, for long distance transportation battery electric vehicles are seen as not feasible. It is stressed that optimized diesel and natural gas engines, which will be released on the market in the medium-term, are highly significant for heavy-duty vehicles and buses. [11, p. 13, 19, 25]

3.2.2 Renewable Energy Carriers

This roadmap further goes into detail about different fuels and their production such as Fischer Tropsch fuels, biomethane, bioethanol and hydrogen storage, production and refueling infrastructure. It is also mentioned that following biofuels are already deployed on the market: HVO, bioethanol from sugar and starch and FAME produced from vegetable oil, animal fats and used cooking oil. The roadmap predicts that the importance of HVO as a fuel will rise in the future. Because of the conflict with food production, a change in resources for bioethanol is seen as necessary; however, the use of lignocellulose as a feedstock for bioethanol production is only projected to reach market maturity from 2025 onwards. It is reported that with the target of 10% of the total energy consumption of the transportation sector coming from renewable sources in 2020, set by the Renewable Energy Directive, the use of different renewable energy carriers becomes necessary. [11, p. 50-55]

3.3 Roadmap 2030+ (2018)

The structure of the roadmap "Eco-Mobility 2030^{plus}" published by the A3PS in 2018, is very similar to the roadmap of 2015. However, the chapter for the internal combustion engine includes the use of renewable fuels. [12, p. 3]

3.3.1 Powertrains

As in the previous roadmaps, it is projected that in the medium and long term advanced internal combustion engines and hybrid systems remain the most dominant powertrains. To comply with new emission regulations and to reduce fuel consumption, further improvements to diesel and gasoline must be made. It is also mentioned that multi fuel operation demands little additional research but offers significant potential to reduce emissions. Similar to previous roadmaps, regarding trucks and buses optimized diesel and natural gas engines are still seen as relevant. [12, p. 12, 13]

As the first battery electric and hybrid systems are available on the market, it is stressed that more research is necessary to make these technologies more affordable. Whereas Plug-In hybrid electric vehicles can produce less emissions than conventional hybrid systems, because of the higher battery capacity, pure electric vehicles offer the benefit of emitting no tailpipe emission during road use. The roadmap also mentions the beginning of the sale of battery powered heavy-duty vehicles and the possibility that trucks with a range of up to 800km would be available from 2020 onwards. [12, p. 25, 26, 28, 29]

For fuel cell vehicles the high production cost is listed as the hardest obstacle to overcome. Also, the use of fuel cells as range extenders is discussed. [12, p. 34, 35]

3.3.2 Renewable Fuels

This roadmap further elaborates on renewable energy carriers including fuels such as methanol, DME and OME from biomass, algae-based biofuels and e-fuels; however, it is not mentioned when these fuels will reach market maturity. Fischer-Tropsch fuels produced from biomass are projected to be deployed on the market in the long term. Renewable fuels are mentioned to be especially important for sectors which are hard to electrify such as heavy-duty operations, but further research is needed to develop biofuels made from waste, algae, lignocellulose biomass, CO_2 and hydrogen. [12, p. 19-22]

3.4 Roadmap 2030+ (2022)

The “Austrian Roadmap for Sustainable Mobility – a long-term perspective” released in 2022 by the A3PS, stands out because of its entirely different structure compared to its predecessors. The discussed powertrains are listed in the following order: battery electric powertrains, fuel cell technologies hybrid powertrains. For the first time the internal combustion engine does not have its own chapter and is only part of the hybrid powertrain section. However, it is still acknowledged that thermodynamic powertrains will remain the most widely spread technology, but the market share of advanced propulsion systems is continuously increasing. [9, p. 3, 11]

3.4.1 Powertrains

It is recognized that although battery electric vehicles are already on the market, improvements to the affordability and battery technology must be made to increase the impact on the environment. [9, p. 13]

The roadmap acknowledged that significant progress on fuel cell technologies has been made, and first passenger cars have been deployed but the cost of those vehicles is still a big obstacle regarding the introduction into the mass market. Similarly further improvements to make hydrogen as a fuel economically feasible, need to be made, as well as expanding the hydrogen refueling station network. [9, p. 23-30]

To meet the ambitious emissions targets, hybrid and internal combustion engine powered vehicles need to become more energy efficient, as well as using renewable fuels and hydrogen as the power source. This can be achieved by operating the engine in hybrid vehicles to function as a fuel converter. Because of the large number of these vehicles, the gain in fuel efficiency allows for significantly lower CO_2 emissions. In contrast to the previous roadmaps the use of CNG as a possible technology for passenger vehicles and heavy-duty applications to reduce CO_2 emissions is not mentioned in this roadmap. [9, p. 33, 34]

Engines operated on hydrogen or synthetic fuels and fuel cell vehicles are listed as relevant research and development areas for light and heavy commercial vehicles. It is also reported that battery electric buses and trucks with a range of up to 400km have been released on the market. [9, p. 14, 34]

3.4.2 Renewable Energy Carriers

In this roadmap it is stressed that renewable energy provides the largest potential to reduce the amount of GHG emitted. It highlights that e-fuels and hydrogen have superior energy density to batteries and thus, internal combustion engines will still be necessary to power heavy-duty vehicles. It is also suggested that ethanol blends of up to 20% could reduce emissions significantly. The revised version of the Renewable Energy Directive is also listed as the main driver for the deployment of renewable energy carriers. Furthermore, the roadmap provides an extensive overview of the hydrogen production via electrolysis, storage and refueling stations. [9, p. 40-48]

4 Climate Acts and Politics

The transportation sector is one of the major contributors to climate change and air pollution. Thus, political efforts have been made to reduce the amount of GHG emissions produced by road vehicles and to increase the share of renewable energy in the transportation sector. As a result, climate agreements were introduced on an international level by the United Nations and the EU.

4.1 Kyoto Protocol

The first international agreement to limit and reduce the amount of GHG emitted was the Kyoto Protocol which was signed in 1997. In this convention the EU and 37 industrialized countries agreed to lower their GHG emissions by an average of 5% between 2008 and 2012 compared to the levels in 1990. [13]

To fulfill the targets delineated by the Kyoto Protocol, Austria agreed to reduce the annual greenhouse gas emissions between 2008-2012 by 13%. [14, p. 7]

This agreement was extended in Doha 2012, from 2013 until 2020. In this the EU established the objective to reduce emissions compared to 1990 by 20%. [15]

4.2 Paris Agreement

The Paris Agreement was adopted by 195 parties in 2015 and came into action in November 2016. The goal formed by this convention is, that compared to pre-industrial levels the average global temperature should rise no more than 2°C and through additional efforts should be kept under 1.5°C. [16]

4.3 European Green Deal

To reach the targets set by the Paris Agreement, the EU introduced the European Green Deal in 2019. The objective of this strategy is to lay out the strategic transition path to become climate neutral by 2050. [17]

4.4 Fit for 55

To achieve climate neutrality by 2050, several laws were introduced in 2019. This package is called Fit for 55. With this climate act the EU needs to reduce its emission of GHG by 55% until 2030. The package sets binding emission reduction targets for each member state. Furthermore, it includes new progressive standards for exhaust gas emissions for cars, trucks and vans. By 2035, newly registered cars and vans will be prohibited from emitting any CO_2, which corresponds to a direct ban of the internal combustion engine due to the European tank-to-wheel evaluation of the vehicle emissions. It was adopted as part of the new fleet emission regulations in 2023. [18]

4.5 Renewable Energy Directives

4.5.1 Renewable Energy Directive I

The first Renewable Energy Directive (RED I) was adopted in 2009 by the EU and stated that in 2020, 10% of the total energy consumption of the transportation sector in each member state has to be renewable. [19]

4.5.2 Renewable Energy Directive II

The Renewable Energy Directive II (REDII) is a revision of RED I and sets the obligatory target that at least 14% of the total energy consumed in 2030 in the transportation sector needs to be renewable. Additionally, the directive outlines minimum shares for the consumption of advanced biofuels and biogas of the total energy consumed, which are manufactured out of advanced feedstock. The EU passed the Renewable Energy Directive II in December of 2018 and entered it into force in July of 2021. [20]

4.5.3 Renewable Energy Directive III

The Renewable Energy Directive III (RED III) is a recast of RED II, adopted in 2023. It increased the share of renewable energy of the transportation sector to 29% in 2030, with a further reduction of 14.5% in greenhouse gas intensity. The share of biogas and advanced biofuels was also adapted to at least 1% in 2025 and 5.5% in 2030, with a minimum share of 1% coming from non-biological origin. [21]

4.6 Fleet Emission Regulations

In the Regulation (EU) 443/2009 the average target for new passenger cars is set to 130g CO_2/km with the aim of reaching 95g CO_2/km for 2020 [22]. In April of 2019, the European Parliament set the fleet target for 95g CO_2/km for cars and 147g CO_2/km for light commercial vehicles with the introduction of Regulation (EU) 2019/631. From 2025, the target would be reduced by 15% for both categories and from 2030 onwards a further decrease of 37.5% for cars and 31% for light commercial vehicles from the 2021 reference values were set. This directive was passed as a contributing measure to reach the targets set out by the Paris Agreement. [23]

To facilitate the announcement from the Fit for 55 package the Regulation (EU) 2023/851 was passed in 2023 as an amendment to Regulation (EU) 2019/631, which increased the reduction of emissions for 2030 to 55% and 50% respectably. Furthermore, from 2035 onwards both the fleet target for passenger and light duty commercial vehicles was set at a CO_2 emission reduction of 100%. [24]

4.7 Alternative Fuels Infrastructure Directive

First introduced in 2014 and revised in 2023 the Alternative Fuels Infrastructure Directive, provides the framework for the construction of a new trans-European network for refueling and charging stations specifically for alternatively powered vehicles. This includes mandatory distance and power output targets for electric vehicle recharging stations, along with public hydrogen refueling stations that must be accessible every 200km along the TEN-T core network and in every urban node. [25]

5 Vehicle Statistics

Since the first roadmap was published, the share of alternative propulsion systems of newly registered vehicles has diversified significantly in Austria and the EU, leading to an ongoing change in the vehicle fleet.

5.1 New Vehicle Registrations

5.1.1 Austria

5.1.1.1 Passenger Cars

In Austria the share of newly registered passenger cars equipped with alternative propulsion systems has increased significantly as seen in Figure 1. Petrol engines remain the first choice for passenger cars, whereas the share of diesel engines has continuously declined from 2017 to 2024 as depicted in Figure 2. This decline compared to gasoline vehicles can be linked to the Volkswagen diesel scandal, which was made public in September of 2015. The perception of diesel engines shifted as concerns were raised regarding the air quality and public health, due to the emission of NOx and particulate matter. As a result, discussions regarding a possible ban of diesel vehicles in Austrian and European cities originated [26], [27]. In 2023 for the first time there were more new battery electric vehicles registered than diesel ones. The rise in battery electric vehicles can be particularly attributed to purchase subsidies and tax benefits put in place by the Austrian government for consumers and companies, which include for instance the exemption from the standardized consumption tax (NoVA) and up until April 2025, the engine related insurance tax. [28], [29] Hybrid systems however, are the most common alternative powertrains, of which petrol hybrid electric cars are the most popular as presented in Figure 3. The number of cars powered by natural gas has decreased, while vehicles utilizing hydrogen and LPG as energy source only make up a negligible amount of newly registered vehicles. [30]

The total drop in new passenger vehicle registrations after 2019 was caused by the Covid-19 pandemic. As the government issued lockdowns, vehicle production halted and dealerships were forced to close, the registration numbers plummeted in 2020. [31, p. 6]

Furthermore, the resulting semiconductor and supply chain shortages in 2021 and 2022 resulted in a further decrease in new vehicle registrations. [32, p. 6], [33, p. 4]

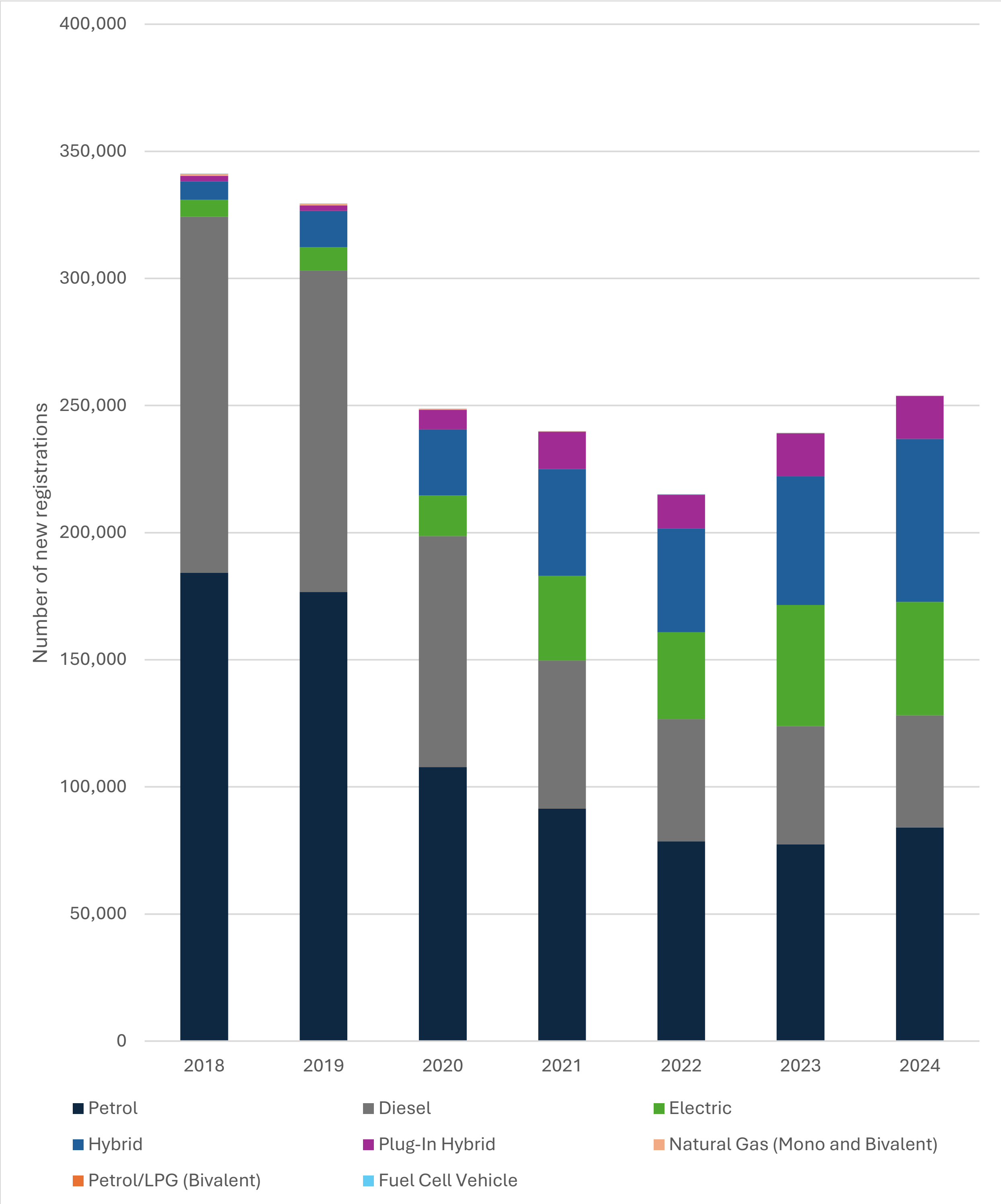

Figure 1: Newly Registered Cars in Austria by Powertrain; own illustration [30]

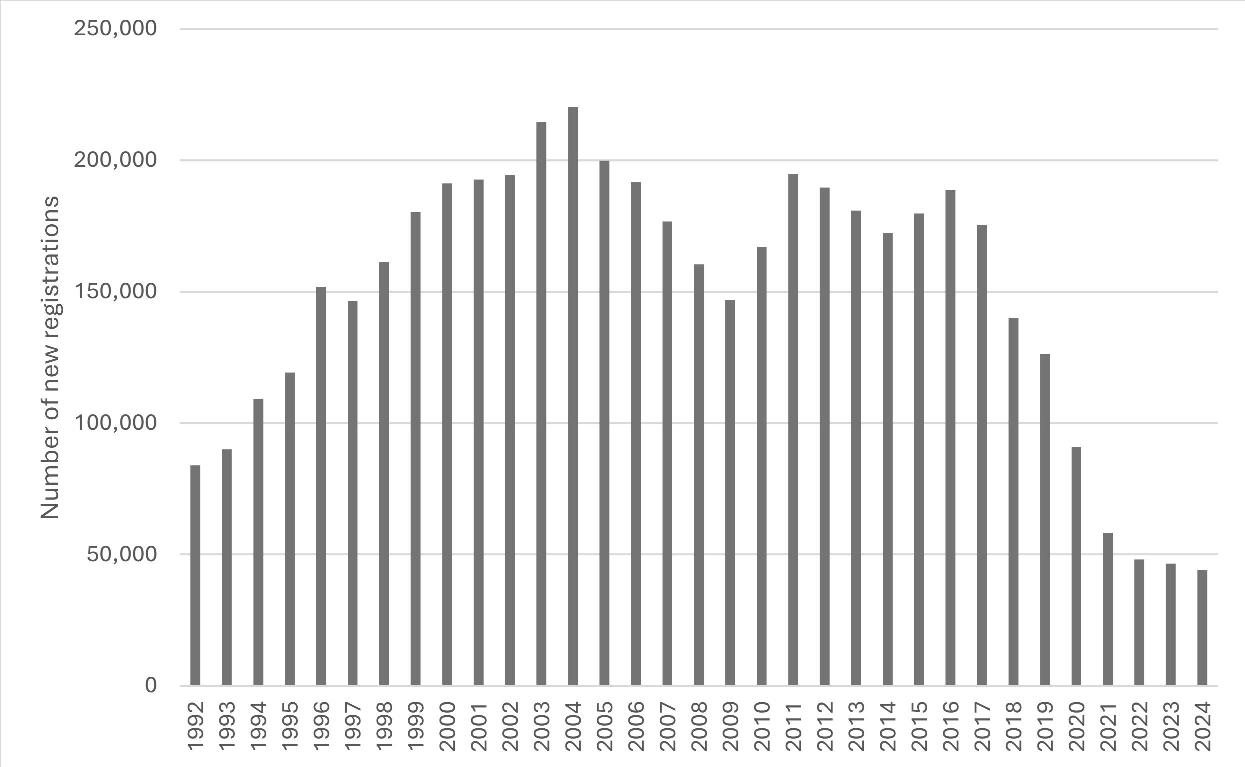

Figure 2: New Registrations of Diesel Passenger Vehicles in Austria; based on [34] and translated

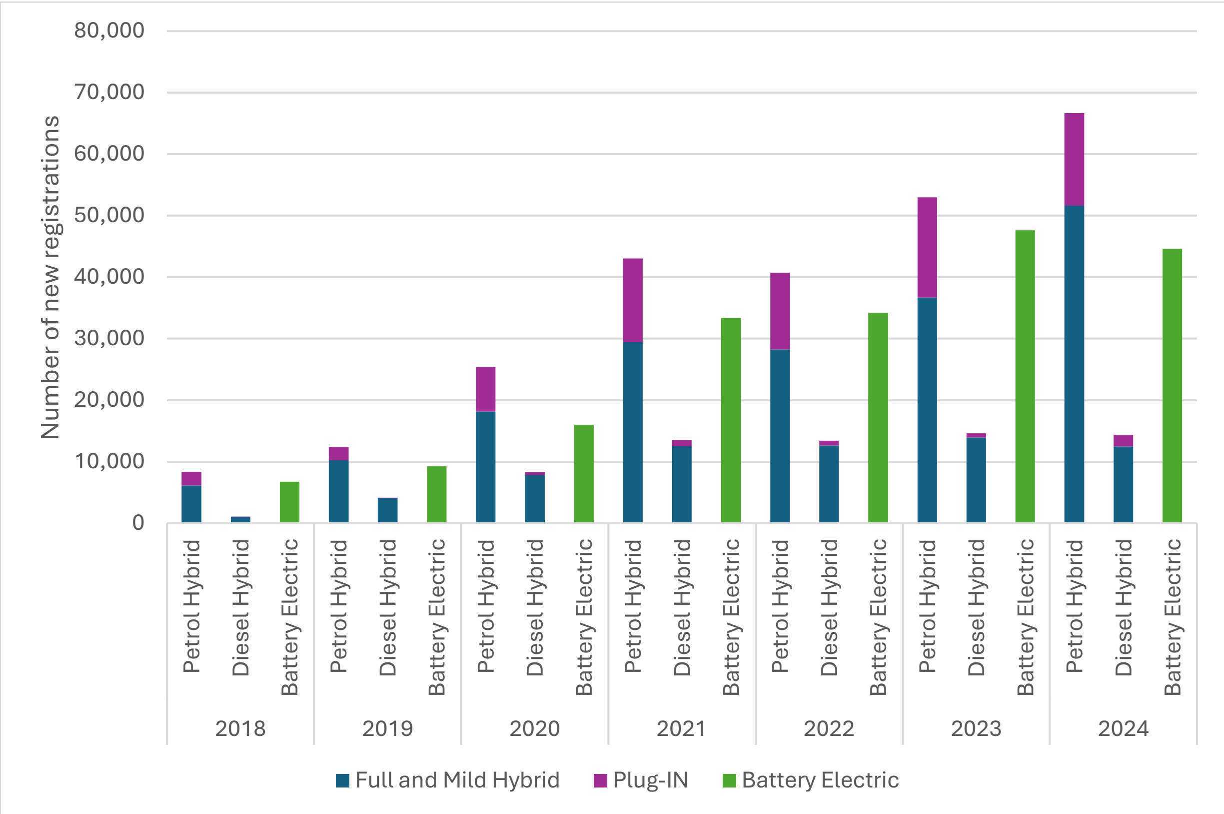

Figure 3: Comparison of Newly Registered Alternatively Powered Vehicles in Austria; own illustration [30]

5.1.1.2 Trucks and Buses

Figure 4 and Figure 5 highlight the ongoing dominance of diesel engines for the heavy-duty and bus sector. However, from 2012 onwards electric powertrains have continuously been the most common alternative truck propulsion system. In 2023 electric powertrains made up over 80% of newly registered alternatively powered trucks, which is illustrated in Figure 6. [35–37]

Regarding buses, as depicted in Figure 7, until 2013 liquid and natural gas engines were the prevailing advanced powertrain solutions. Starting in 2012 electric buses gained relevancy and from 2014 onwards, besides an exception in 2017, hybrid diesel and electric buses became the leading alternative drivetrains in Austria. [36, p. 6.13]

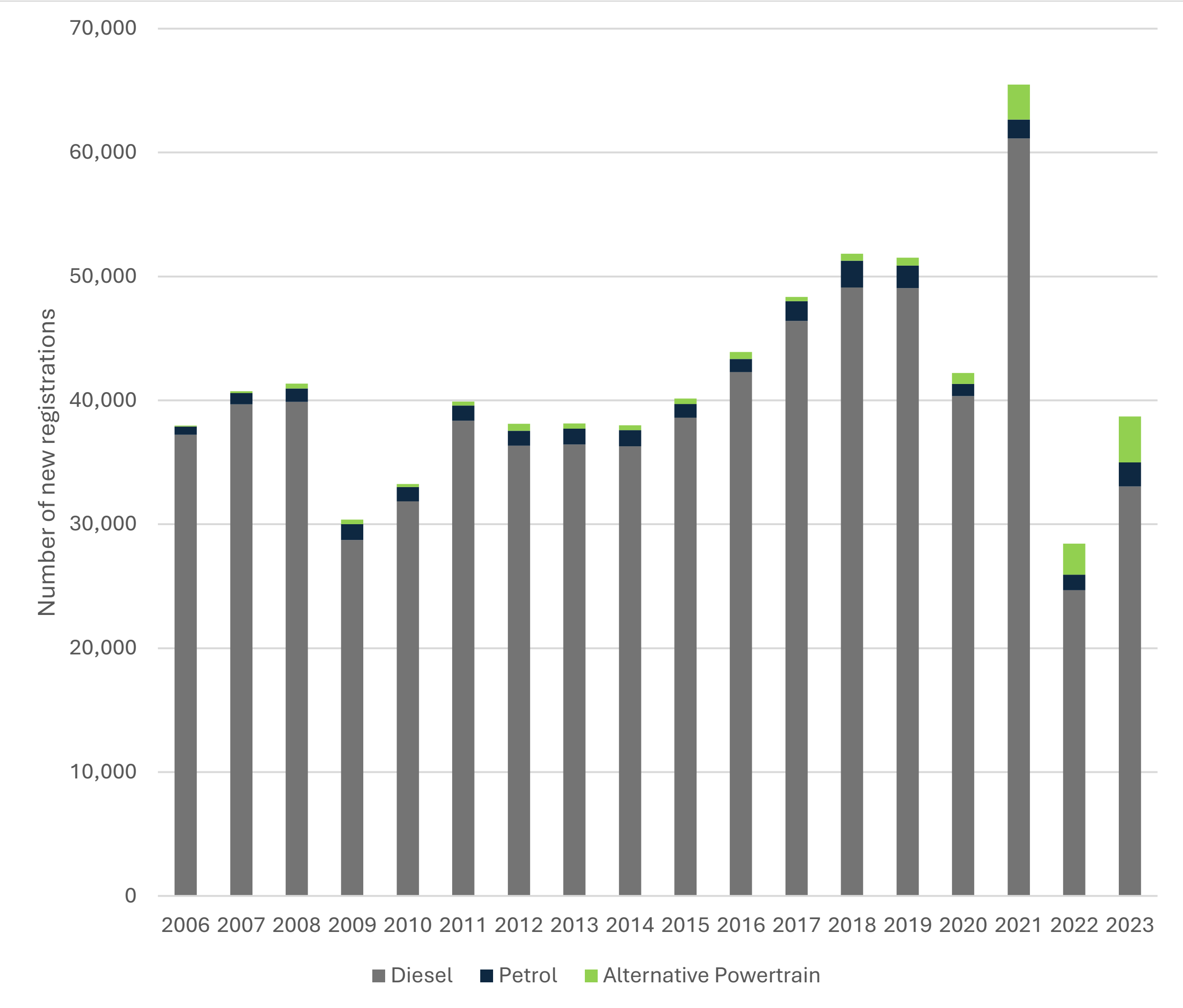

Figure 4: New Registrations of Trucks in Austria by Powertrain from 2006 to 2023; based on [37] and translated

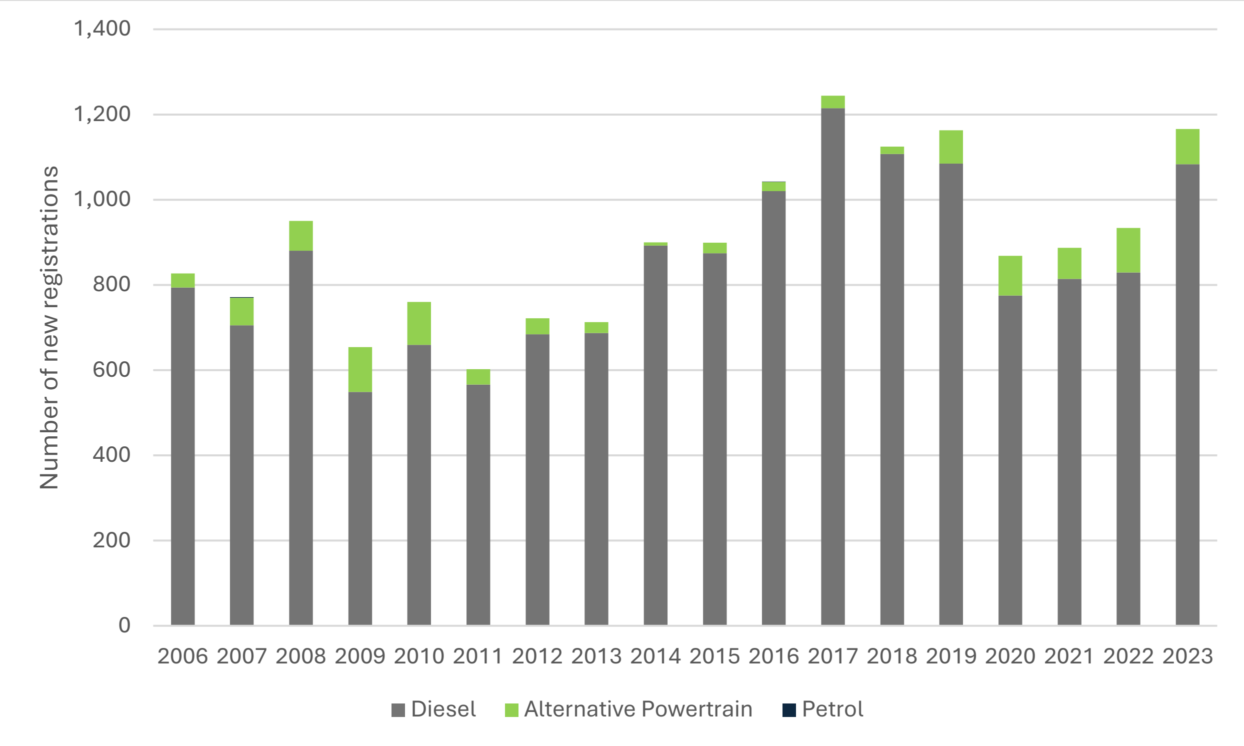

Figure 5: New Registrations of Buses in Austria by Powertrain from 2006 to 2023; based on [35] and translated

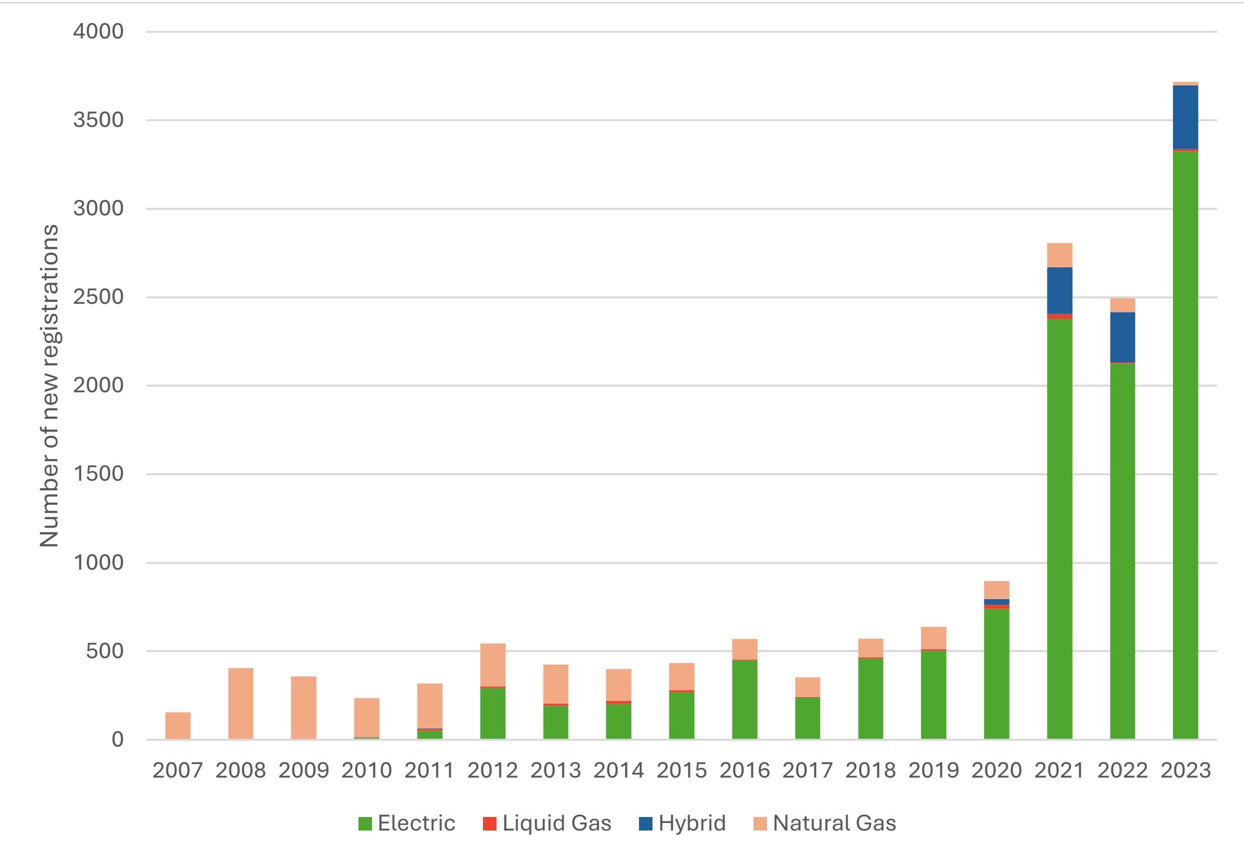

Figure 6: New Truck Registration of Selected Alternative Powertrains; based on [36, p. 6.13] translated

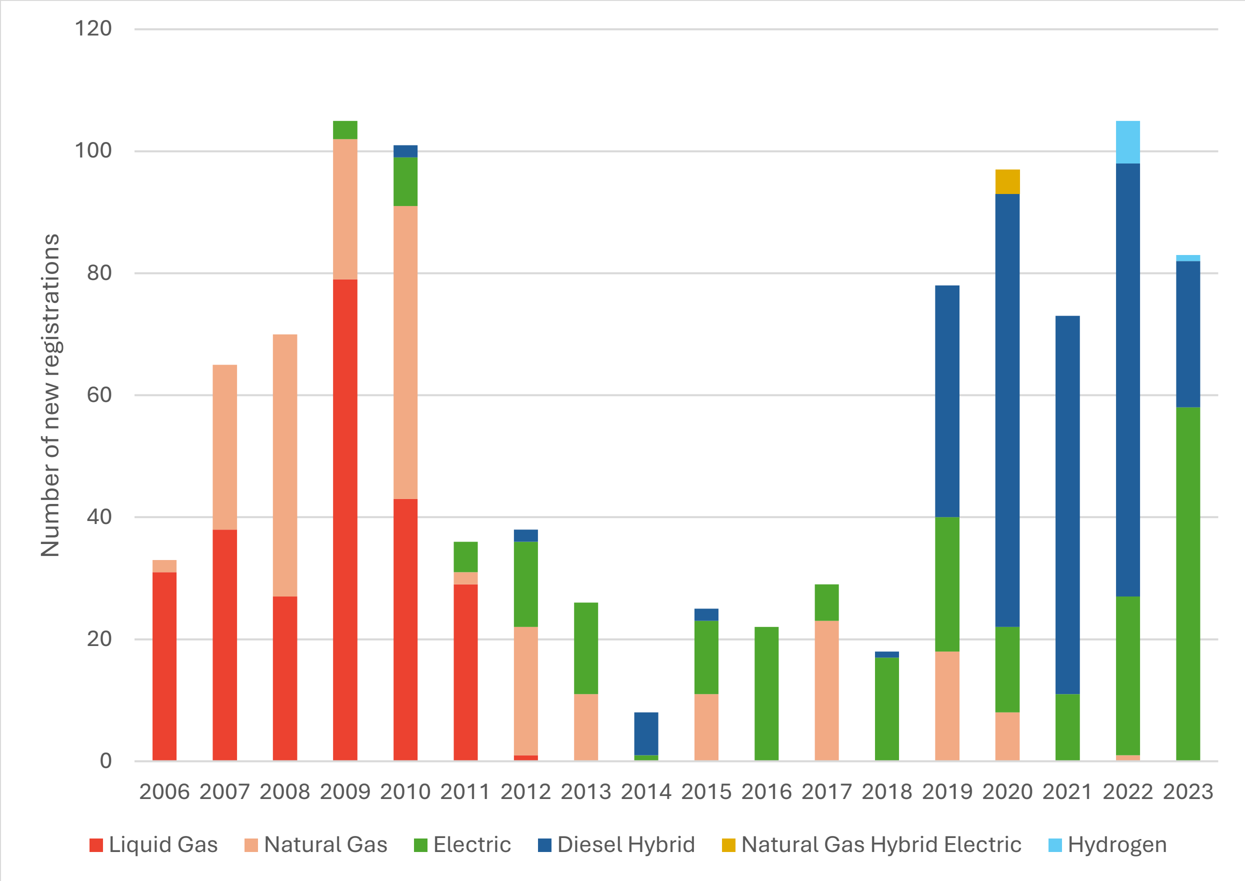

Figure 7: New Registrations of Alternatively Powered Buses in Austria; based on [36, p. 6.16] translated

5.1.2 European Union

5.1.2.1 Passenger Vehicles

In the EU newly registered passenger vehicles have become substantially more diverse regarding their powertrain. Battery electric, plug-in, full and mild hybrid systems have over time increased their market share significantly as shown in Figure 8. In contrast to the development of electric and hybrid vehicles, the number of new registrations of diesel cars, has declined considerably since 2016. The decline in the number of diesel car registrations can be linked to the diesel scandal and the resulting announcement of driving bans for various diesel cars in cities across Europe [27]. As a consequence, petrol powered vehicles became the most common powertrain. New registration numbers of CNG vehicles declined, while the number of LPG vehicles has remained relatively constant, see Figure 9. [38], [39]

As previously mentioned in chapter 5.1.1 the decline in vehicle registrations after 2019 can mainly be attributed to the Covid-19 pandemic and supply chain shortages. [31–33]

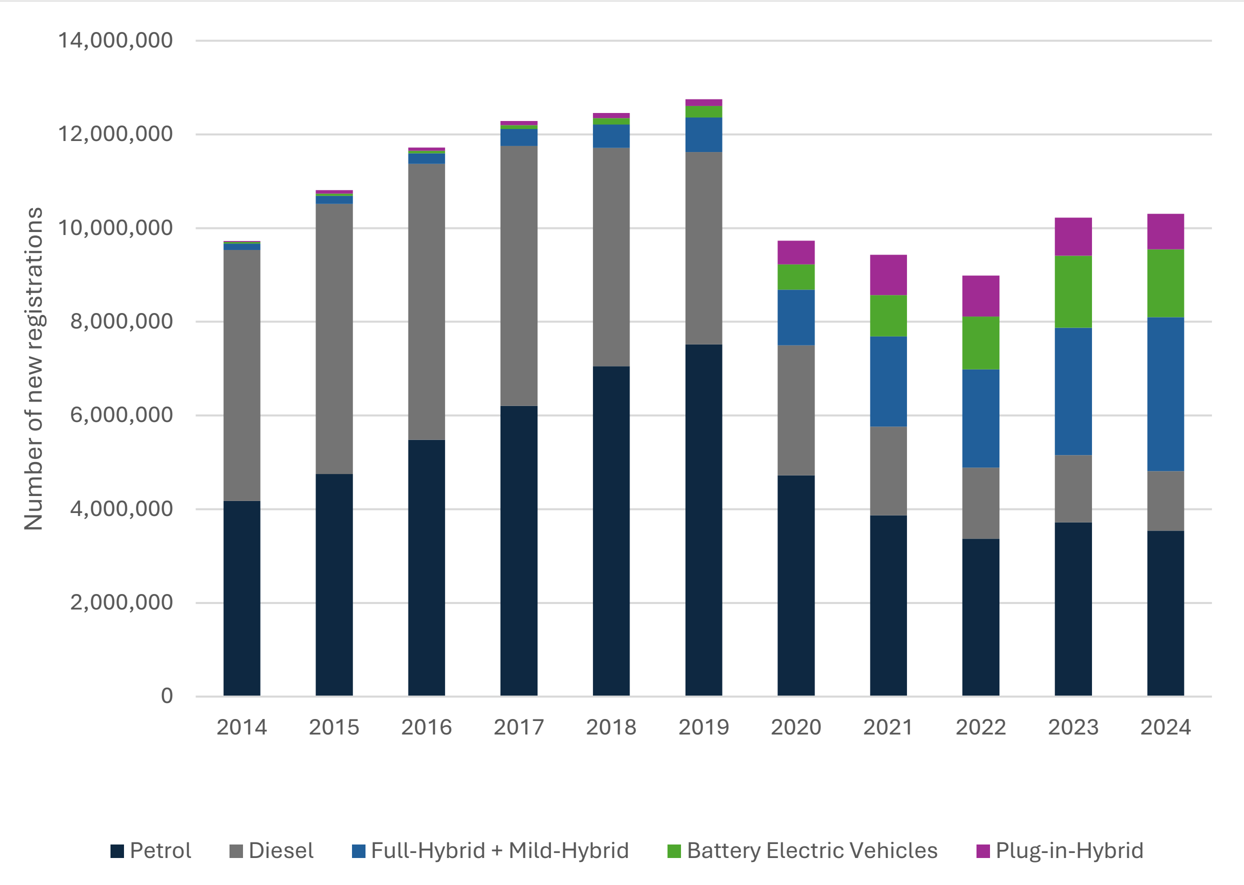

Figure 8: New Passenger Car Registrations by Powertrain in the EU; based on [39] and translated

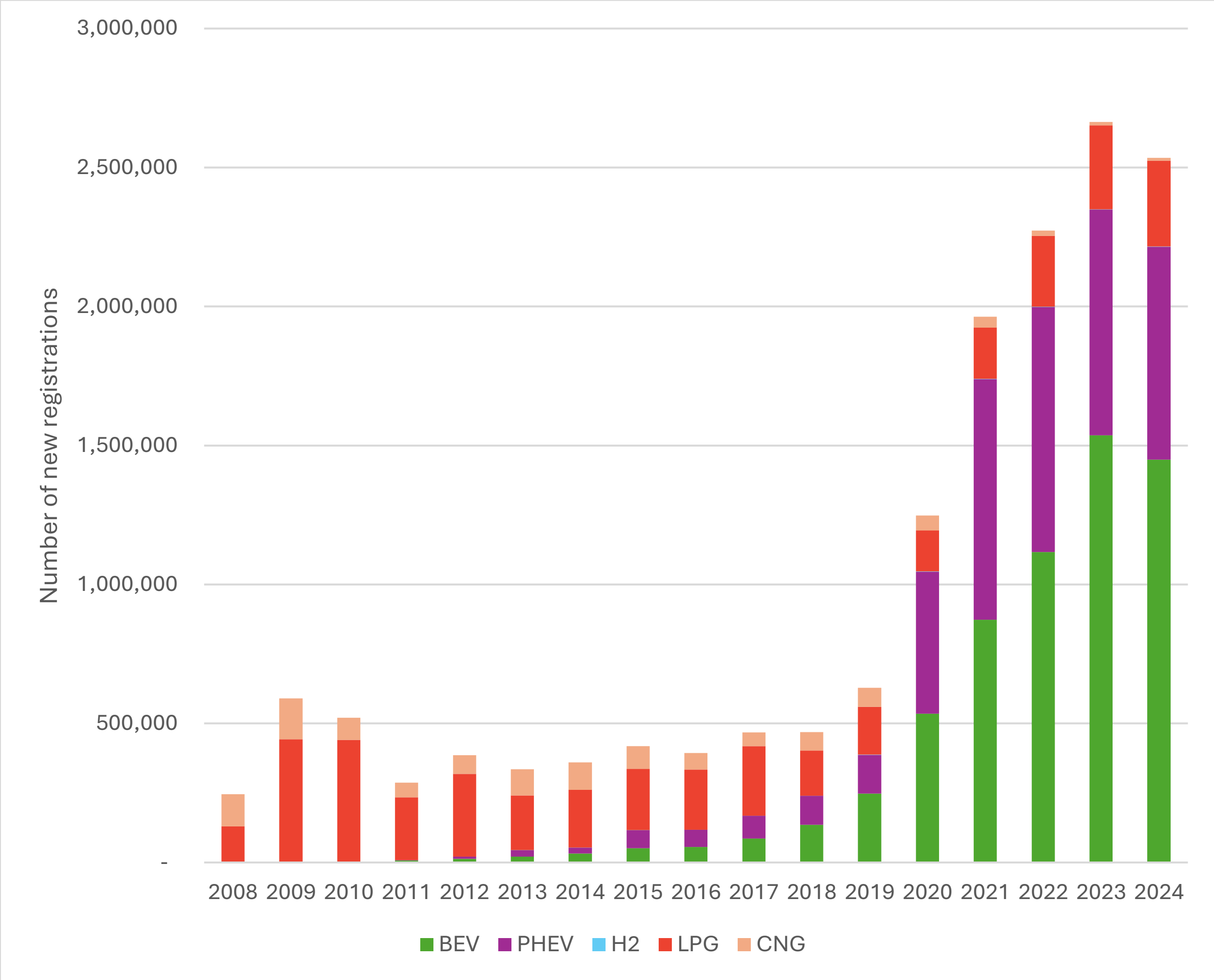

Figure 9: Number of Newly Registered Alternative Fueled Passenger Cars in the EU; based on [38]

5.1.2.2 Trucks and Buses

New trucks in the EU are, as portrayed in Figure 10, still predominantly powered by diesel engines. CNG powertrains were up until 2023 the most common newly registered alternative drivetrains; however, as shown in Figure 11 the share of battery electric trucks has steadily increased and thus, in 2024 overtook CNG. The overall share of alternative powertrains in 2024 was around 4.5%, with hydrogen and plug-in technologies only making up an insignificant share as depicted in Figure 12. [38], [40]

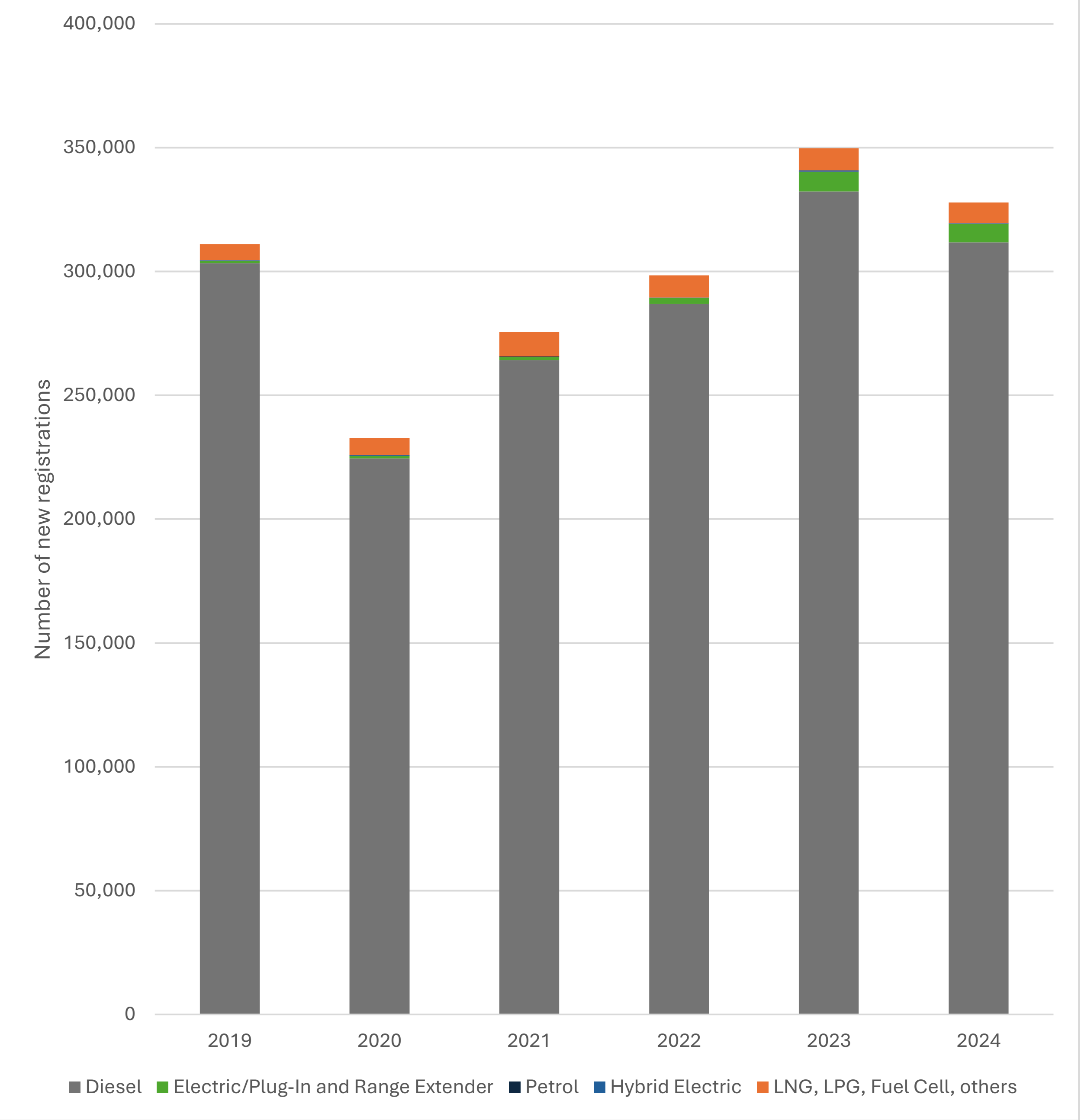

Figure 10: New Truck Registrations in the EU by Powertrain; based on [40] and translated

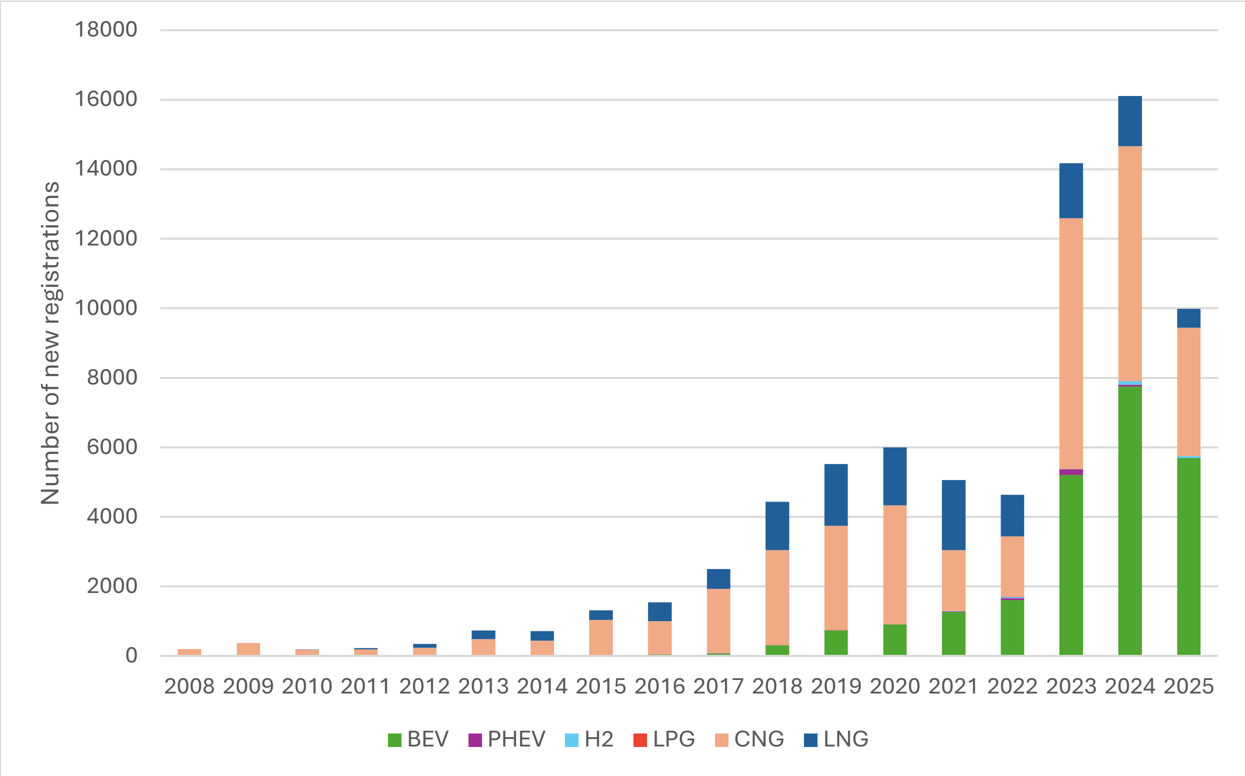

Figure 11: Number of Newly Registered Alternative Fueled Trucks in the EU; based on [38]

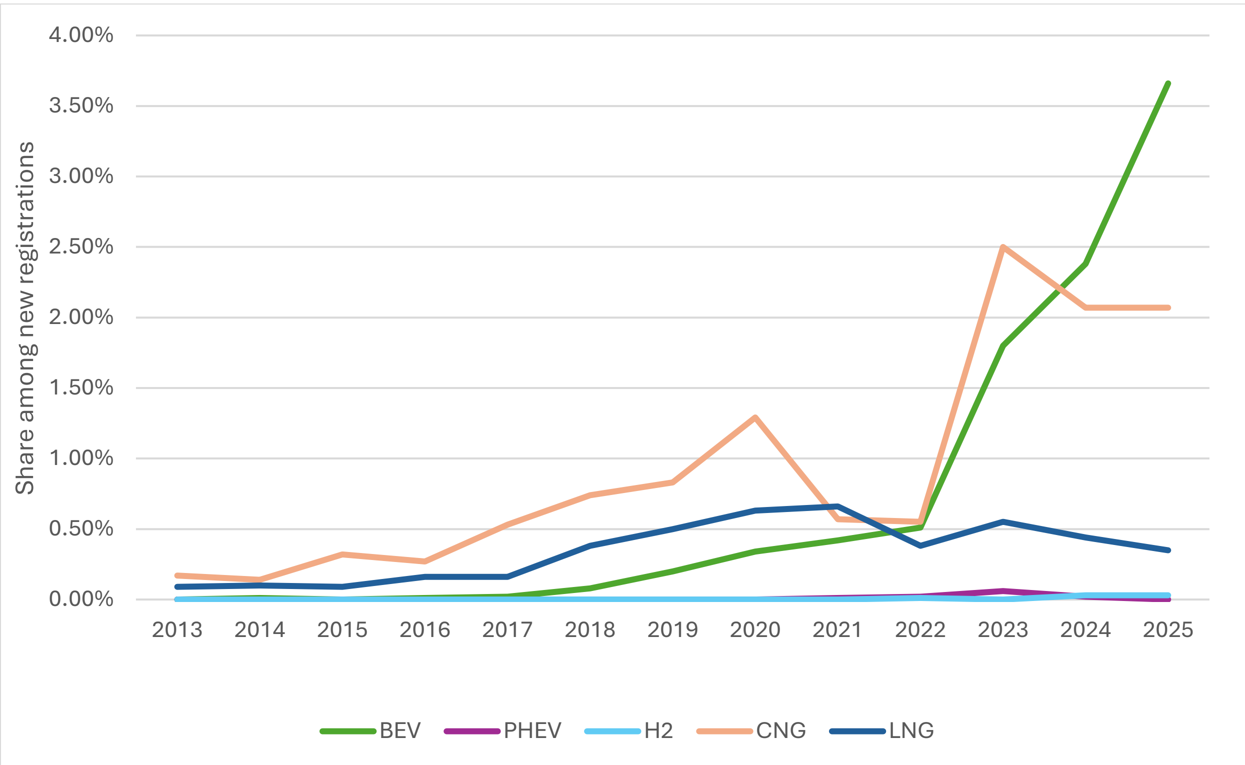

Figure 12: Newly Registered Alternative Fueled Trucks as a Percentage of the Total Number of Registrations in the EU; based on [38]

Up until 2018 the majority of newly registered alternatively powered buses in the EU were operated with CNG, as seen in Figure 13. Since 2019 battery electric buses have taken over as the most common alternative to diesel engines. Figure 14 shows that from 2013 to 2024 CNG vehicles made up 3-8.5% of new bus registrations, while in 2024 battery electric buses accounted for over 18% of all new bus registrations. [38]

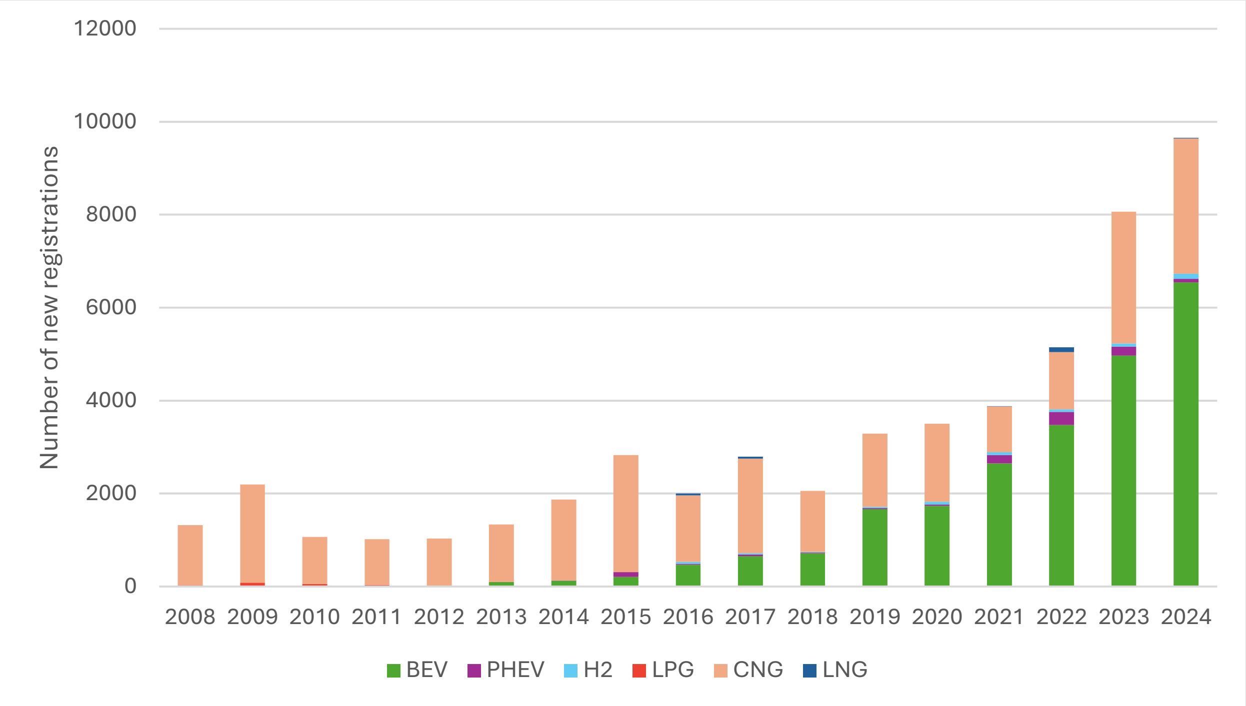

Figure 13: Number of Newly Registered Alternative Fueled Buses in the EU; based on [38]

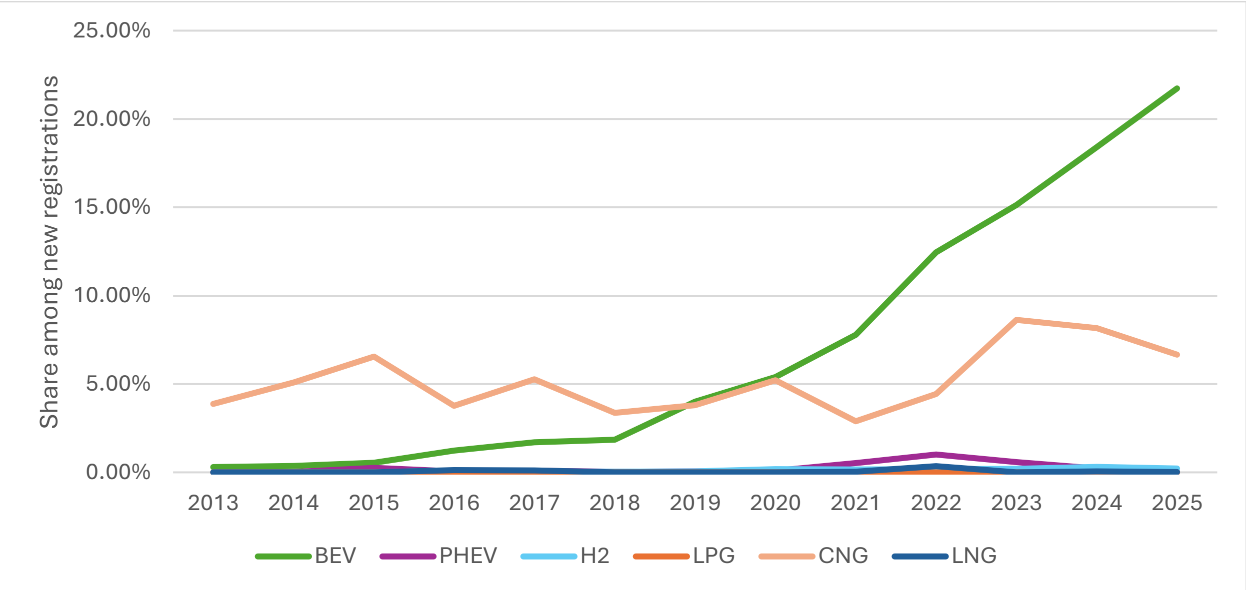

Figure 14: Newly Registered Alternative Fueled Buses as a Percentage of the Total Number of Registrations in the EU; based on [38]

5.2 Existing Vehicle Fleet

Alternative propulsion systems recently made up a considerable share of new vehicle registrations. As the development of diversifying the existing vehicle fleet is a gradual process, it will take time, until the full effect of the transformation is reflected in the overall number of vehicles.

5.2.1 Austria

5.2.1.1 Passenger Cars

The Austrian car fleet has overall increased since 2019. Despite steadily declining numbers of diesel engines, they have remained the most common powertrain as illustrated in Figure 15, followed by petrol powered cars, whose number has also decreased since 2022. The share of alternatively powered vehicles, on the other hand, has increased over the years and is essentially made up of hybrid and battery electric vehicles in the following order: petrol hybrid, battery electric and diesel electric cars. LPG and CNG passenger cars did not make up a significant share, and the number has also been declining since 2019, thus in 2024 less than 5000 of these vehicles were registered. The amount of hydrogen vehicles has increased since 2019 but still only 62 were registered in 2024. [30]

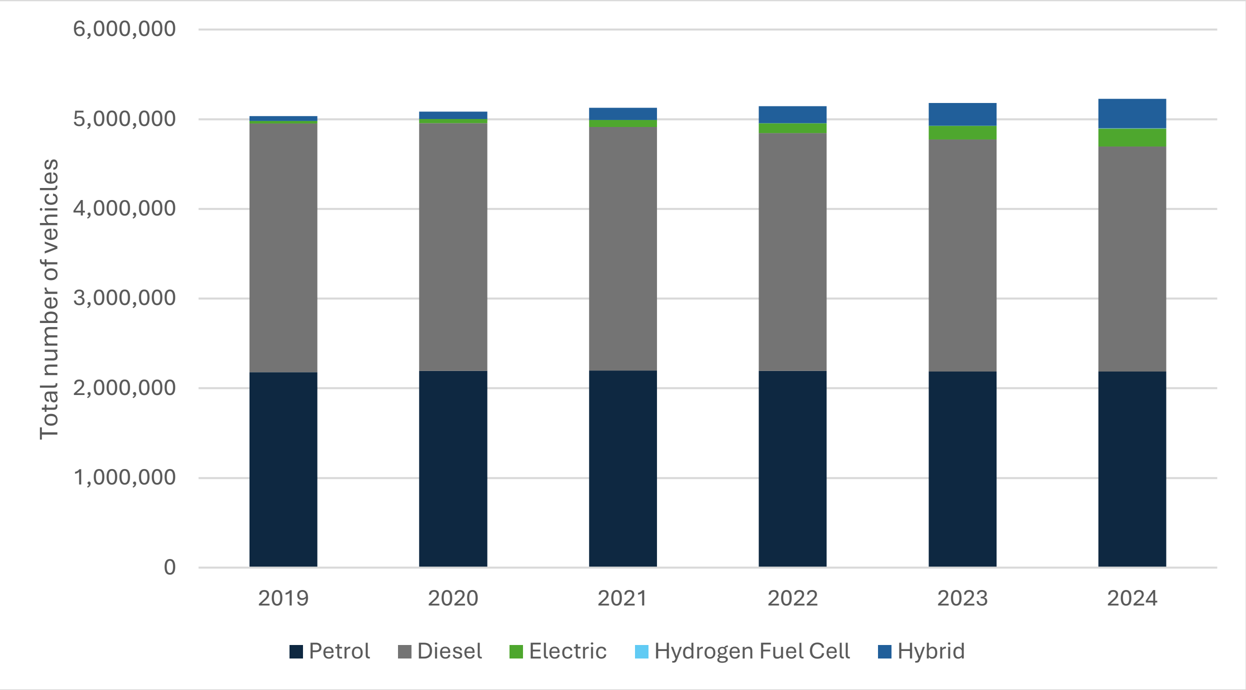

Figure 15: Austrian Car Fleet by Powertrain; own illustration [30]

5.2.1.2 Trucks and Buses

The number of electric commercial vehicles in Austria has increased steadily; however, compared to the total fleet the number remains insignificant, see Figure 16 and Figure 17, with the most of these vehicles being light commercial vehicles. [41], [42]

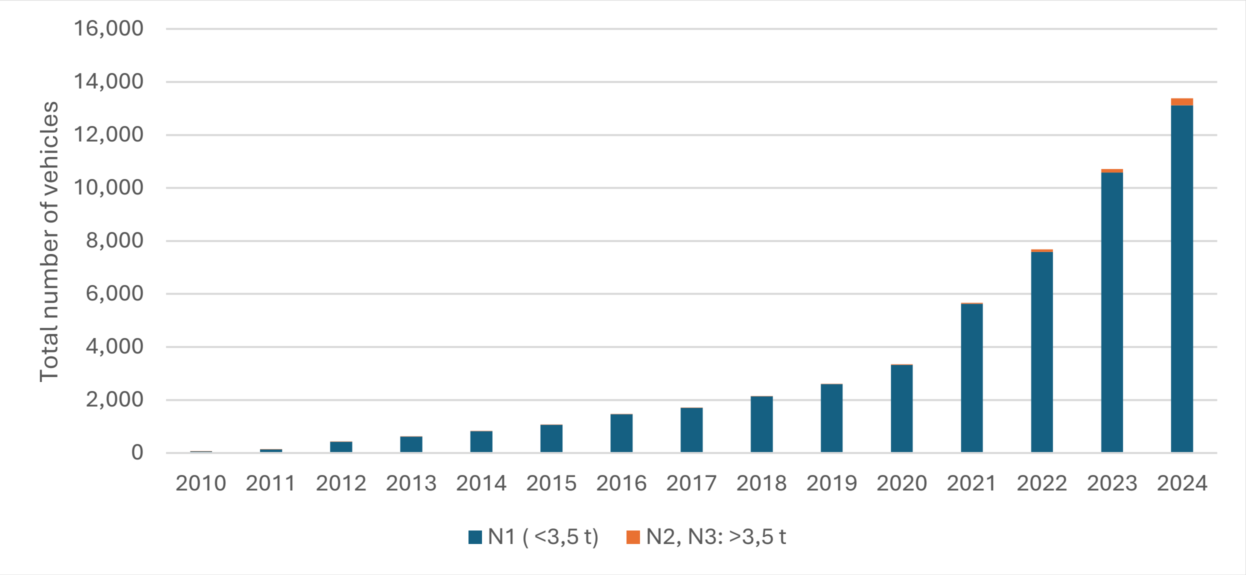

Figure 16: Electric Commercial Vehicle Fleet in Austria; based on [41] and translated

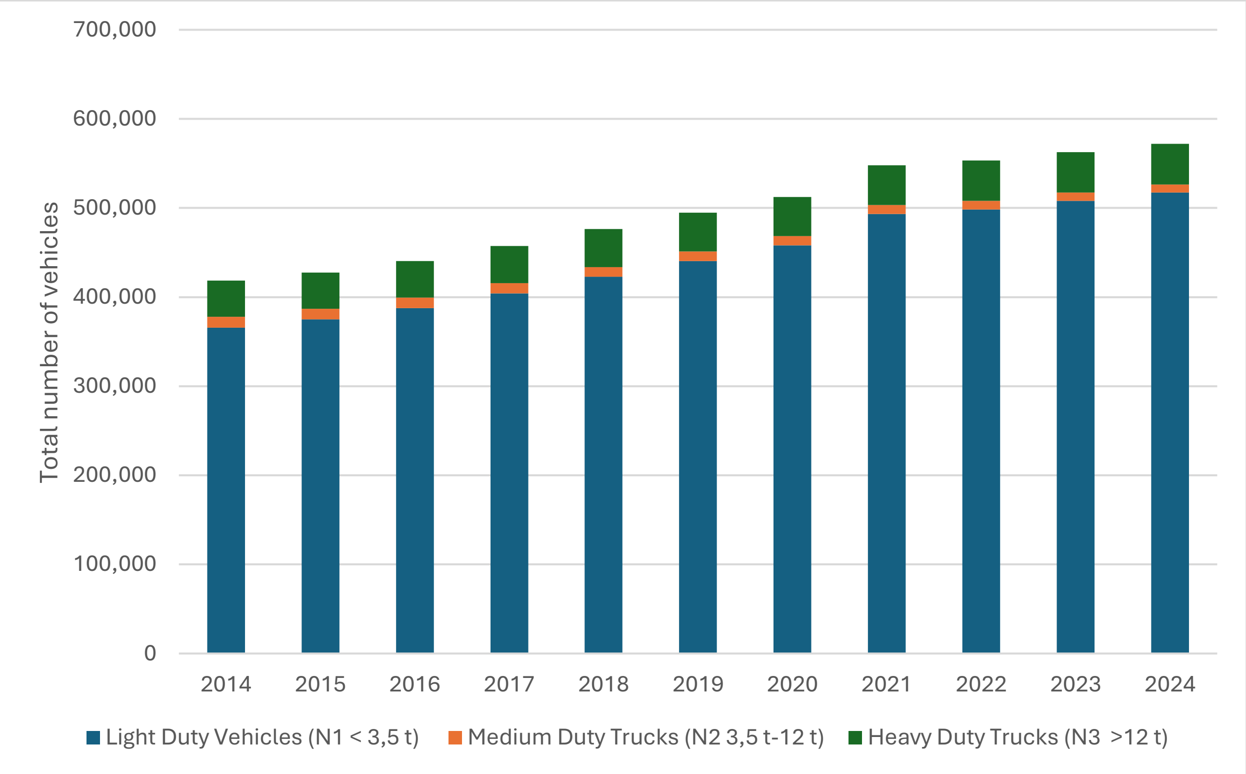

Figure 17: Commercial Vehicles Fleet in Austria; based on [42] and translated

The Austrian electric bus fleet increased more gradually but still the share among the total number of buses is comparably little, as shown in Figure 18 and Figure 19. [43], [44]

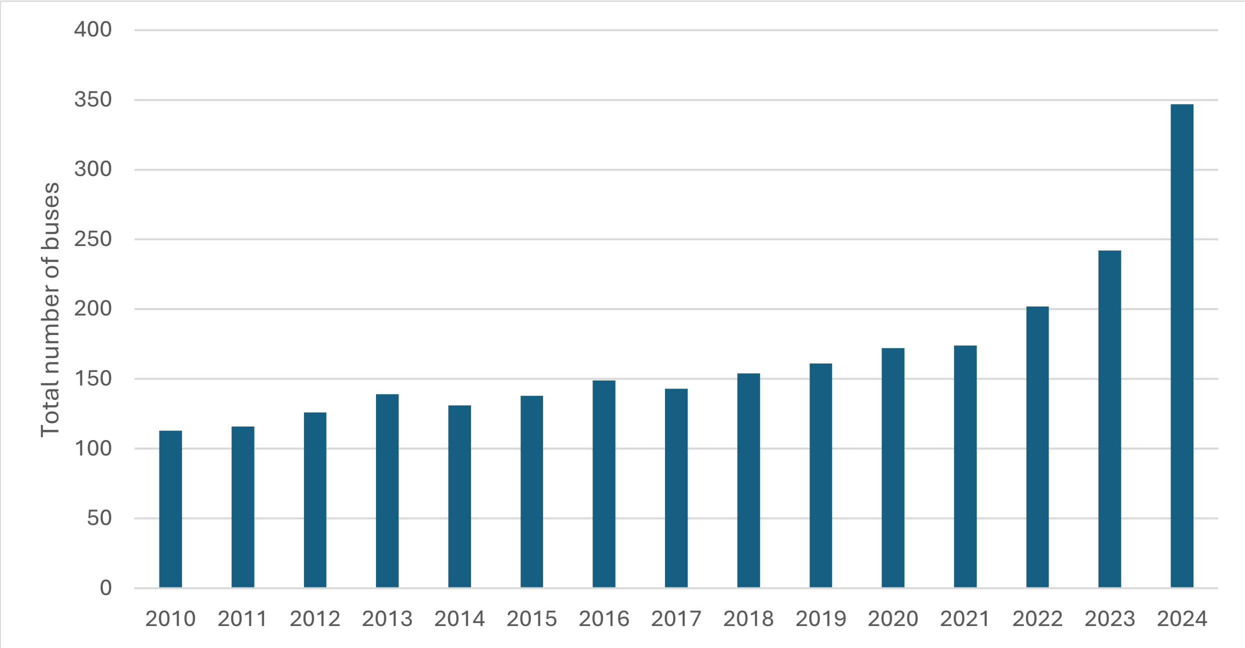

Figure 18: Fleet of Electric Buses in Austria; based on [44] and translated

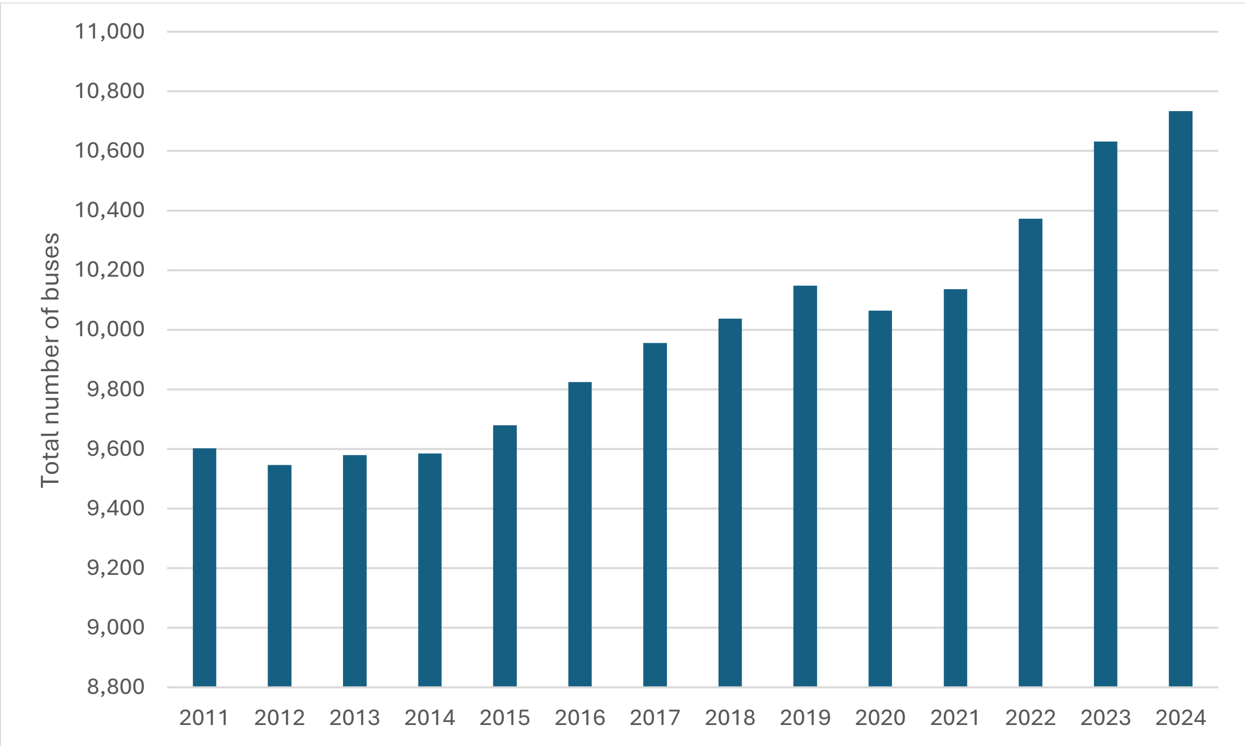

Figure 19: Bus Fleet in Austria; based on [43] and translated

5.2.2 European Union

5.2.2.1 Passenger Cars

The share of diesel and petrol cars in the vehicle fleet of the EU declined from 2022 to 2023 as seen in Figure 20, but still makes up by far the largest part of the fleet. While the share of mild and full hybrid and battery electric powertrains grew, the amount of Plug-In hybrids doubled (2022: 1%, 2023: 2.1%). Figure 21 and Figure 22 highlight that LPG makes up the largest share among alternatively powered vehicles, over six out of the eight million vehicles in 2024 however, were registered in Poland or Italy. [45], [46] Natural gas-powered vehicles are more common in other EU countries than in Austria, as these made up over 3% of total passenger cars in the EU in 2023. [38], [47]

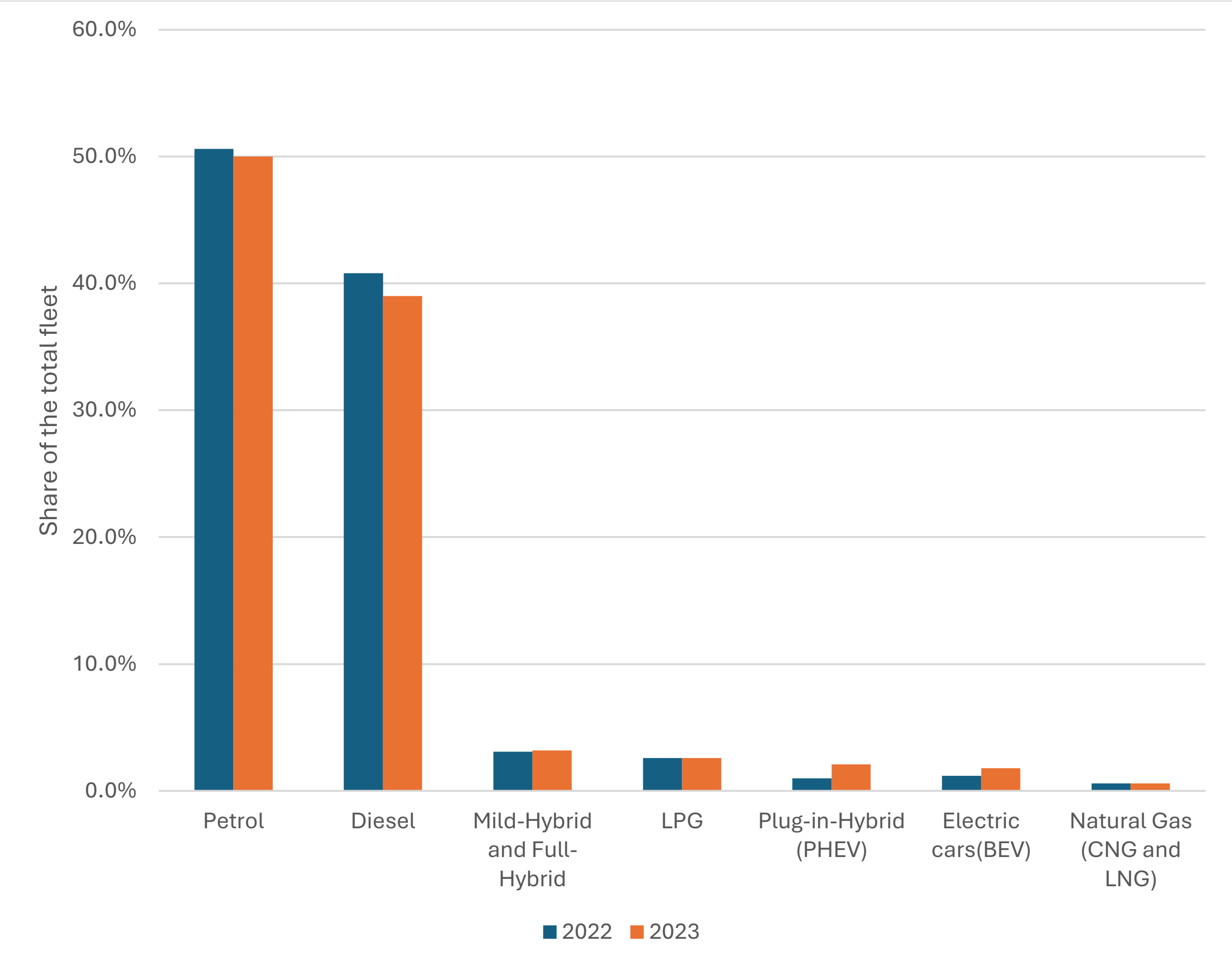

Figure 20: Share of Alternative Powertrains of the Passenger Car Fleet in the EU in 2022 and 2023; based on [47] and translated

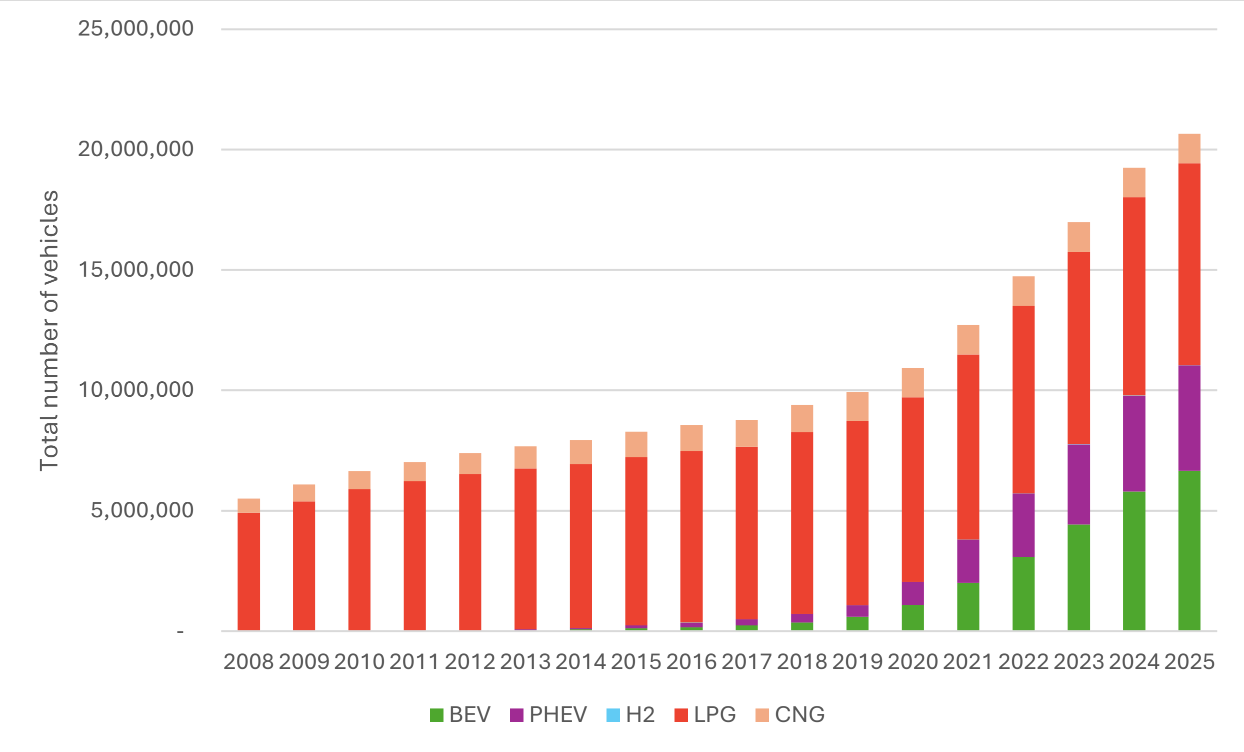

Figure 21: Total Number of Alternative Fueled Passenger Cars in the EU; based on [38]

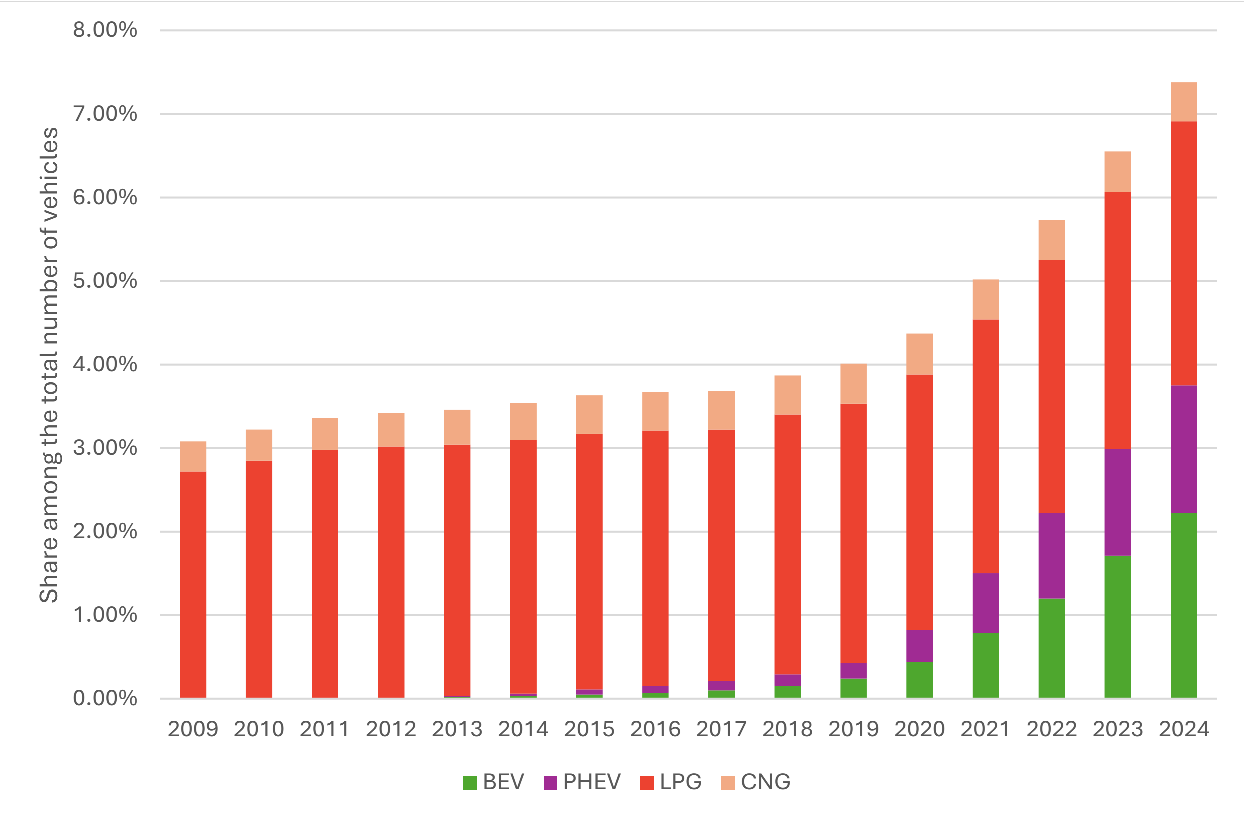

Figure 22: Fleet of Alternative Fueled Passenger Cars as a Percentage of the Total Fleet in the EU; based on [38]

5.2.2.2 Trucks and Buses

In 2022, 96% of the trucks registered in the EU were powered by diesel engines, alternative drivetrains accounted for less than 1.5% of all trucks [48, p. 17]. CNG, LPG and LNG powertrains have been the most widespread alternative compared to diesel as shown in Figure 23. The number of hydrogen trucks and hybrid electric drivetrains has remained negligible, the market share of battery electric vehicles on the other hand has increased progressively since 2013. [38], [48]

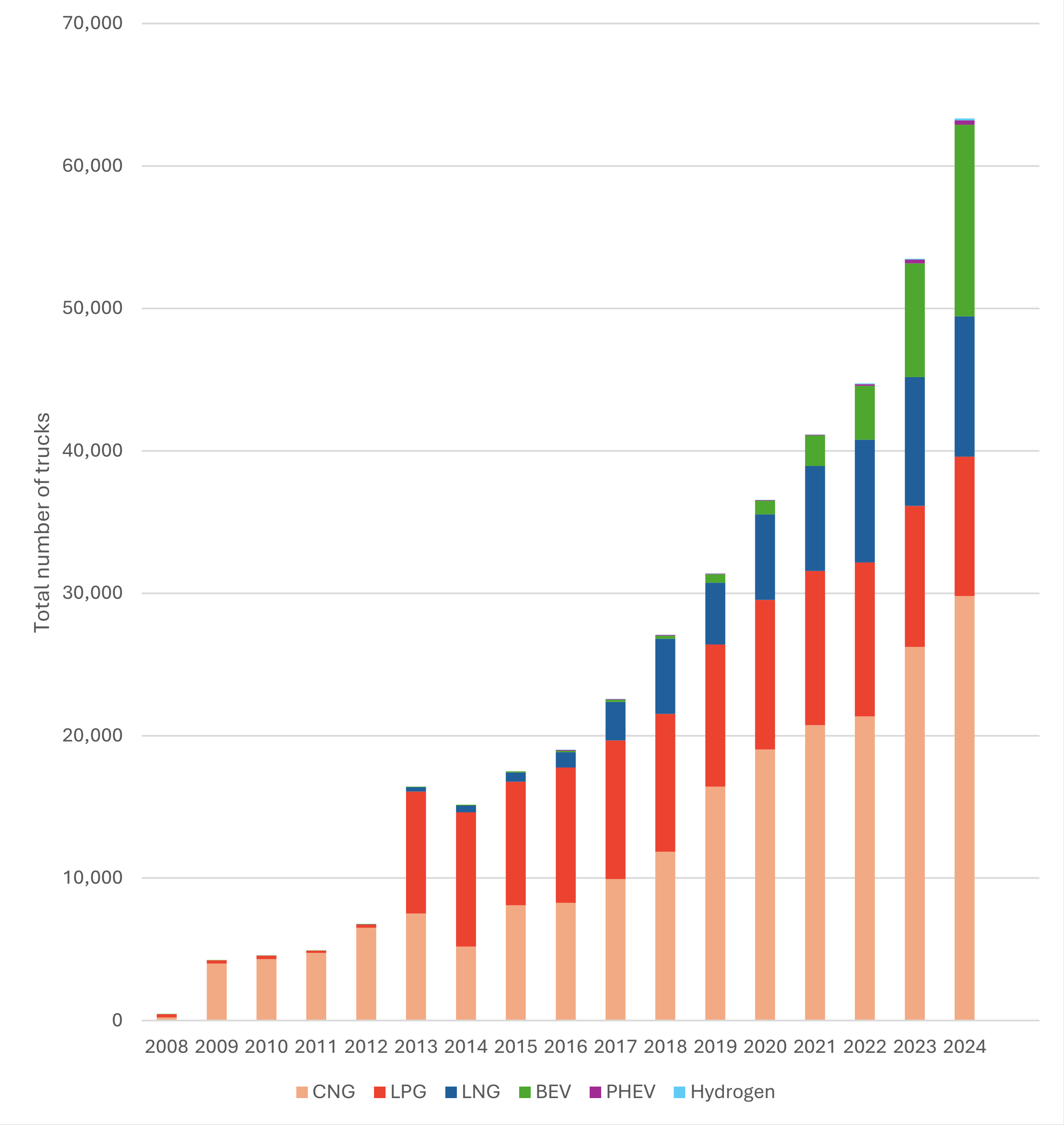

Figure 23: Truck Fleet in the EU Powered by Alternative Powertrains; based on [38]

The number of alternatively powered buses in the EU has grown steadily since 2012. CNG prevails as the most relevant alternative powertrain, while battery electric buses have become increasingly important. Other alternative technologies such as LNG, LPG, PHEV and hydrogen have in comparison remained insignificant, as presented in Figure 24. [38]

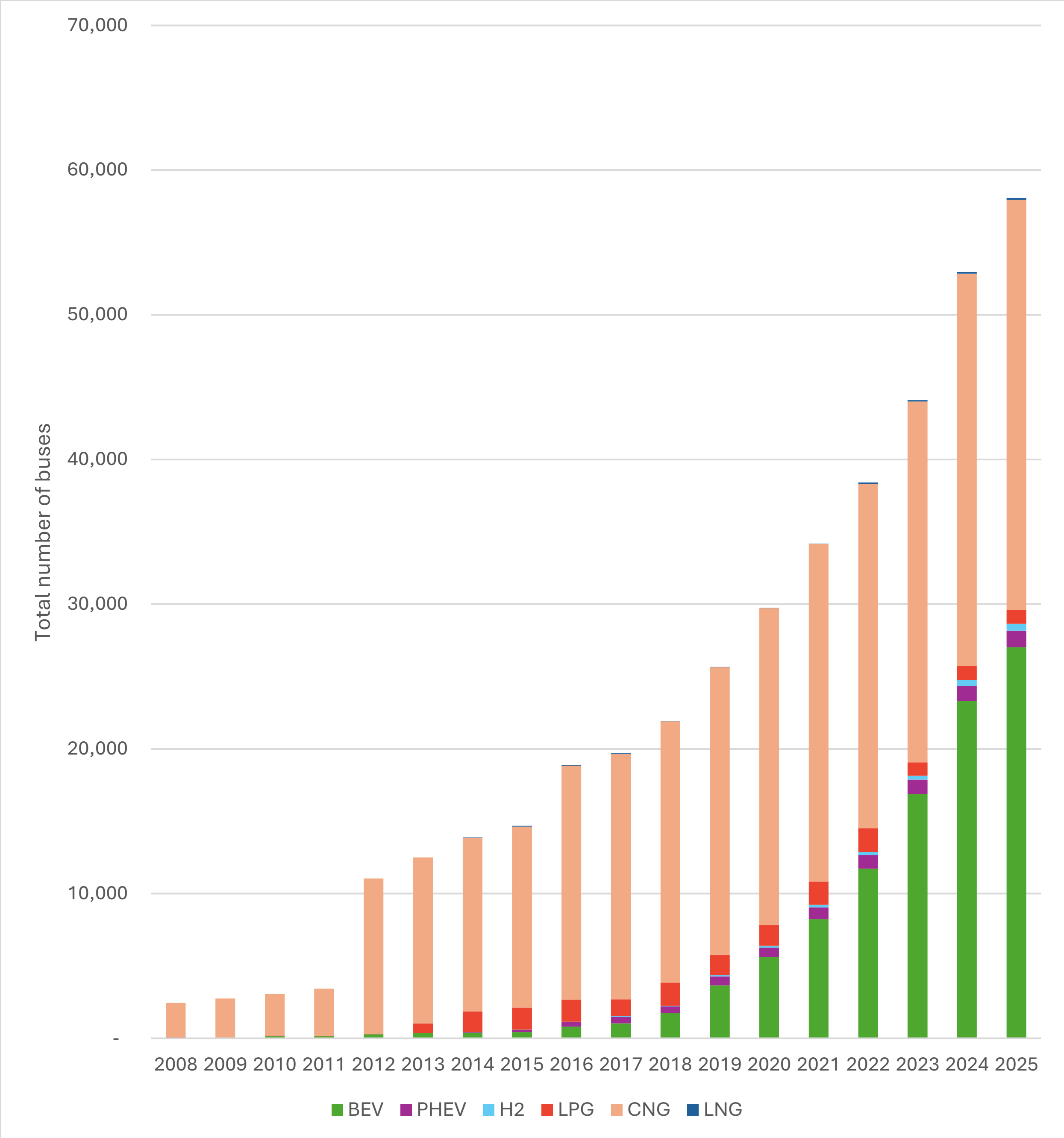

Figure 24: Total Number of Alternatively Fueled Buses in the EU; based on [38]

6 Overview of Renewable Energy Carriers

6.1 Austria

In Austria fossil diesel remained the top-selling fuel, blended with up to 7% biodiesel followed by gasoline, with an ethanol content of up to 10%, see Figure 25. Other alternative fuels such as LPG, CNG, LNG and fossil hydrogen were sold in comparably negligible amounts in 2023. [49, p. 34]

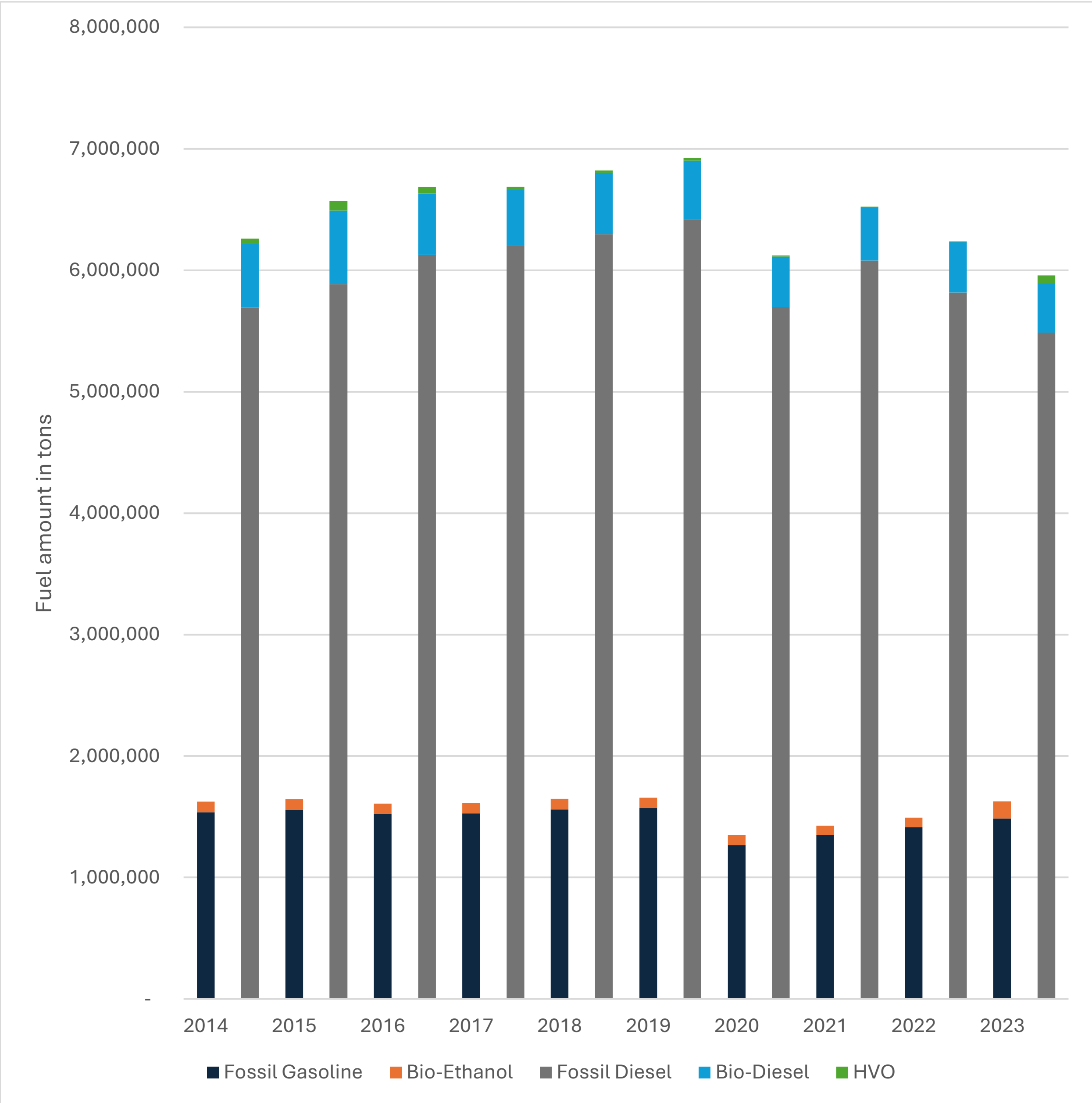

Figure 25: Petrol and Diesel Fuels Sold in Austria; own illustration [50]

Diesel is the most consumed fuel for transport in Austria; thus, FAME biodiesel is by far the bestselling biofuel as presented in Figure 26. The FAME biodiesel sold in 2023 was primarily produced from conventional resources (66.2%), such as rapeseed and soybeans, nearly a third came from waste materials (32.7%), mainly used cooking oil, advanced biofuels only accounted for a share of 1.1%. The greatest amount of HVO was consumed in 2015 but then decreased until 2022, in 2023 the share significantly increased again (Figure 26), with over 40% of the HVO being used as pure fuel. 48.6% of the HVO was sold as an advanced biofuel, with palm oil mill effluent being the main feedstock, 40% was obtained from other waste products and only 11.5% were produced from conventional feedstocks. [49, p. 44, 53, 57]

The sale of bioethanol remained relatively constant up to 2022, the sizeable increase in 2023 was caused by the nationwide introduction of E10 that year, with about 10% being ETBE (Figure 26). The main resources for bioethanol sold in 2023 was corn and wheat, in total conventional feedstock contributed 84.7%, 8.6% was produced from waste materials, and 6.7% were counted as advanced biofuels. [49, p. 5, 40, 55]

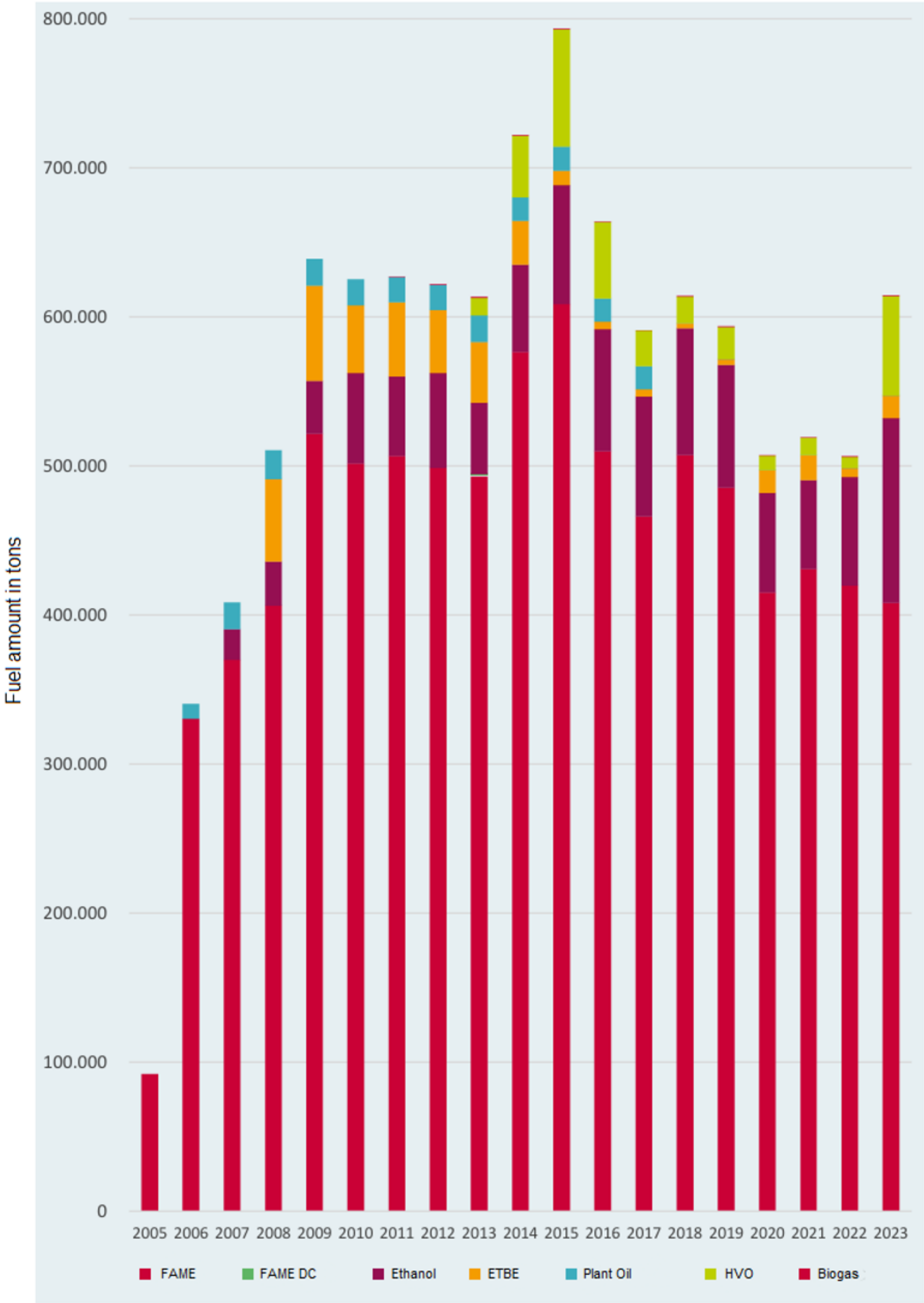

Figure 26: Sale of Biofuels in Austria; based on [49, p. 44] translated

In 2022 less than 1% of the total energy consumed in road transport came from electricity [51] but this share is set to grow alongside the number of battery electric vehicles as the amount of recharging stations is also continuously increasing, see Figure 27.

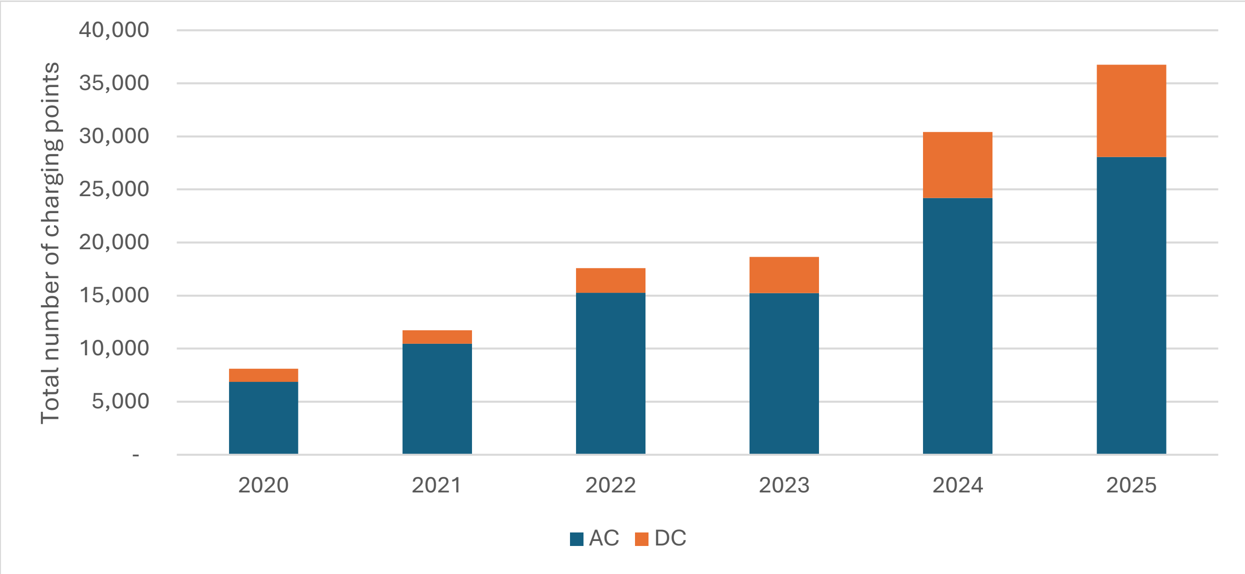

Figure 27: Total Number of Recharging Points for Electric Vehicles in Austria; based on [52]

6.2 European Union

The road transportation sector is the largest consumer of energy in the EU, being responsible for 31% of total consumption. As seen in Figure 28, diesel and petrol are still the most dominant energy carriers for road transportation, with the share of LPG (2%), natural gas (0.7%), electricity (0.3%), renewables and biofuels (6.4%) amounting to 9.4% in 2022. The percentage of biofuels stayed relatively constant as the blending content of bioethanol and biodiesel is limited, while the share of electric energy consumed rose from 0.05% in 2018 to 0.34% in 2022. [51] As a result of the increasing demand for electricity, the network of charging stations accessible to the public expanded, with in 2025 there being over one million recharging points in operation in the EU, see Figure 29.

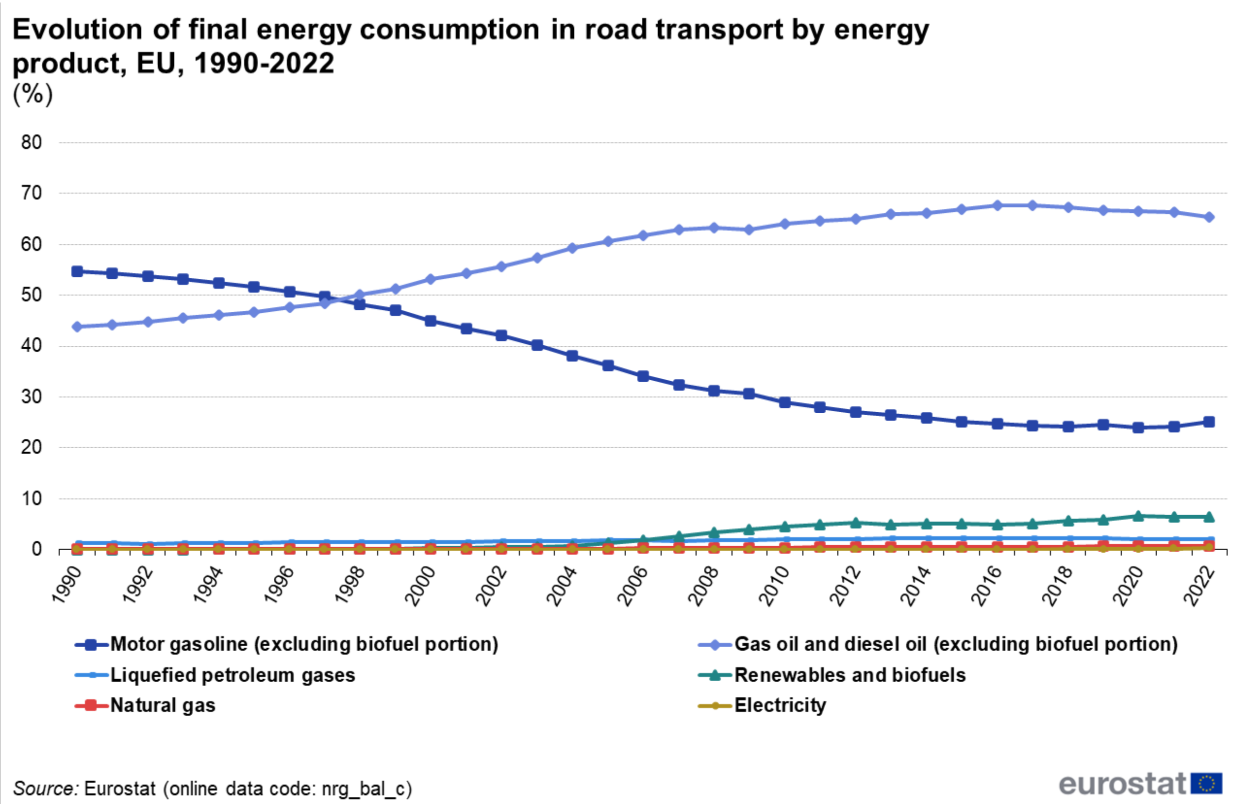

Figure 28: Evolution of final Energy Consumption in Road Transportation by Energy Product [51]

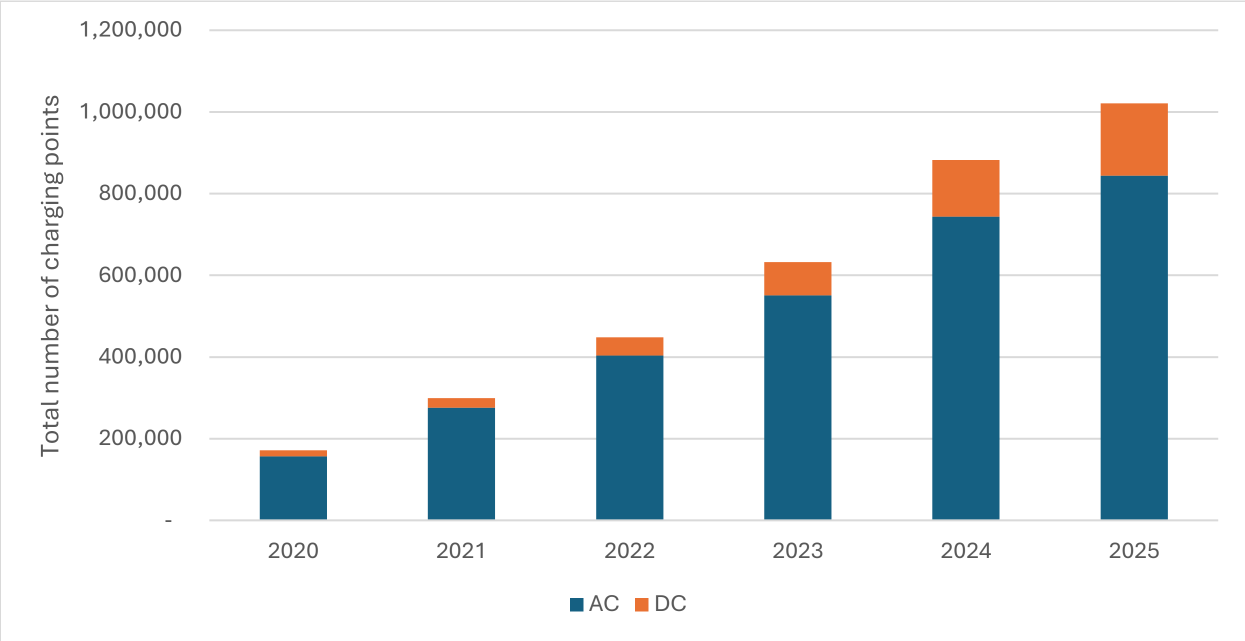

Figure 29: Total Number of Recharging Points for Electric Vehicles in the EU; based on [53]

The total amount of biofuels consumed in the EU has grown since 2015, with the production of FAME, HVO, bioethanol and biomethane being performed on a commercial scale [54, p. 15, 16]. Biodiesel remains the most dominant renewable fuel, followed by bioethanol. The share of biogas used in road transportation has also increased; however, the consumption remains small compared to the previously mentioned fuels, as portrayed in Figure 30.

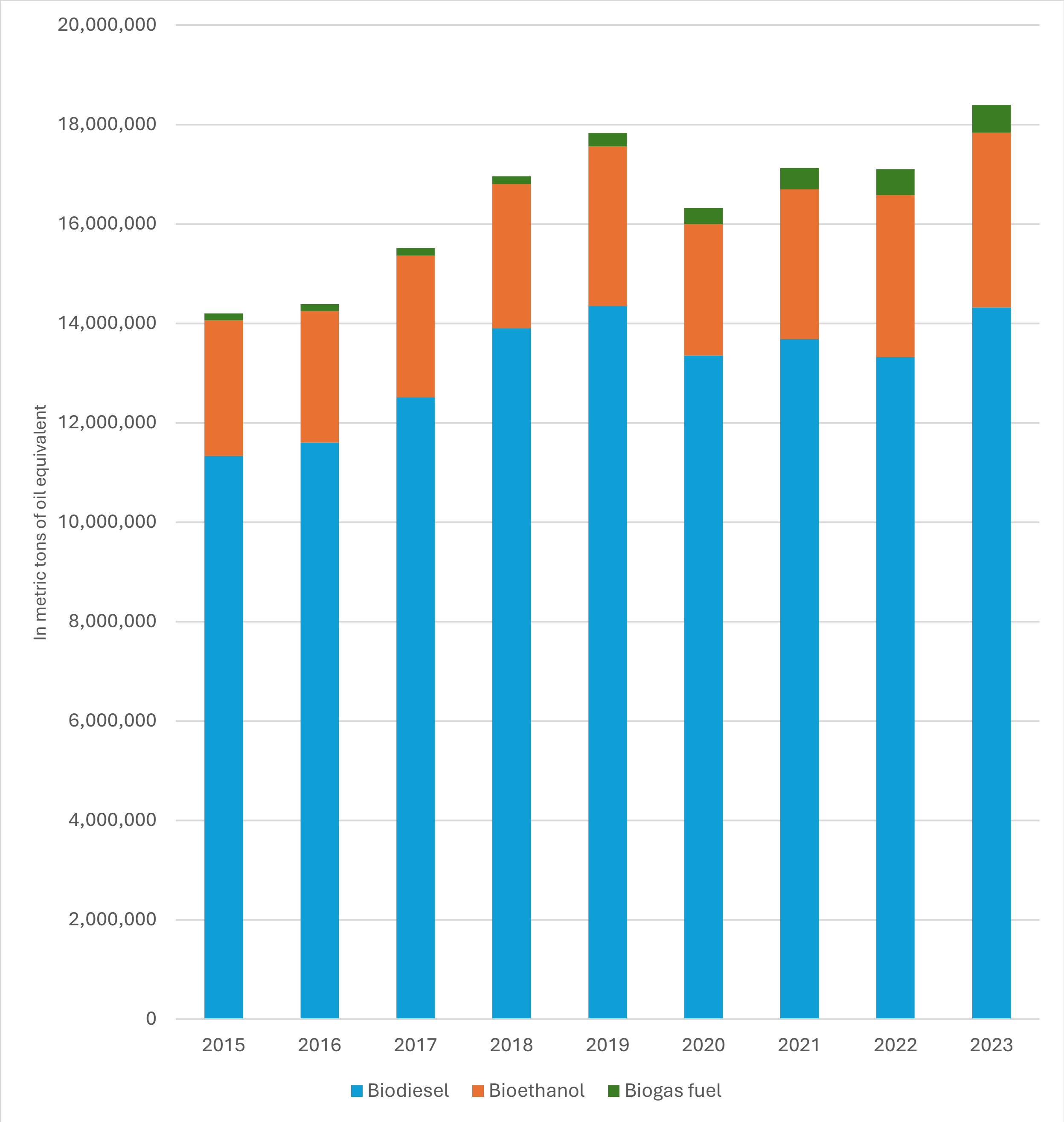

Figure 30: Biofuels Consumption for Transportation in the European Union; based on [55]

Although the annual production of HVO in the EU has nearly doubled since 2014, conventional FAME biodiesel remains the most relevant renewable fuel produced for diesel engines, see Figure 31. Figure 32 highlights that the main feedstock used to produce bio and renewable diesel in 2022 continued to be rapeseed oil (42%), used cooking oil (25%), animal fats (7%) and soybean oil (6%). The percentage of palm oil used for production has declined since 2019. [54, p. 21], [56]

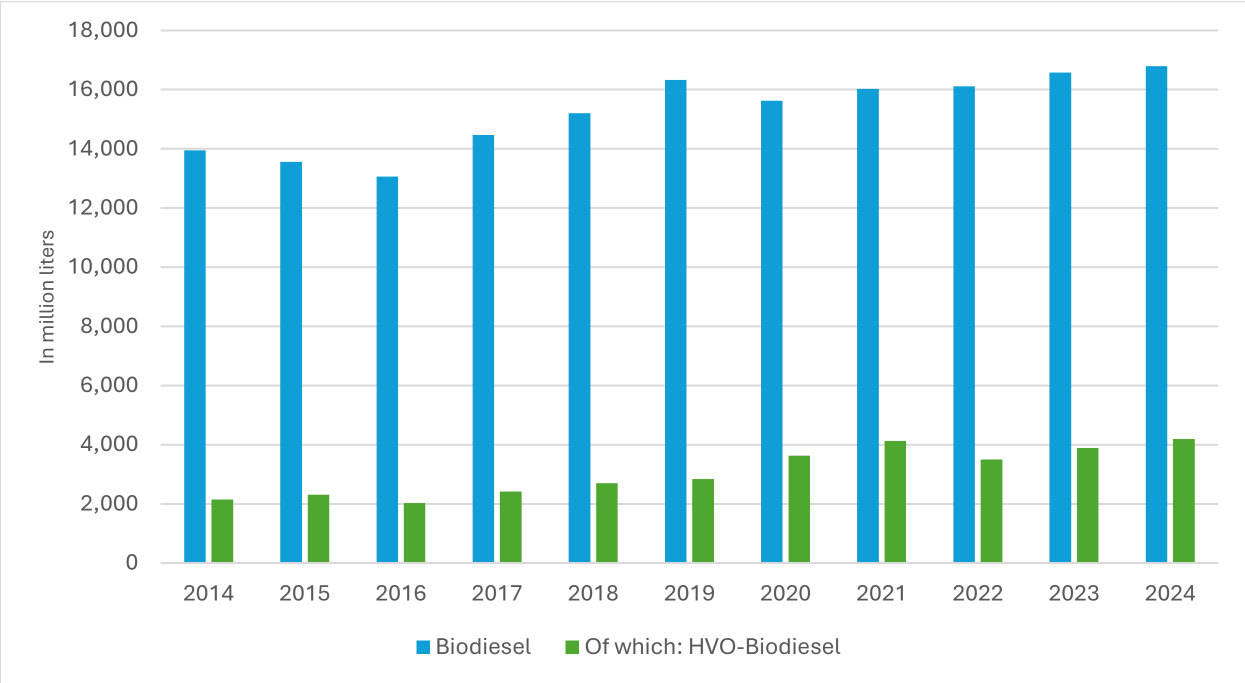

Figure 31: Production of Biodiesel and Renewable Diesel (HVO) in the EU, in Million Liters; based on [56] and translated

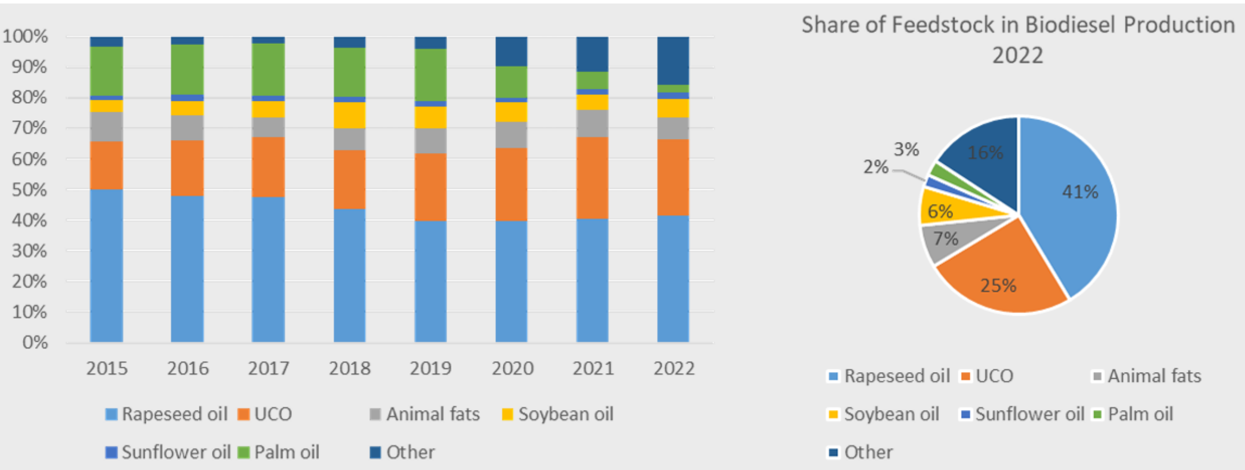

Figure 32: Biodiesel Feedstock used for Production in the EU [54, p. 21]

In Europe bioethanol is still mostly produced from sugar and starch containing plants with only 1% being obtained from lignocellulosic feedstock in 2022. The most common crops used for production of bioethanol have remained corn, sugar beets and wheat as demonstrated in Figure 33. [54, p. 22]

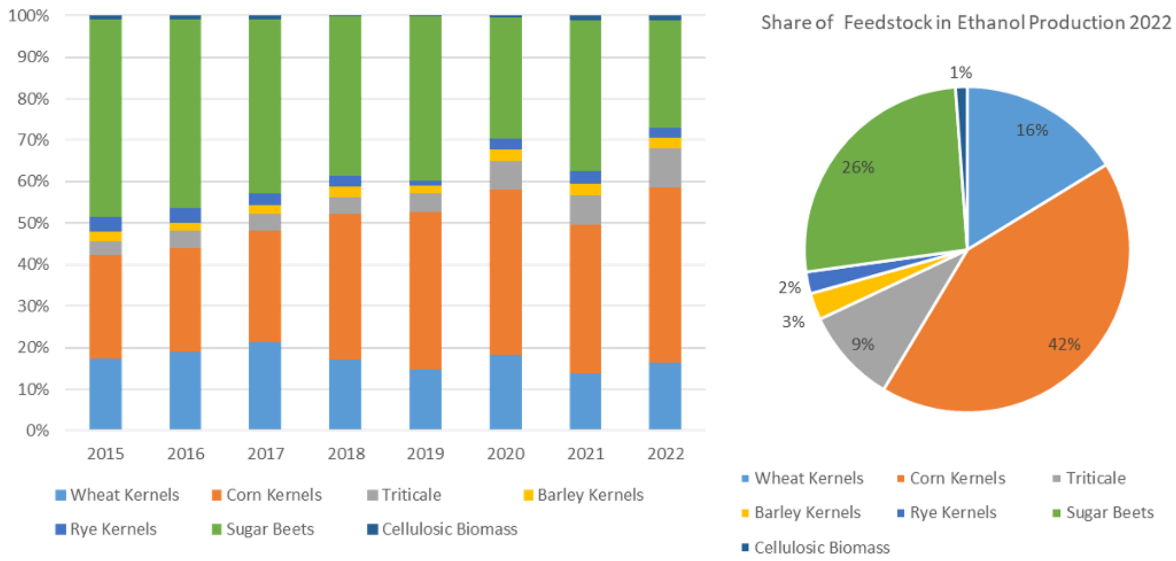

Figure 33: Bioethanol Feedstock used for Production in the EU [54, p. 22]

The utilization of hydrogen as an energy carrier to reduce the amount of GHG emitted from road transportation requires large scale commercial production of green hydrogen and an adequate number of refueling stations. As the number of fuel cell electric vehicles remains relatively little, the consumption of hydrogen in road transportation is currently negligible. In the EU 89.9% of the hydrogen in 2023 was produced by reforming fossil fuels, while 9.2% was obtained as a byproduct of various chemical processes. Water electrolysis only generated a share of 0.4% of the total output, 0.5% of the hydrogen was created by reforming methane in combination with carbon capture. [57, p. 15, 16] Furthermore, hydrogen production via electrolysis is more expensive than conventional production methods. [57, p. 66]

The number of publicly accessible hydrogen refueling stations has increased steadily in the last decade to 187 in 2024, see Figure 34, with most of them being located in Germany. With the target of there being a refueling station every 200km along the Trans-

European Transport Network and every urban note by 2030, the amount of hydrogen refueling stations is set to expand. [57, p. 38, 39]

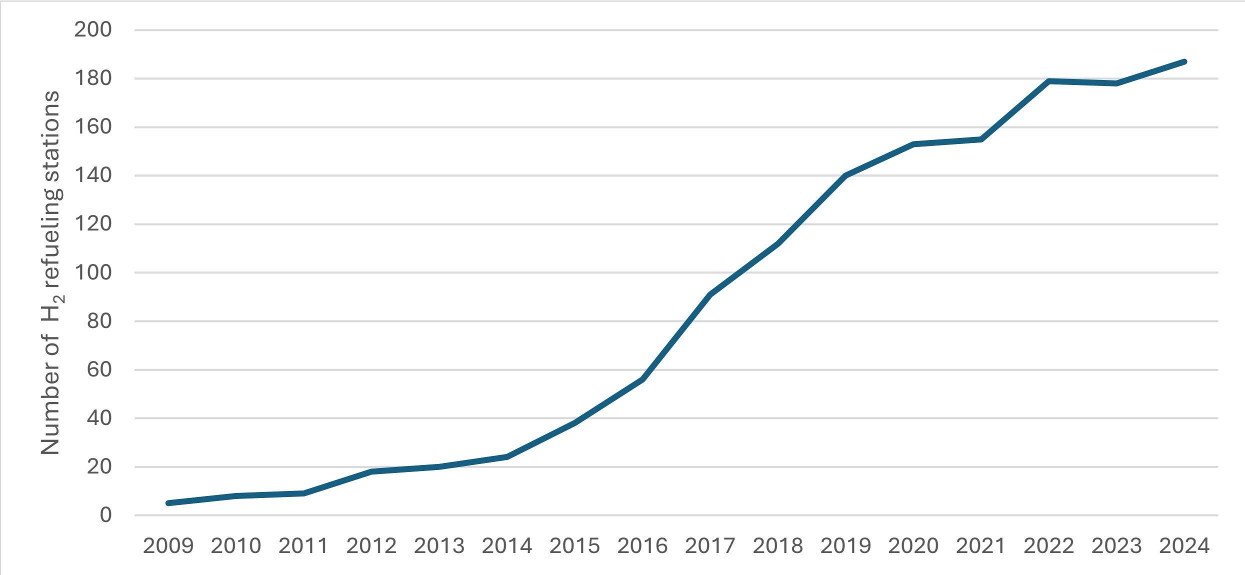

Figure 34: Number of Public Hydrogen Refueling Stations; based on [57]

Fuel production via the Fischer-Tropsch process such as coal-to-liquid and gas-to-liquid are already established on the market; however, the production of biofuels from biomass still has not been deployed at a large commercial scale. Further research is needed to overcome remaining technical challenges [54, p. 105]. Other fuels such as OME, DME and algae-based fuels are still not produced at commercial scale. Bio methanol is primarily seen as an attractive fuel for maritime shipping vessels [54, p. 25].

7 Analysis of the A3PS Roadmaps

7.1 Change of the Structure of the Roadmaps

All A3PS roadmaps discuss the following powertrain technologies: internal combustion engines, battery, hybrid and fuel cell electric powertrains. Regarding the arrangement and categorization of the listed powertrains and renewable fuels, the structure of the individual roadmaps differs.

The roadmaps published in 2015 and 2018 share the same layout, as the powertrain technologies are split up in chapters and listed as follows: Advanced internal combustion engines containing spark and compression ignition engines, electric powertrains consisting of battery and hybrid electric drivetrains and fuel cell technologies. The only exception is the position of the renewable energy carriers, which are discussed in a separate chapter in the 2015 version and in the 2018 roadmap listed in the chapter containing advanced thermodynamic powertrains. The roadmap of 2011 has a very similar structure to the 2015 and 2018 ones, the main difference being that fuel cell technologies are part of the electric and partially electric drivetrain chapter, as well as the renewable fuels having their own section. (see chapter: 3)

The structure of the 2022 roadmap differs from the previous editions, as the relevant powertrains are recategorized and rearranged in following order: Battery electric powertrains, fuel cell systems and hybrid drivetrains, which contain the internal combustion engine. The different renewable energy carriers are elaborated in a separate chapter after the powertrains. (see chapter: 3)

Generally, it can be stated that, since 2011 every roadmap has provided a more in-depth analysis of the relevant research and development trends and demands regarding alternative powertrains and renewable energy carriers than its predecessors.

7.2 Possible Influence of Political Decisions and Regulatory Frameworks on the Roadmaps

The A3PS roadmaps reflect the forecast of the different working groups regarding future technology trends of the Austrian automotive industry and are possibly influenced by politics. Especially climate laws and agreements could have a strong impact on the structure of the roadmaps as these provide the framework for the future development of powertrains and renewable fuels. Consequently, these conventions lead to stricter emission regulations and renewable energy targets for the automotive industry and have a steering effect, like the European tank-to-wheel approach for the emission regulation.

Regarding a possible influence of the Austrian Federal Ministry for Innovation, Mobility and Infrastructure on the roadmaps, Dr. Dorda emphasized in an Interview that the content of the roadmaps was always entirely created by the A3PS members and that the ministry did not try to exert any influence on the decision-making process. [58] [own translation] Further, Dr. Dorda stated that: “At the same time the ministry highly appreciates the content of these roadmaps providing first-hand information on the development pathways and goals of Austria’s industry and research institutions for the development of advanced vehicle technologies. This is of utmost importance for tuning the R&D-funding instruments to the research needs of Austrian stakeholders and national priorities.” [58]

The similar structure of the 2011 and 2015 roadmaps might be an indicator for a low level of political and regulatory pressure. Another factor could be that besides the internal combustion engine other alternative powertrains were not yet on the market and thus, the relevant research and development areas and trends were not as clear. Furthermore, the structure and content of the 2018 roadmap is comparable to its 2015 predecessor. This may indicate that the Paris climate agreement had no significant influence on research and development trends in Austria. It is possible that it was then uncertain which approaches would be taken by the Austrian government and the EU to achieve the targets set out by the Paris agreement.

However, as the EU unveiled the Green Deal in 2019 and the Fit for 55 package in 2021, including a prospective ban of internal combustion engines in 2035, a shift towards prioritizing vehicles, which do not emit CO_2 during operation was imposed [18], [59]. As the newly announced legislation focuses on tank-to-wheel evaluation, the stricter CO_2 fleet emission targets benefit BEV, FCEV and hybrid electric vehicles, therefore pressure on the automotive industry increased. This could be a possible reason why the roadmap 2030+ published in 2022 is structured in a completely different way than its predecessors, as a research and development transformation towards alternative powertrains has become mandatory. This may also be indicated by the order in which the powertrain technologies are listed, first there are the battery electric vehicles, then fuel cell vehicles and lastly hybrid powertrains. Additionally, the chapters discussing battery and fuel cell technologies, as well as hydrogen as an energy source, go further into detail than the section about hybrid automotive powertrains. The internal combustion engine is for the first time not listed as a separate chapter and only part of hybrid powertrains. Furthermore, it is also emphasized that from a climate perspective the use of hybrid powertrains and internal combustion engines in the future will only be reasonable if the fuel is renewable. Regarding the restructuring of the 2022 roadmap Professor Prenninger, from AVL List GmbH and chairman of the A3PS board stated that: “It was tried to find a compromise between the political framework set by the EU as well as national authorities and what companies need to offer in order to remain competitive.” [60] [own translation]

For the implementation of renewable energy carriers, the Renewable Energy Directives issued by the EU were mentioned in the 2015, 2018 and 2022 roadmaps as the driving force (see chapter: 3). This is a clear indication for the influence of politic frameworks on research and development directions and evidently the roadmaps.

7.3 Comparing the Research and Development Demands and Predictions of the Roadmaps to the real Development of the Mobility Sector

Since the first roadmap was published in 2011, the mobility landscape has evolved considerably. Some technologies mentioned in these roadmaps were introduced successfully, others were abandoned or are not yet on the market. Consequently, the research and development demand for the Austrian automotive industry changed in the timeframe covered by the roadmaps. The findings of the following section are graphically illustrated in Figure 35 at the end of the chapter.

7.3.1 Passenger Vehicles

All four roadmaps emphasized that the internal combustion engine will remain the most dominant powertrain technology in the foreseeable future. This remained true as both the passenger vehicle fleet in Austria and the EU, are as of 2024 still predominantly powered by petrol and diesel engines, although the share of these conventional powertrains has been slowly declining in the Austrian and the EU fleet (Figure 15, Figure 20). The number of new registrations of internal combustion powered cars has changed considerably, as since 2017 in Austria (Figure 2), and 2016 in the EU the number of newly registered diesel vehicles has decreased significantly (Figure 8). The market share of new petrol cars dropped considerably in 2020 and further declined slowly in both Austria and the EU (Figure 1, Figure 8). The strong decline of diesel vehicles compared to petrol cars may have been caused by the Volkswagen diesel scandal, which became public in September 2015. [27]

Stressed in every roadmap until 2018 was the potential of CNG as an alternative energy carrier to lower CO_2 emissions of spark ignition engines by up to 25%, with comparably little research and development required. Despite this, CNG and LPG powered cars only make up less than 1% of the total fleet in Austria [30] with the number declining for years and slightly over 3% in the EU (Figure 20), with most of these vehicles being registered in Italy and Poland. [45], [46] Professor Prenninger mentioned, that there were efforts to introduce CNG vehicles in Austria, however the market did not adopt this technology. [60] [own translation]

Every roadmap stressed that battery electric powertrains require extensive research and development efforts to improve performance, energy density, durability and affordability. Lithium-Ion battery technology has massively improved over the last decade, which allowed for larger ranges for vehicles (see chapter: 3). Now there are a variety of different models for every passenger vehicle segment available. Numerous incentives and tax regulations were introduced by national governments to make the purchase of battery electric vehicles more attractive, especially for companies. The market share of pure electric vehicles among newly registered cars and the total fleet has continuously risen in both the EU and Austria in recent years. (Figure 1, Figure 8, Figure 15, Figure 21)

In the 2015 publication and later roadmaps hybrid powertrains were mentioned to become more important, especially 48V systems and were expected to be established in the market by 2020-2025. This prediction was correct, which can be seen in the number of new hybrid vehicles registered in Austria but also the EU. For the first time, in 2022 more hybrid vehicles were registered than pure diesel ones. In Austria as well as in the EU there are more hybrid vehicles on the road than battery electric ones. Especially mild and full hybrid vehicles have become increasingly important, as of 2024 hybrid vehicles are the second most popular engine choice in Austria and the EU after petrol powered cars. (Figure 1, Figure 8)

Even though fuel cell technology has been discussed extensively in every roadmap published, only a handful of fuel cell vehicles are on the road today. The high cost of these vehicles remains a problem regarding the introduction to the market. In an Interview Dr. Trattner from HyCentA Research GmbH and expert group leader of the A3PS fuel cell and hydrogen working group, stated that while the price of fuel cells has decreased considerably in recent years, the high-pressure tank continues to be a key contributor regarding the overall costs of these propulsion systems. [61] [own translation]

The large investments in research and development necessary to successfully bring fuel cell technologies, hydrogen storage, infrastructure and renewable production to the market are stressed as obstacles in all roadmaps (see chapter: 3). Considering that hydrogen as a fuel is reported to be of great importance for reaching climate targets, fuel cell electric powertrains have not been produced in high enough numbers. The cost of constructing and operating a hydrogen refueling station is significantly higher than conventional ones and thus, a limiting factor. In Austria the OMV announced in 2025 that every public hydrogen refueling station will be shut down, as the demand is insufficient [62].

Nevertheless, fuel cell systems are listed as especially applicable for buses and heavy-duty vehicles in Austria [63, p. 22], Dr. Trattner stated that fuel cells are still considered a relevant technology for passenger vehicles, since their superior energy efficiency compared to conventional combustion engines is more pronounced in passenger cars. [61] [own translation]

7.3.2 Trucks and Buses

For heavy-duty vehicles natural gas powertrains alongside diesel engines, were listed as relevant technologies to reduce emissions in every roadmap up to 2018. Diesel trucks still dominate the market with a market share in both new registrations and the existing fleet of over 90%. CNG powered trucks are the most common alternative to diesel ones in the EU but never made up a significant share of new registrations. (Figure 11)

As long-distance transportation is a difficult sector to decarbonize, hydrogen was seen to be an attractive technology; however, the number of fuel cell electric vehicles remains very small. Moreover, city buses were mentioned in the roadmaps to be a first market for PEM fuel cells, the small number of these buses registered in the EU and Austria have only a limited impact on the climate [38], [64]. The continuing rise of fuel cell electric buses was also noted by Dr. Trattner: “In public local transportation, the introduction of buses is well under way and will surely continue consistently.“ [61] [own translation]

Up to 2015 battery electric powertrains were not seen as a suitable option for long-distance transportation. The 2018 roadmap mentioned that from 2020 onwards battery electric trucks with a range of up to 800km would be available. However, this prediction turned out to be incorrect, as the 2022 roadmap reported that the first generation of battery electric trucks and buses was introduced to the market with a range of up to 400km. (see chapter: 3)

7.3.3 Alternative Fuels and Renewable Energy Carriers

The importance of renewable energy carriers is stressed in every roadmap, even stating that these fuels have the largest potential to reduce emissions. Especially for sectors which are difficult to electrify, such as heavy-duty applications, renewable fuels are regarded as very important, due to their high energy density (see chapter: 3). As of today, the only renewable fuels produced on a commercial scale are FAME, bioethanol, HVO and biomethane. Overall, the production and consumption of these energy carriers have increased since 2011; however, most of the FAME and bioethanol used are still 1st generation biofuels (see chapter: 6). Lignocellulose as a feedstock for bioethanol was listed to reach market readiness in the long term (2020-2035+) in the 2011, 2015 and 2018 roadmaps, in 2022 it was reported that this process was at a demonstrational stage, as of 2022 1% of bioethanol in the EU was obtained from cellulosic biomass. [9–12], [57] In the 2011 (for 2015-2020), 2015 and 2018 roadmaps fuel blends of up to 10% of FAME (B7) and bioethanol (E10) are mentioned. E10 was introduced in 2023 in Austria and is used in many countries in the EU, but a 7% content of FAME remains the standard diesel fuel in the EU. Additionally, it was projected that the HVO content could reach around 30% of diesel between 2020 and 2030 [10], this has not been accomplished yet in the EU and Austria. (see chapter: 6)

The importance of green hydrogen as an energy carrier for both fuel cells and internal combustion engines, was discussed extensively especially in 2015 and 2018 but as of 2025, most of the produced hydrogen is derived from natural gas (see chapter: 3, 6). Furthermore, this vehicle fleet remains small in both Austria and the EU, thus the role of hydrogen as a fuel used for transportation is currently negligible. Nevertheless, the number of fuel cell vehicles, refueling stations and the production capacity of hydrogen via electrolysis continues to grow in the EU. (see chapter: 6)

Other fuels and processes have been listed in different roadmaps such as OME, DME, methanol, e-fuels, Fischer-Tropsch and algae-based fuels, as possible paths for the future but currently have not been deployed on the market for various reasons. (see chapter: 6)

Although renewable electricity was not discussed in the sections about renewable energy carriers, it was mentioned alongside the research and development demands for battery electric vehicles as an unconditional resource for the success of electric powertrains (see chapter: 3). The amount of electricity used in road transport has significantly increased, as the fleet of battery electric vehicles grew but still accounts for less than 1% of the total energy consumed in this sector. Additionally, a sizeable public charging infrastructure has been constructed, and the generation of renewable electric energy has increased steadily throughout the EU since 2011. [51]

Between 2011 and 2018 the use of CNG, as an alternative fuel to reduce CO_2 emissions was mentioned in the chapters regarding optimized internal combustion engines [10], [11]. In Austria far less than 1% of the total vehicle fleet was powered by gas engines, and the number has been decreasing for years [30]. In the EU only in Italy (2024: CNG: 2.5%, LPG: 6.77%) [65], Poland (2024: 12.54%) [46] and Bulgaria (2024: LPG: 6.48%) [66] a significant share of the total vehicle fleet is powered by alternative fuels of either CNG or LPG.

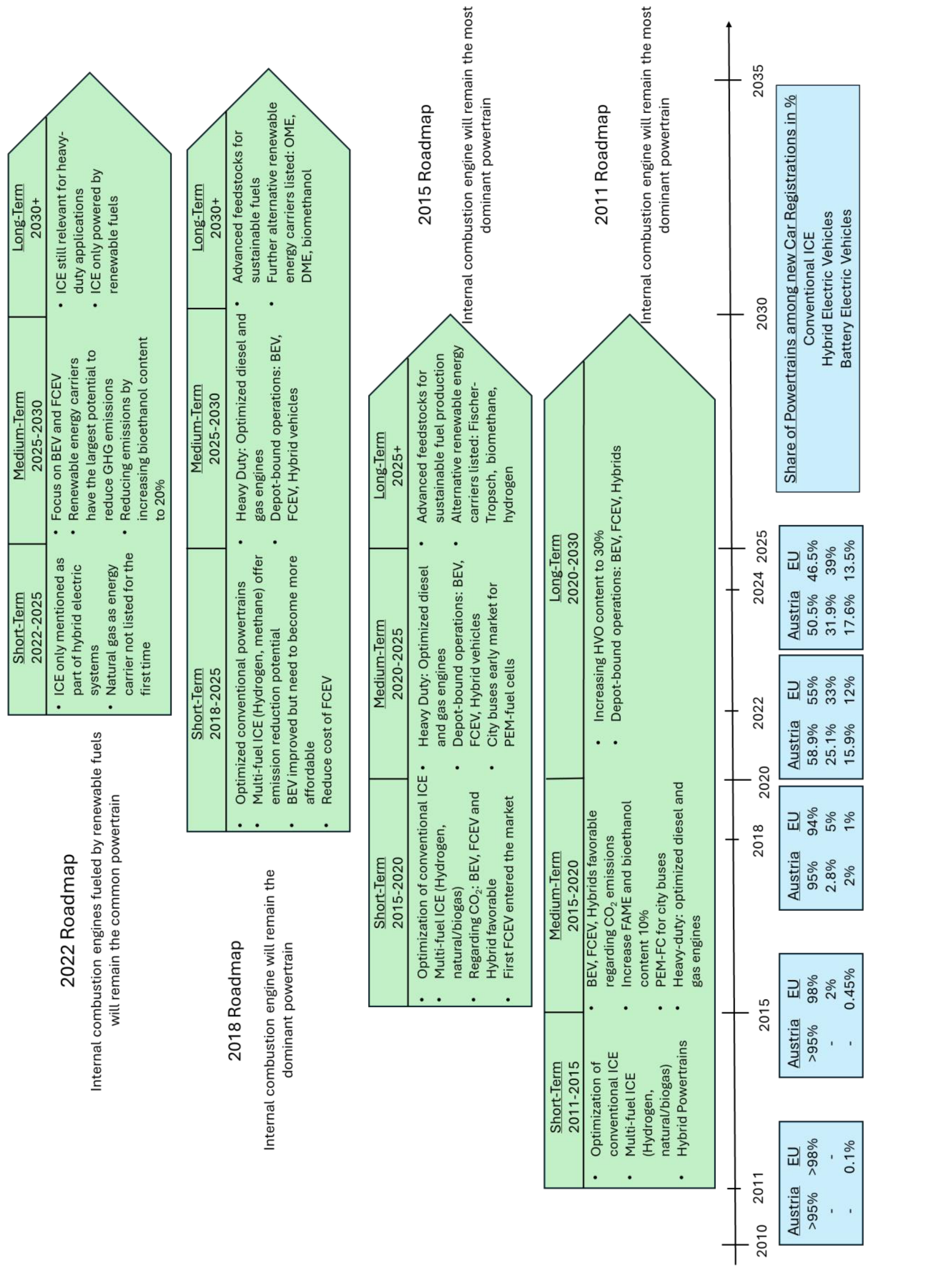

Figure 35: Graphic depiction of the actual change of the mobility sector, compared to the projections listed in the A3PS roadmaps; own illustration

7.4 Comparison of the Content of the A3PS Roadmaps to selected ERTRAC Roadmaps

7.4.1 ERTRAC Roadmaps

The European Road Transportation Research Advisory Council (ERTRAC) is a strategic platform for research activities, regarding road transportation at the European level. To summarize and communicate the current relevant innovation areas, roadmaps and strategic research agendas are published by ERTRAC [67]. The following paragraphs provide a brief summary of the main conclusions of selected publications.

The roadmap “Energy Carriers for Powertrains”, published in 2014, by ERTRAC, offers detailed descriptions of various renewable fuels for road transportation, infrastructure and compatibility with powertrains. To effectively reduce the amount of CO_2 emitted by transport, higher powertrain efficiency and the development of sustainable energy carriers are concluded as efficient measures. By 2050 it is projected that renewable electricity will make up the largest share of decarbonized energy, with the total energy supply becoming more diversified. Natural gas is mentioned as a promising and realistic pathway for decarbonization, as a CO_2 emission reduction of up to 25% is possible compared to fossil gasoline. Furthermore, increasing the ethanol blend and the production of drop in fuels for diesel engines, without interfering with food production are listed as relevant challenges. [68, p. 6, 18]

In 2016 ERTRAC published the “Future Light and Heavy Duty ICE Powertrain Technologies” roadmap, which compiles relevant light and heavy-duty powertrain technologies and suitable energy sources to reduce emissions. It is concluded that internal combustion engines (including hybrids) will remain the most dominant propulsion technology until 2030 and beyond. The impact of efficient and optimized engines is regarded as significant for the reduction of emissions, mainly CO_2 and fuel consumption. Hybrid electrification, sustainable and low carbon alternative fuels such as natural gas are mentioned as key technologies to further reduce emission, while keeping costs low. [69, p. 5, 11, 14]

“A Mapping of Technology Options for Sustainable Energies and Powertrains for Road Transport”, published in 2022, provides an overview of suitable energy carriers and propulsion systems for the reduction of GHG emissions. Electrification of road transportation is listed as the most pivotal step towards achieving decarbonization, enabling different drivetrain configurations such as BEV, FCEV, PHEV and hybrid electric vehicles. The use of internal combustion engines is only mentioned as a part of hybrid electric concepts or some heavy-duty applications, operated solely on sustainable fuels, with the hybrid vehicles being propelled most of the time by electrical energy. The document also discusses various liquid and gaseous renewable energy carriers. Hydrogen is projected to become a key technology as a fuel, for energy storage and as a feedstock. [70, p. 4, 5, 7]

7.4.2 Comparison of the Roadmaps published by the A3PS and ERTRAC

The ERTRAC roadmaps assessed in this chapter offer a much more in-depth view of the discussed powertrains and renewable fuels suitable for GHG emissions reduction, than the ones published by the A3PS. Despite this, it can be stated that both organizations reach similar overall conclusions.

ERTRAC and the A3PS suggest following approaches to reduce the amount of GHG emissions caused by road transport: increasing the efficiency of propulsion systems, electrification, the use of renewable energy carriers and the transition towards more advanced feedstock for sustainable fuel production. Other similarities mentioned by the A3PS up until 2018 and by ERTRAC in 2014 and 2016, include the potential of natural gas as an alternative energy carrier to reduce emissions; however, in 2022 ERTRAC shifts its focus to biomethane. Optimized diesel engines are also mentioned as key technologies for heavy-duty vehicles by both organizations. (see chapter: 3, 7.4.1)

A striking similarity between both the 2022 A3PS and ERTRAC roadmaps is that both focus on zero emission vehicle concepts such as battery and fuel cell electric vehicles to reduce the emission of CO_2. Additionally, the use of internal combustion engines is solely listed as a part of plug-in and hybrid electric powertrains or for long-distance heavy-duty applications, while using sustainable renewable fuels to operate. This further exemplifies the political pressure caused by the new legislation introduced by the EU, which was present at the time of creation of these roadmaps. (see chapter: 3.4, 7.4.1)

8 Analysis and Development of the Presentations held at the Eco-Mobility Conferences

The A3PS yearly hosts an international conference, with the objective of providing an overview of current and future research activities regarding advanced propulsion systems, vehicle technology and renewable energy carriers [71]. The following chapter categorizes the presentations held at the Conferences since 2010 [71] by their subject in following categories: internal combustion engines, battery and hybrid electric powertrains, fuel cell technologies and hydrogen, or alternative and renewable fuels. Presentations which focus on information regarding the future of mobility and various advanced powertrains are categorized in “Sustainable Mobility and Future Powertrains”, all other topics are grouped in “others”, for example advanced vehicle concepts.

As portrayed in Figure 36, the number of presentations from 2010 to 2019 remained relatively constant aside from 2015. The drop off in 2020 can be attributed to the Covid-19 pandemic as the conference lasted only one day and was held as an online live event. Besides the category “others”, battery and hybrid electric propulsion systems have consistently been discussed as powertrain technologies at the yearly Eco-Mobility conferences. Hydrogen and fuel cells were also the subject of numerous presentations every year, additionally in 2014 the entire first day of the conference was dedicated to this matter. Presentations covering alternative and renewable energy carriers and internal combustion engines accounted for a comparably small amount of the total number. A sizable number of presentations covered various topics over the years, which can be categorized into sustainable mobility and future powertrains.

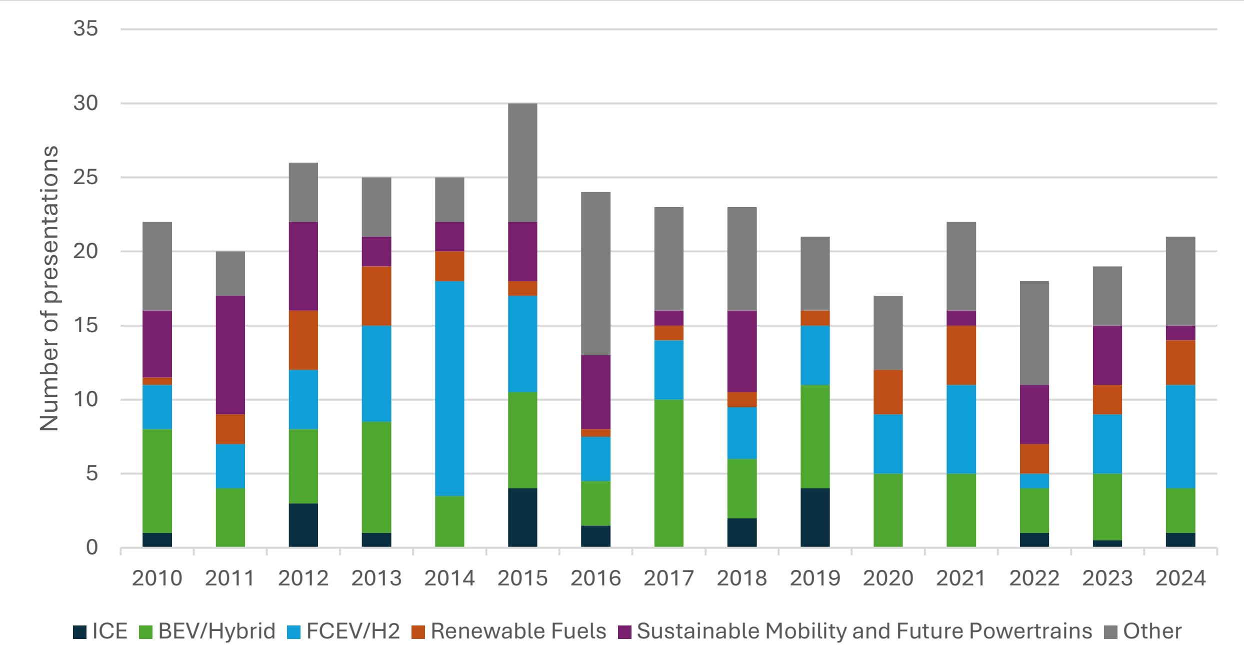

Figure 36: Presentations held at the Eco-Mobility Conferences, categorized by Subject; own illustration [71]

Compared to the real development of the road transportation sector, it can be stated that despite internal combustion engines remaining the most dominant powertrain technology, the share of presentations is small, for instance in 2020 and 2021 there was not a single presentation which directly discussed this subject. In contrast to this, since 2010 a lot of presentations have focused on hydrogen and fuel cells (Figure 36), despite the very limited role these technologies have held in road transportation market in both the EU and Austria (see chapter: 5). Battery and hybrid electric propulsion systems have also been featured extensively at conferences and have in recent years gained sizable market share among new registrations.

9 Conclusion

Regarding the real development of road transportation in Austria and the EU the roadmaps correctly identified that the internal combustion engine remained the most widespread powertrain for passenger cars, buses and heavy-duty vehicles. Generally, it can also be stated that the A3PS roadmaps, as well as the presentations at the Eco-Mobility conferences have extensively covered partial and fully electric powertrains and fuel cell technologies. While hybrid and battery electric vehicles have successfully been introduced to the market, fuel cell vehicles are still only produced in limited numbers. (see chapter: 7.3, 8)

For decarbonization of the mobility sector, the importance of renewable energy carriers was stressed in all roadmaps, as of 2025 only FAME, HVO and bioethanol are widely used. Other sustainable fuels which were listed to be introduced to the market in the long-term (2025+, 2030+) in various roadmaps, are as projected still not produced at large commercial scale. (see chapter: 7.3.3)

The restructuring of the 2022 roadmap can be linked to the introduction of the Green Deal and Fit for 55 by the EU, which among others presented new fleet emissions regulations for passenger cars and light vehicles. The RED II is named as a key political driver to increase the adoption of more sustainable renewable fuels and energy carriers. (see chapter: 7.2)

The considered reports published by ERTRAC provide a more in-depth assessment of the discussed powertrain technologies and renewable energy carriers compared to the A3PS roadmaps. Nevertheless, the content and the conclusions reached by both organizations are consistent with each other. (see chapter: 7.4.2)

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